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Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —

Part 7: Semiconductor and display industries

Émissions de sources fixes — Détermination des émissions de gaz à effet de serre dans les industries énergo-intensives —

Partie 7: Industries des semi-conducteurs et des écrans

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions*.

A list of all parts in the ISO 19694 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

0.1 General

This document for the semiconductor and display industry is based on *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*.

This document, which deals with specific requirements for the semiconductor and display industry, has been harmonized with ISO 14064-1 and ISO 19694-1, which deal with broader requirements. ISO 19694-1 and this document provide a harmonized method for:

— measuring, testing and quantifying methods for greenhouse gas (GHG) emissions;

— assessing the level of GHG emissions performance of production processes over time, at production sites; and

— establishing and providing reliable, accurate and quality information for reporting and verification purposes.

0.2 Overview of semiconductor and display manufacturing process

Semiconductor and display manufacture include processes, such as TFD or plasma EWC of silicon-containing materials, that result in significant carbon dioxide emissions. These emissions are the results of the FC gases and nitrous oxide used in the manufacturing process. Other GHG emissions in semiconductor and display industry include the CO_2 and CH_4 from direct emissions of combustion, transportation, manufacturing process or indirect emissions (e.g. room heating, on-site transports, on-site power generation, external power production and external transports).

FC gases are used in two important steps of electronics manufacturing:

a) plasma EWC of silicon-containing materials, and

b) cleaning of the chamber walls of TFD and diffusion tools after processing substrates.

The semiconductor and display industry use N_2O as an input gas in TFD processes, and in other manufacturing processes that use N_2O, such as diffusion and dry removal of photoresist.

The process emission of FC gases and N_2O should be estimated using the *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*. In this document, references are made to the relevant parts of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories* depending on the element used for appropriate guidance that includes formulae, tables, etc. However, the *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories* can be corrected if some errors are detected. Therefore, companies are strongly encouraged to keep referring to Reference [4] and to replace the Annex B with the latest corrected version of Chapter 6, Volume 3 of the *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories* when it is made available.

Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —

Part 7:
Semiconductor and display industries

1 Scope

This document provides a methodology for calculating greenhouse gas (GHG) emissions from the semiconductor and display industry. This document includes the manufacture of semiconductor devices, microelectromechanical systems (MEMS), photovoltaic (PV) devices and displays. This document allows to report GHG emissions for various purposes and on different bases, such as a per-plant basis, per-company basis (by country or by region) or an international group basis. This document addresses all of the following direct and indirect sources of GHG:

— direct GHG emissions [as defined in ISO 14064-1:2018, 5.2.4 a)] from sources that are owned or controlled by the company, such as emissions resulting from the following sources:

  — process: fluorinated compound (FC) gases and nitrous oxide (N_2O) used in etching and wafer cleaning (EWC), remote plasma cleaning (RPC), in situ plasma cleansing (IPC), in situ thermal cleaning (ITC), N_2O thin film deposition (TFD), and other N_2O using process;

  — fuel combustion related to equipment and on-site vehicles, room heating/cooling;

  — fuel combustion of fuels for on-site power generation;

— indirect GHG emissions [as defined in ISO 14064-1:2018, 5.2.4 b)] from the generation of imported electricity, heat or steam consumed by the organization.

Other indirect GHG emissions [as defined in ISO 14064-1:2018, 5.2.4 c) to f)], which are the consequence of an organization's activities, but arise from GHG sources that are owned or controlled by other organizations, are excluded from this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO 19694-1:2021, *Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries — Part 1: General aspects*

ISO 14064-1:2018, *Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*

Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. 2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories *(2019 Refinement*), Volume 3, Chapter 6 Electronics. URL: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19694-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
base year
specific, historical period identified for the purpose of comparing *greenhouse gas emissions* (3.14) or *greenhouse gas* (3.13) removals or other greenhouse gas-related information over time

Note 1 to entry: Base year emissions or removals may be quantified based on a specific period (e.g. a year or part of year where seasonality is a feature of the *organization's* (3.27) activity) or averaged from several periods (e.g. several years).

[SOURCE: ISO 19694-1:2021, 3.3, modified — Note 1 to entry has been added.]

3.2
carbon dioxide equivalent
CO_2e
unit for comparing the radiative forcing of a *greenhouse gas* (3.13) to that of carbon dioxide

Note 1 to entry: The carbon dioxide equivalent is calculated using the mass of a given greenhouse gas multiplied by its *global warming potential* (3.15).

[SOURCE: ISO 14064-1:2018, 3.1.13]

3.3
chemical vapour deposition
CVD
process for manufacturing preforms by which vapours and gases react chemically to produce deposits at the surface of a substrate

3.4
equity share
percentage of economic interest in, or benefit derived from, a *facility* (3.7)

Note 1 to entry: Under this approach, an *organization* (3.27) (corporation, group) or a company consolidates its *greenhouse gas emissions* (3.14) according to the (pro rata) equity share it holds in each operation, i.e. according to ownership. As an exception, no emissions are consolidated for so-called fixed asset investments where a company owns only a small part of the total shares of an operation and exerts neither significant influence nor financial control; other possible exceptions relate to the economic substance of a relationship.

3.5
etching
removal of surface material

Note 1 to entry: Etching can be applied with liquids agents (wet chemical etching) or with gases in a recipient (dry etching, plasma etching). The etching agent reacts chemically with the substrate.

[SOURCE: ISO 12679:2011, 3.3]

3.6
etching and wafer cleaning
EWC
removal process of chemical and particle impurities without altering or damaging the wafer surface after *etching* (3.5) the surface material

3.7
facility
single installation, set of installations or production processes (stationary or mobile), which can be defined within a single geographical boundary, organizational unit or production process

[SOURCE: ISO 14064-1:2018, 3.4.1]

3.8
fixed combustion emission
emission from the fixed combustion, including power generation, heat and electricity generation

3.9
fluorinated compounds and N_2O
FCs and N_2O
types of fluorinated compounds and liquids used to manufacture electrical products

EXAMPLE CF_4, C_2F_6, C_3F_8, c-C_4F_8, C_4F_6, c-C_5F_8, CH_3F, CH_2F_2, CHF_3, C_2HF_5, NF_3, SF_6, COF_2, F_2, C_4F_8O and N_2O.

3.10
fossil fuel
fuels from fossilized materials listed by the Intergovernmental Panel on Climate Change (IPCC)

EXAMPLE Coal, oil, natural gas and peat.

[SOURCE: ISO 19694-3:2023, 3.18]

3.11
fuel combustion
intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or to be used away from the apparatus

3.12
global warming potential
GWP
index, based on radiative properties of *greenhouse gases* (3.13), measuring the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon (e.g. 100 years), relative to that of carbon dioxide (CO_2)

[SOURCE: ISO 14064-1:2018, 3.1.12, modified — "(e.g. 100 years)" has been added to the definition.]

3.13
greenhouse gas
GHG
gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds

Note 1 to entry: For list of greenhouse gases, see latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report.

Note 2 to entry: Water vapour and ozone are anthropogenic as well as natural greenhouse gases but are not included as recognized greenhouse gases due to difficulties, in most cases, in isolating the human-induced component of global warming attributable to their presence in the atmosphere.

[SOURCE: ISO 14064-1:2018, 3.1.1]

3.14
greenhouse gas emission
GHG emission
release of a *greenhouse gas* (3.13) into the atmosphere

[SOURCE: ISO 14064-1:2018, 3.1.5]

3.15
greenhouse gas emission factor
emission factor
coefficient relating *greenhouse gas* (3.13) activity data with the *greenhouse gas emission* (3.14)

[SOURCE: ISO 14064-1:2018, 3.1.7, modified — "GHG" has been removed from the second term and Note 1 to entry has been deleted.]

3.16
greenhouse gas inventory
GHG inventory
list of *greenhouse gas sources* (3.17) and *greenhouse gas* (3.13) sinks, and their quantified *greenhouse gas emissions* (3.14) and greenhouse gas removals

[SOURCE: ISO 14064-1:2018, 3.2.6]

3.17
greenhouse gas source
GHG source
process that releases a *greenhouse gas* (3.16) into the atmosphere

[SOURCE: ISO 14064-1:2018, 3.1.2]

3.18
electricity grid
grid
public electricity network

[SOURCE: ISO 52000-1:2017, 3.4.8]

3.19
indirect greenhouse gas emission
indirect GHG emission
greenhouse gas emission (3.14) that is a consequence of an *organization's* (3.27) operations and activities, but that arise from *greenhouse gas sources* (3.17) that are not owned or controlled by the organization

Note 1 to entry: These emissions occur generally in the upstream and/or downstream chain.

[SOURCE: ISO 14064-1:2018, 3.1.11]

3.20
in situ plasma cleaning
IPC
technique using chemically reactive oxygen plasma to remove hydrocarbon contaminants

3.21
in situ thermal cleaning
ITC
combined process of pyrolysis and oxidation

3.22
lower heat value
LHV
net calorific value
NCV
absolute value of the specific heat (enthalpy) of combustion, for unit mass of the fuel burned in oxygen at constant pressure under such conditions that all the water of the reaction products remains as water vapour (at 0,1 MPa), the other products being as for the gross calorific value, all at the reference temperature

[SOURCE: ISO 1928:2020, 3.1.3, modified — the term “net calorific value at constant volume” has been replaced with “lower heat value”, the admitted term "net calorific value" has been added, and "(enthalpy)" has been added to the definition.]

3.23
micro-electromechanical system
MEMS
DEPRECATED: micro-electromechanical device
system composed of one or more integrated microsized components, such as sensors, actuators, transducers, resonators, oscillators, mechanical components and electric circuits

Note 1 to entry: In the definition, "microsized" is used to mean a size of less than a few millimetres.

Note 2 to entry: Technologies relating MEMS are extremely diverse and include fundamental technologies (such as design, material, processing, functional element, system control, energy supply, bonding and assembly, electric circuit, and evaluation), basic sciences (such as micro-science and engineering) as well as thermodynamics on a micro-scale and microtribology.

Note 3 to entry: The singular and plural forms of the term "MEMS" are identical.

[SOURCE: IEC 62047-1:2016, 2.1.1, modified — the term has been changed to "micro-electromechanical device" and the previous term "micro-electromechanical system" has been listed as a deprecated term; Notes 1 and 2 to entry have been revised.]

3.24
monitoring
continuous or periodic assessment of *greenhouse gas emissions* (3.14) and *greenhouse gas* (3.13) removals or other greenhouse gas-related data

[SOURCE: ISO 14064-1:2018, 3.2.12]

3.25
N_2O other process
semiconductor and display manufacturing process other than *N_2O thin-film deposition* (3.34) using N_2O

EXAMPLE Diffusion and dry removal of photoresist.

3.26
N_2O thin film deposition
N_2O TFD
thin-film deposition using N_2O as an input gas

3.27
organization
person or group of people that has its own functions with responsibilities, authorities and relationships to achieve its objectives

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, association, charity or institution, or part or combination thereof, whether incorporated or not, public or private.

[SOURCE: ISO 14064-1:2018, 3.4.2]

3.28
organizational boundary
grouping of activities or *facilities* (3.9) in which an *organization* (3.27) exercises operational or financial control or has an *equity share* (3.4)

[SOURCE: ISO 14064-1:2018, 3.4.7]

3.29
photovoltaic device
PV device
device which produces an electric potential difference between two points in a material by the absorption of photons

3.30
process emission
emission from industrial processes involving chemical transformation other than combustion

[SOURCE: ISO 19694-1:2021, 3.36, modified — "including chemical and mineralogical transformations" has been changed to "involving chemical transformation".]

3.31
remote plasma cleaning
RPC
plasma processing method in which the plasma and material interaction occurs at a location remote from the plasma

3.32
reporting boundary
grouping of *greenhouse gas emissions* (3.14) or greenhouse gas removals reported from within the *organizational boundary* (3.28) as well as those significant *indirect greenhouse gas emissions* (3.19) that are a consequence of the *organization's* (3.27) operations and activities

[SOURCE: ISO 14064-1:2018, 3.4.8]

3.33
source stream
specific fuel type, raw material or product that

a) creates emissions of relevant *greenhouse gases* (3.13) at one or more emission sources as a result of its consumption or production;

b) contains carbon and is included in the calculation of *greenhouse gas emissions* (3.14) using a mass balance methodology

3.34
thin film deposition
TFD
process of producing thin films by physical vapour deposition or *chemical vapour deposition* (3.3) as well as other techniques

3.35
transport combustion emission
combustion emission from transportation activities

3.36
uncertainty
parameter associated with the result of quantification which characterizes the dispersion of the values that can be reasonably attributed to the quantified amount

Note 1 to entry: Uncertainty information typically specifies quantitative estimates of the likely dispersion of values and a qualitative description of the likely causes of the dispersion.

[SOURCE: ISO 14064-1:2018, 3.2.13]

3.37
verification
process for evaluating a statement of historical data and information to determine if the statement is materially correct and conforms to criteria

[SOURCE: ISO 14064-1:2018, 3.4.9]

4 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

CVD	chemical vapour deposition
DRE	destruction removal efficiency
EF	emission factor
EWC	etching and wafer cleaning
FC	fluorinated compound
GHG	greenhouse gas
GWP	global warming potential
IPC	in situ plasma cleansing
IPCC	intergovernmental panel on climate change
ITC	in situ thermal cleaning
KPI	key performance indicator
LHV	lower heat value
MEMS	microelectromechanical systems
NER	normalized emission rate
OEM	original equipment manufacturer
PI	performance indicator
PV	photovoltaic
TFD	thin film deposition
RPC	remote plasma cleaning
WSC	World Semiconductor Council

5 Determination of GHG emissions principles

5.1 General

The determination of GHG emissions can in principle be done through a mass balance method or through stack emission measurement or a combination of these two approaches. The choice of appropriate methodology should depend on the obtention of accurate results with acceptable measurement uncertainties at reasonable costs.

5.2 Major GHG emissions in semiconductor and display

GHG emissions in semiconductor and display industry include the family of FCs, N_2O and CH_4, which are from direct emissions of combustion, transportation and manufacturing processes, or from indirect emissions.

5.3 Determination based on mass balance

The GHG emissions of an installation may be determined based on mass balance. Emissions from source streams are calculated from input or production data, obtained by means of measurement systems, and additional parameters from laboratory and analysis [including the reduction of mass of gas i (D_i), the use rate of gas *i* (U_i), the emission factor of by-product ($B_{k,i}$)]. Standard factors may also be used; references to these factors are provided in ISO 19694-1.

5.4 Determination based on stack emission measurements

The GHG emissions of an installation may also be determined by measurement. Emissions from an emission source are determined based on the measurement of the concentration of the relevant GHG in the flue gas and the flowrate of the flue gas. Measurement standards to be applied on stack emission measurements are provided in ISO 19694-1 and *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

6 Inventory boundaries

6.1 General

Drawing appropriate boundaries is one of the key tasks in an emissions' inventory process.

6.2 Organizational boundaries

Organizational boundaries define which parts of an organization – for example, wholly owned operations, joint ventures and subsidiaries – are covered by an inventory, and how the emissions of these entities are consolidated. The requirements to create organizational boundaries in ISO 19694-1 shall be applied.

In this document, reporting covers the main direct and indirect GHG emissions associated with semiconductor and display production as required in Clauses 7, 8 and 10. These emissions also include those related to consumption of fuels, materials and electricity in upstream and downstream operations.

Separate inventories may be established for individual facilities as appropriate, for instance, if they are geographically separated or run by distinct operators. The impacts of such a division will cancel out when emissions are consolidated at an organizational or group level.

Table 1 — Reporting boundaries for the semiconductor industry

Emission source			Type of GHGs							Included within boundaries
			CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3	
Direct emissions	Fixed combustion emissions	Room heating/ cooling	○	○	○					Fossil fuels used for operating the boiler
		Power / heat generation	○	○	○					Fossil fuels used in the emergency generator
	Transport combustion emissions	Transport and distribution	○	○	○					Transport to processing facilities
	Process emissions	EWC				○	○	○	○	Plasma etching and wafer cleaning of silicon materials
		RPC				○	○	○	○	Remote plasma cleaning
		IPC				○	○	○	○	In situ plasma cleaning
		ITC				○	○	○	○	In situ thermal cleaning
		N_2O TFD			○					Cleaning of the chamber from the TFD process
		N_2O other process			○					N_2O process other than TFD
Indirect emissions		Imported electricity	○	○	○					Use of purchased electricity production consumed in the company's equipment
		Imported steam / heat	○	○	○					

6.3 Reporting boundaries

Reporting boundaries refer to the types of sources of emissions covered by an inventory and shall follow ISO 14064-1.

Each semiconductor and display plant shall asses its direct GHG emissions sources and indirect GHG emission sources. The assessment shall include GHG emissions from all stages of the manufacturing process undertaken at the plant. Clause 7 provides detailed guidance on the different sources of direct emissions occurring in semiconductor and display plant. Indirect emissions are addressed in Clause 8.

Companies shall use the reporting boundaries outlined in Tables 1 and 2 for the determination of GHG emissions for the semiconductor and display plant. Any deviation from the boundaries shall be reported and explained.

Table 2 — Reporting boundaries for the display industry

<table>
<tr><th colspan="3" rowspan="2">Emission source</th><th colspan="7">Type of GHGs</th><th rowspan="2">Included within boundaries</th></tr>
<tr><th>CO_2</th><th>CH_4</th><th>N_2O</th><th>HFCs</th><th>PFCs</th><th>SF_6</th><th>NF_3</th></tr>
<tr><td rowspan="7">Direct emissions</td><td rowspan="2">Fixed combustion emissions</td><td>Room heating/ cooling</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td><td></td><td>Fossil fuels used for operating the boiler</td></tr>
<tr><td>Power / heat generation</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td><td></td><td>Fossil fuels used in the emergency generator</td></tr>
<tr><td>Transport combustion emissions</td><td>Transport and distribution</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td><td></td><td>Transport to processing facilities</td></tr>
<tr><td rowspan="4">Process emissions</td><td>Etching</td><td></td><td></td><td></td><td>○</td><td>○</td><td>○</td><td>○</td><td>Plasma etching of silicon materials</td></tr>
<tr><td>RPC</td><td></td><td></td><td></td><td>○</td><td>○</td><td>○</td><td>○</td><td>Remote plasma cleaning</td></tr>
<tr><td>IPC</td><td></td><td></td><td></td><td>○</td><td>○</td><td>○</td><td>○</td><td>In situ plasma cleaning</td></tr>
<tr><td>N_2O TFD</td><td></td><td></td><td>○</td><td></td><td></td><td></td><td></td><td>Cleaning of the chamber from the TFD process</td></tr>
<tr><td colspan="2" rowspan="2">Indirect emissions</td><td>Imported electricity</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td><td></td><td rowspan="2">Use of purchased electricity production consumed in the company’s equipment</td></tr>
<tr><td>Imported steam / heat</td><td>○</td><td>○</td><td>○</td><td></td><td></td><td></td><td></td></tr>
</table>

7 Direct GHG emissions and their determination

7.1 General

Direct GHG emissions are emissions from sources of the respective plant. In the semiconductor and display manufacture, GHG emissions include the family of FCs including fluorinated liquids, N_2O and CH_4 which may result from, but are not restricted to, the following sources:

— fuel combustion for on-site power generation

— process emission, including:

a) plasma EWC of silicon-containing materials, and

b) cleaning of the chamber walls of TFD and diffusion tools after processing substrates.

The reporting entity shall prepare a full inventory of all direct GHG emissions sources of the plant.

The amount of FCs and N_2O direct GHG emissions can be determined by the mass balance based method or by the continuous stack measurement based method.

Generally, companies are encouraged to measure the required parameters at plant level for site-specific gases. Where plant- or company- specific data are not available, standard or default factors should be used. Emission factors, formulae and reporting approaches for these sources are described in Clauses 7 and 8.

7.2 Direct GHG emissions from combustion and transportation

Direct GHG emissions from combustion can occur from sources that are owned or controlled by the organization, such as boilers, furnaces and vehicles. GHG from combustion and transportation include CO_2, CH_4, and N_2O. To determine the direct GHG emissions from combustion and transportation, obtain the following data:

— mass flow or volume flow (activity data);

— emissions factors;

— calorific values for fuels;

— oxidation or conversion factors.

GHG emissions from the fuel combustion can be calculated based on the mass, net calorific value and chemical composition of fuels entering the process. It is important to note that the applied net calorific value always has to match the type of the fuel.

The GHG emissions from combustion and transportation shall be determined using the mass balanced based method given in Formula (1).

$$E = f_{cons} \cdot H_i \cdot F_E \cdot F_o \qquad (1)$$

where

E are the total annual GHG emissions of the regarding fuel, in tCO_2e/year;

f_{cons} is the amount of fuel consumed, in t/year;

H_i is the lower heat value (LHV) of fuel, in GJ/t;

F_E is the emission factor of fuel, in tCO_2e/GJ;

F_o is the oxidation factor of fuel (dimensionless); an oxidation factor of 1 means complete oxidation.

The GHG emissions from fuel shall be summed to give the total emissions of the fuels for the entire plant.

The reporting entity shall calculate GHG emissions in accordance with ISO 19694-1.

The reporting entity shall follow sampling methods in accordance with ISO 19694-1.

7.3 Direct GHG emissions from process emissions

7.3.1 General

The use of FCs and N_2O is considered under the process emission. The GHG emissions originating from the use of FC gas and N_2O in the semiconductor and display manufacturing process shall be calculated.

FC gases include perfluoromethane (CF_4), perfluoroethane (C_2F_6), perfluoropropane (C_3F_8), perfluorocyclobutane (c-C_4F_8), 1,3-hexafluorocyclopentene (C_4F_6), octafluorotetrahydrofuran (C_4F_8O), octafluorocyclopentene (c-C_5F_8), fluoromethane (CH_3F), difluoromethane (CH_2F_2), trifluoromethane (CHF_3), pentafluoroethane (C_2HF_5), nitrogen trifluoride (NF_3) and hexafluoride (SF_6). This method is also applicable to the determination of COF_2 and F_2 emissions.

In general, FCs that are GHGs or whose use during the manufacturing of electronic devices can result in emissions of GHGs should be determined.

In the manufacturing processes, some portions of FC input gas are transformed into FC gas by-products such as CF_4, C_2F_6, C_4F_6, C_3F_8, CH_3F, CH_2F_2 and CHF_3. Several of these by-products can also be formed even if no carbon-containing FCs, F_2, NF_3, SF_6, and ClF_3, are fed into the process that include etching carbon containing materials or cleaning chambers used to deposit carbon-containing thin films.

The semiconductor sector includes six process types as follows: EWC, RPC, IPC, ITC, N_2O TFD and N_2O other process. The display sector is differentiated into four process types: etching, RPC, IPC and N_2O TFD.

Methods to determine emissions of FC gases, fluorinated liquids, and N_2O that are used in the semiconductor and display manufacturing processes are mainly classified into three tiers:

— Tier 1 is applicable only in cases where facility-specific data are not available. Tier 1 gives the aggregated estimate of GHG and N_2O emissions based on production figures (surface area of substrate used during the production of electronic devices).

— Tier 2a is only applicable to the semiconductor industry or industries with processes similar to semiconductor manufacturing, such as MEMS. Tier 2a uses the default emission factors based on gas consumption.

— Tier 2b is only applicable to the semiconductor industry and to MEMS manufacturing that uses tools and processes similar to those used to manufacture semiconductors. Tier 2b uses the default emission factors that are provided by the wafer size being manufactured.

— Tier 2c is applicable to the all sub-sectors, semiconductor (MEMS), display, and PV. Tier 2c uses default emission factors that are provided for distinct process types *p*.

— Tier 3a is applicable to all sub-sectors and uses measured values for parameters. Tier 3a uses emission factors which are measured for recipes or families of similar recipes.

— Tier 3b is applicable to all sub-sectors. Tier 3b measures the amount of GHGs emitted from a specific facility through stack systems. Reporting companies estimate their emissions based on fabrication-specific emission factors.

The steps to determine the direct GHG emissions in the semiconductor and display industry manufacturing processes are given in Figure 1.

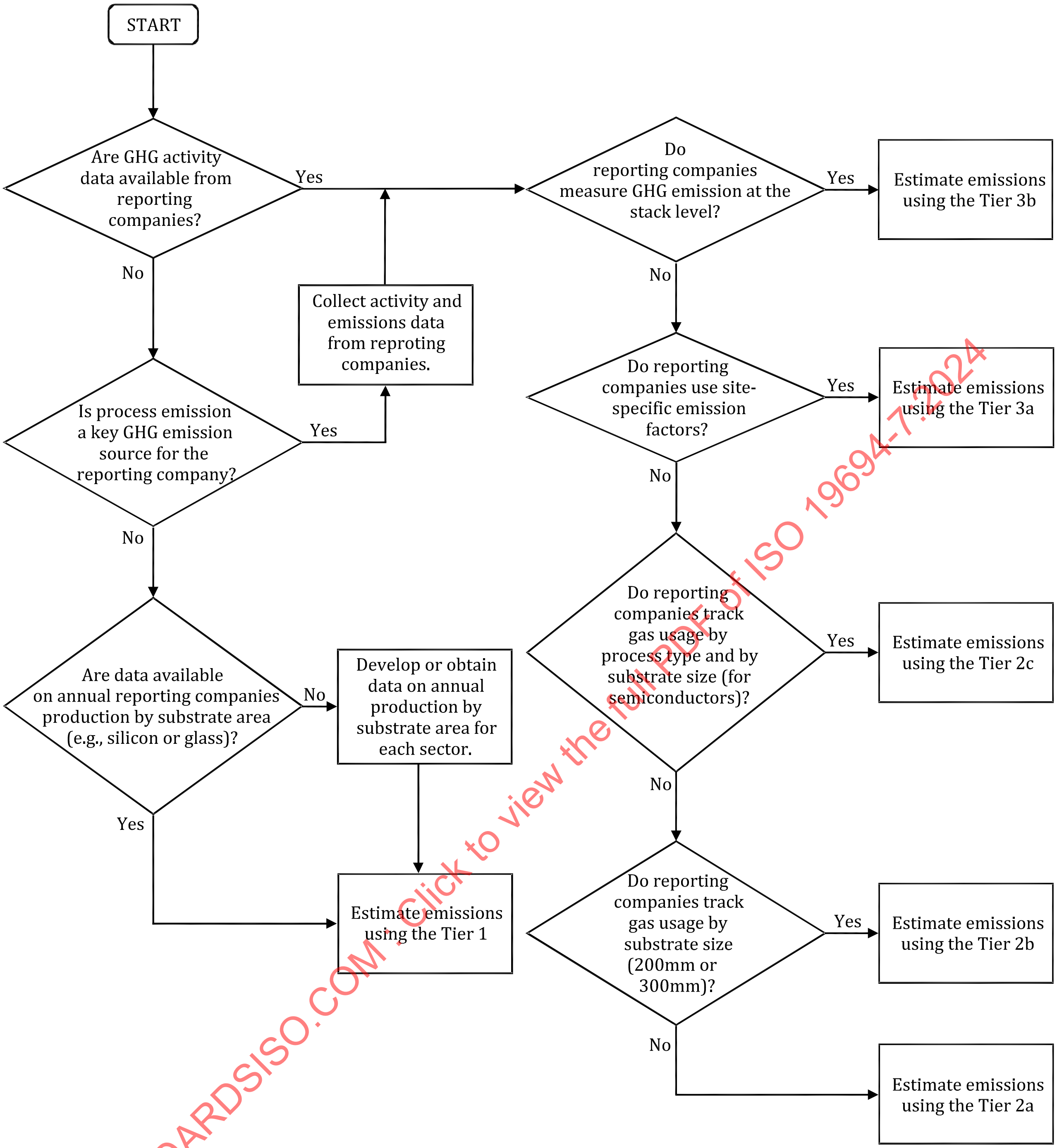


Figure 1 — Flowchart for the determination of the estimation method of GHG emissions from semiconductor and display manufacturing process

NOTE If there are no national regulations, the following suggestion can be used to define key GHG emission sources: key GHG emission sources are emission sources prioritized within the total GHG emission sources of the individual company's emission from Table 1 and Table 2 because their process emission estimates exceed 5 % of the total process emission.

The GHG emissions determination method is exclusively developed for specific FC handling plants using the emission factors. The development of individual facilities emission factors for specific process to estimate emissions is encouraged. When it is not possible to apportion gas consumption for a site-specific level, then the emission factors from IPCC or national factors based on consumption of individual gases may be used as the default emission factors. However, the precision of the emissions' estimate generally improves from a lower tier to a higher tier, due to more site-specific factors.

Emission factors, formulae and reporting approaches for these sources are described in the following subclauses of 7.3.

Generally, companies are encouraged to measure the required parameters at the plant level, as it is expected to provide a more accurate emissions estimate. International default factors can be used when the data for the facilities specific emission factors are not provided. Other default factors (e.g. national) are preferred to the international defaults if deemed reliable and more appropriate. The following sections provide guidance for choosing between different methods for reporting CO_2 emissions from the process, which shall be estimated using *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, ANNEX C.

7.3.2 Tier 1

For Tier 1 method, "Tier 1 METHOD – DEFAULT EMISSION FACTORS BASED ON PRODUCTION" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* shall be referred to.

It is not good practice to modify these, in any way, and the Tier 1 method can only be used if these gases, (CF_4, C_2F_6, C_3F_8, C_4F_6, c-C_4F_8, C_4F_8O, C_5F_8, CHF_3, CH_2F_2, NF_3, SF_6, and N_2O), are to be reported as a complete set.

For each sub-sector of electronic products being manufactured, the calculation of emission relies on a different set of default, gas-specific emission factors. Each default emission factor expresses the average emissions of the relevant gas per unit area of the relevant substrate used during manufacture (including test substrates). For any class of electronic products (input material), the default emission factors are multiplied by the annual production area of the devices, P, expressed in m^2.

The result is a set of annual emissions estimates expressed in kilograms of the gases emitted during the manufacture of that class of electronic products. The Tier 1 GHG emission estimation method is depicted in Formula (2), and the default emission factors are presented in Table B.1.

Tier 1 method for estimation of the set of GHG emissions is calculated according to Formula (2):

$$\{E_i\}_n = \{F_{\mathrm{E},i} \cdot P \cdot [F_{\mathrm{PV}} \cdot \delta + (1-\delta)]\}_n \; (i = 1,\ldots,n) \tag{2}$$

where

$\{E_i\}_n$ is the emission of fluorinated compound gas i or N_2O, in kg;

NOTE $\{\}_n$ denotes the set for each class of products (semiconductors, display, MEMS or PV) and n denotes the number of gases included in each set. The estimates are only valid if made and reported for all members of the set using this Tier 1 methodology.

$F_{\mathrm{E},i}$ is the emission factor for gas i expressed as annual mass of emissions per square meters of substrate surface area for the product class;

P is the annual production m^2 of substrate used as measured by the surface area of substrate used during the production of electronic devices, including test substrates; if annual production is not available from an electronics producer, P may be calculated as the product of the annual manufacturing capacity and annual plant production capacity utilization (fraction) of that producer;

F_{PV} is the fraction of PV manufacture that uses FC gases;

δ is equal to 1 when Formula (2) is applied to PV industries and zero when it is applied to either semiconductor or TFT-display industries;

i is the input gas.

Tier 2 and Tier 3a methods are expected to be more accurate than the Tier 1 method because they rely on the actual consumption of individual gases and account for the use of emissions control technology.

7.3.3 Tier 2a

For Tier 2a method, "Tier 2a Method" under "Tier 2 METHOD – DEFAULT EMISSION FACTORS BASED ON PRODUCTION" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* should be referred to.

The Tier 2a method is applicable to semiconductor manufacturing and to MEMS manufacturing that is carried out using tools and processes similar to those used to manufacture semiconductors. The Tier 2a method does not distinguish between wafer sizes or among process types for most GHGs; the Tier 2a method uses the default emission factors provided in Table B.2.

Tier 2a method for the emission of input gas i is calculated according to Formula (3):

$$E_i = C_i \cdot (1 - U_i) \cdot (1 - D_i) \quad (3)$$

where

E_i is the emission of unreacted input gas i, in kg;

C_i is the consumption of input gas i, in kg;

U_i is the use rate of gas i (fraction destroyed or transformed in process);

D_i is the overall reduction of mass of gas i emissions (site-specific fraction, calculated per Formula 6.8 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*).

Tier 2a method of the by-product emission is calculated in according to Formula (4):

$$B_{\mathrm{BPE},k} = \sum_i \left[C_i \cdot B_{k,i} \cdot (1 - D_k) \right] \quad (4)$$

where,

$B_{\mathrm{BPE},k}$ is the emission of by-product k generated from the conversion of all input gases i, in kg;

C_i is the consumption of input gas i, in kg;

$B_{k,i}$ is the emission factor for by-product k generated from input gas i, in kg of by-product k create/kg of gas i consumed;

D_k is the overall reduction of mass of gas k by-product emissions, in site-specific fraction, calculated per Formula 6.9 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*;

k is the by-product gas.

By-product emissions from hydrocarbon fuelled combustion emissions control systems are calculated according to Formula (5):

$$E_{\mathrm{EAB},i,\mathrm{CF4}} = C_i \cdot (1 - U_i) \cdot (1 - \eta) \cdot A_{\mathrm{AB},i,\mathrm{CF4}} \quad (5)$$

where

$E_{\mathrm{EAB},i,\mathrm{CF4}}$ is the emission of CF_4 from hydrocarbon-fuel-based combustion emissions control systems when direct reaction with hydrocarbon fuel and fluorinated species is certified not to occur by the emissions control original equipment manufacturer (OEM) or electronics manufacturer, in kg;

C_i is the consumption of input gas i, where only NF_3 used in RPC processes or F_2 for the purpose of Formula (5) (Formula 6.7 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*), in kg;

U_i is the use rate of gas *i* (fraction destroyed or transformed in process);

H is the ratio of emissions control systems certified not to form CF_4, within emissions control systems to the total number of emissions control systems in the facility, (site-specific fraction);

$A_{AB,i,CF4}$ is the mass fraction of NF_3 used in RPC processes of F_2 in process exhaust gas that in converted into CF_4 by direct reaction with hydrocarbon fuel and F_2 gas in a combustion emissions control systems; $A_{AB,i,CF4}$ is set to zero if the emissions control OEM or electronics manufacturer can ensure that the rate of conversion from F_2 to CF_4 or from NF_3 to CF_4 is <0,1 percent; otherwise, a default value of $A_{AB,NF3,CF4}$ = 0,093 or $A_{AB,F2,CF4}$ = 0,116 should be used [*i* is equal to only NF_3 used in RPC processes or F_2 for the purpose of Formula (5) (Formula 6.7 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*].

For the total annual input gas *i* consumption, C_i, on a facility basis for each fluorinated compound and N_2O in the input method (Tier 2 and Tier 3a), see "GAS CONSUMPTION AND APPORTIONING FOR TIERS 2 AND 3" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

7.3.4 Tier 2b

For Tier 2b method, see "Tier 2b Method" under "Tier 2 METHOD – DEFAULT EMISSION FACTORS BASED ON PRODUCTION" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

The Tier 2b method is only applicable to the semiconductor sub-sector and to MEMS manufacturing that use tools and processes similar to those used in semiconductor manufacture. Tier 2b uses the same set of formulae as the Tier 2a method, but default emission factors are provided by the wafer size being manufactured (≤200 mm or 300 mm) (see Tables B.3 and B.4).

7.3.5 Tier 2c

For Tier 2c method, "Tier 2c Method" under "Tier 2 METHOD – DEFAULT EMISSION FACTORS BASED ON PRODUCTION" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* shall be referred to.

The Tier 2c method is applicable to the semiconductor, display and PV sub-sectors, and to MEMS manufacturing that is carried out using tools and processes similar to those used to manufacture semiconductors. The Tier 2c method is based on a set of formulae that account for default emission factors that are provided for distinct process types *p* (EWC, RPC, IPC, ITC, N_2O TFD, and N_2O other process). The default emission factors for the Tier 2c method are included in Tables B.5 to B.8.

The Tier 2c method is preferred over the Tier 2a or Tier 2b methods in the semiconductor sub-sector because the Tier 2c default emission factors are expected to be more accurate than the other Tier 2 methods factors. However, using the Tier 2c method requires apportioning gas consumption for all gases and process types, which introduces additional complexity.

Tier 2c method for estimation of input gas *i* emissions are calculated according to Formula (6):

$$E_i = \sum_p \left[C_{i,p} \cdot \left(1 - U_{i,p}\right) \cdot \left(1 - D_{i,p}\right) \right] \quad (6)$$

where

E_i are the emissions of unreacted input gas *i*, in kg;

$C_{i,p}$ is the consumption of input gas *i* for process type *p*, in kg;

$U_{i,p}$ is the use rate of gas *i* for process *p* (fraction destroyed or transformed in process);

$D_{i,p}$ is the overall reduction of mass of gas *i* emitted from process type *p*, site-specific fraction calculated per Formula 6.16 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories.*

The tier 2a method for estimation of the emission of by-product emissions from hydrocarbon fuelled combustion emissions control systems is according to Formula (7):

$$B_{\mathrm{BPE},k} = \sum_i \left[\sum_p [C_{i,p} \cdot B_{k,i,p} \cdot (1 - D_{k,p})] \right] \tag{7}$$

where

$B_{\mathrm{BPE},k}$ is the emission of by-product *k* generated from the conversion of all input gases *i* for all process types *p*, in kg;

$C_{i,p}$ is the consumption of input gas *i* for process type *p*, in kg;

$B_{k,i,p}$ is the emission factor for by-product *k* generated from input gas *i* for process type *p*, (kg of by-product gas *k* created/kg of gas *i* consumed for process type *p*);

$D_{k,p}$ is the overall reduction of mass of gas *k* by-product emission for process type *p*, site-specific fraction, calculated per Formula 6.17 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories.*

By-product emissions from hydrocarbon fuelled combustion emissions control systems are calculated according to Formula (8):

$$E_{\mathrm{EAB},i,\mathrm{CF4}} = \sum_p C_{i,p} \cdot (1 - U_{i,p}) \cdot (1 - \eta_p) \cdot A_{\mathrm{AB},i,CF4} \tag{8}$$

where

$E_{\mathrm{EAB},i,\mathrm{CF4}}$ is the emission of CF_4 from hydrocarbon-fuel-based combustion emissions control systems when direct reaction with hydrocarbon fuel and fluorinated species is certified not to occur by the emissions control OEM or electronics manufacturer, in kg;

$C_{i,p}$ is the consumption of input gas *i* for process type *p* [*i* is equal to only NF_3 used in RPC processes or F_2 for the purpose of Formula (8) (Formula 6.15 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*)], in kg;

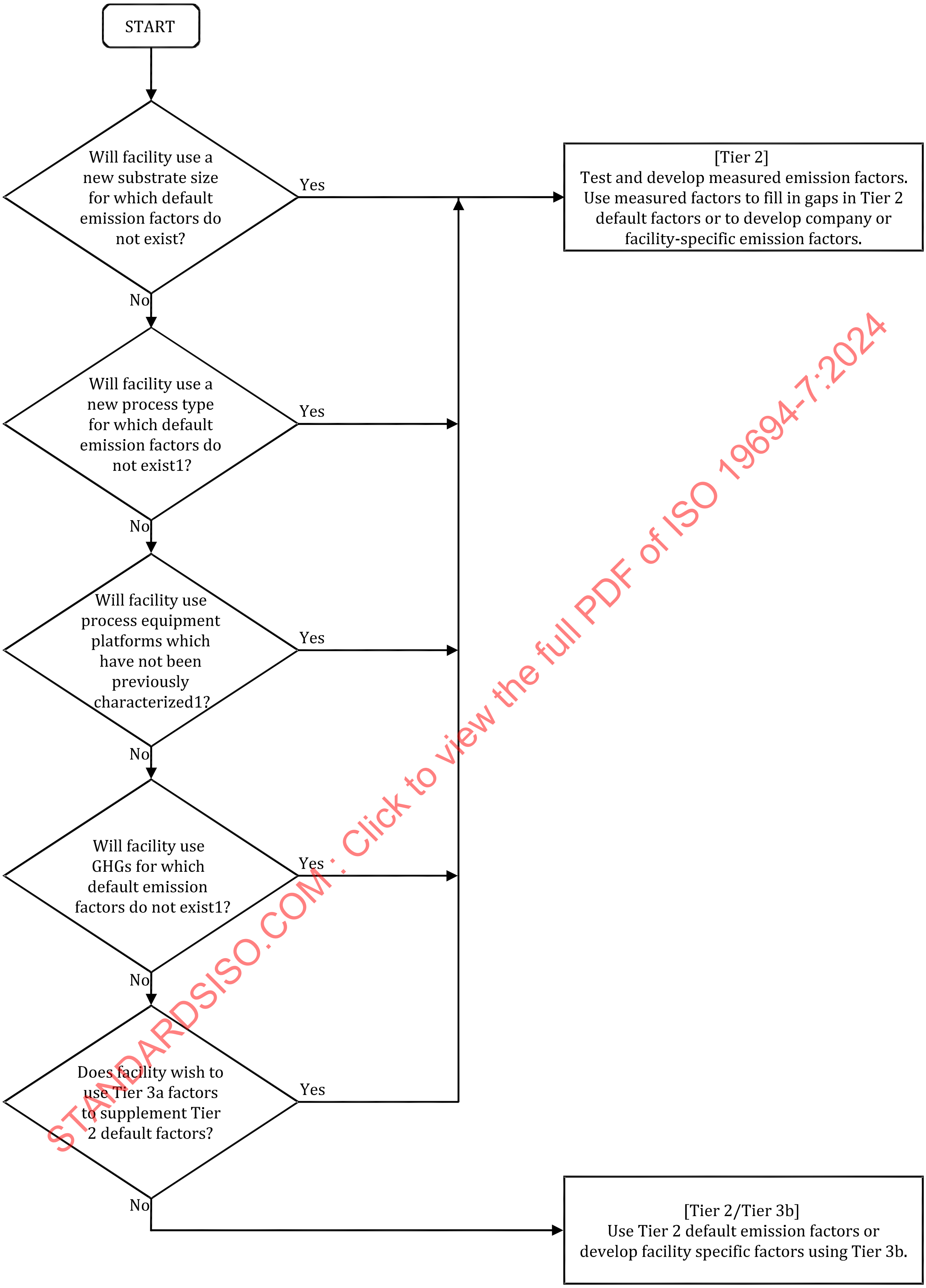
$U_{i,p}$ is the use rate of gas *i* for process *p* (fraction destroyed or transformed in process);

η_p is the ratio of emissions control systems connected to tools running process type *p* and certified not to form CF_4 within emissions control systems to the total number of emissions control systems connected to tools running process type *p* in the facility, (site-specific fraction);

$A_{AB,i,CF4}$ is the mass fraction of NF_3 used in RPC processes and of F_2 in process exhaust gas that is converted into CF_4 by direct reaction with hydrocarbon fuel and F_2 gas in a combustion emissions control systems; $A_{AB,i,CF4}$ is set to zero if the emissions control equipment OEM or electronics manufacturer can certify that the rate of conversion from F_2 to CF_4 or from NF_3 to CF_4 is < 0,1 percent; otherwise, a default value of $A_{AB,NF3,CF4}$ = 0,093 or $A_{AB,F2,CF4}$ = 0,116 should be used [*i* equal to only NF_3 used in RPC processes or F_2 for the purpose of Formula (5) (Formula 6.15 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*)];

p is the process type [RPC using NF_3 or any process type using F_2 for the purpose of Formula (8) (Formula 6.15 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*)].

Figure 2 determines the need for measured emission factors and should be used to determine when Tier 3a measured emission factors can be necessary to supplement Tier 2 default emission factors.



If a new gas and process combination are used that accounts for less than 1 % of facility fluorinated GHG consumption by mass and $(1 - U)$, where U is the rate of the gas, is not measured or not listed, the complier may assume $(1 - U)$ = 0,8, B_{CF4} = 0,15, B_{C2F6} = 0,05.

Figure 2 — Decision tree used to determine the need for measured emission factors

7.3.6 Tier 3a — Measured process-specific parameters

7.3.6.1 General

For Tier 3a method, "Tier 3a Method – Measured process-specific parameters" under "Tier 3 METHODs – SITE-SPECIFIC PARMETERS" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* shall be referred to.

The Tier 3a method can be applied to all sub-sectors (semiconductor, display, PV and MEMS) and uses the same set of formulae as the Tier 2c method. Tier 3a can also be undertaken to develop facility-specific emission factors for broader application in the facility.

7.3.6.2 Minimum sampling frequency of Tier 3a

When the factors are developed using FCs, commonly used in the semiconductor and display industry, measurements are recommended to be performed as follows: the facility is required to report emissions of FCs and N_2O for the first two years for each abatement system gas and process sub-type or process type combination. A random sample of a minimum of 10 % of installed abatement systems must be tested annually for a total minimum of 20 % of abatement systems within two years, or a minimum of 20 % of abatement systems may be tested in the first year[6].

If a facility determines that no substantive changes have occurred in the year following emission calculation, the emission factors determined may remain unchanged, and retesting is not required for analysis items like use rate of gas (U_i) and by-product emission factor (B); however, measurement of destruction removal efficiency (d) is recommended to occur every three years at a minimum, testing a random sample of a least 15 % of installed abatement systems for each gas and process sub-type or process type combinations[6].

7.3.7 Tier 3b — Stack testing

7.3.7.1 General

For Tier 3b method, "Tier 3b Method – Stack testing" under "Tier 3 METHODs – SITE-SPECIFIC PARAMETERS" in 6.2.1.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. shall be referred to.

The Tier 3b method may be applied to all sub-sectors (semiconductor, display, PV and MEMS). Stack testing, the Tier 3b method, measures the amount of GHGs emitted from a specific facility through stack systems.

7.3.7.2 Stack test method

The emissions of each FC gas and N_2O consumed as an input gas is calculated using Formula (9) and each FC gas formed as a by-product is calculated using Formula (10). If a stack system comprises multiple stacks, the emissions from each stack in the stack system should be summed when using Formula (9) or Formula (10).

Total GHG input gas emitted from stack system during sampling period are calculated according to Formula (9):

$$E_{\mathrm{ES},i,s} = W_i \cdot Q_s \cdot \frac{1}{V} \cdot \frac{1}{10^3} \cdot \sum_{m=1}^{N} \frac{X_{i,s,m}}{10^9} \cdot \Delta t_m \qquad (9)$$

where

$E_{ES,i,s}$ is the emission of input gas i from stack system s during the sampling period, in kg;

W_i is the molecular weight of gas i, in g/g·mol;

Q_s is the flow rate of stack system s during the sampling period, in m^3/min;

V is the standard molar volume of gas, (0,024 0 m^3/g·mol at 293,15 K and 101,325 kPa);

$X_{i,s,m}$ is the average concentration of input gas i in stack system s during time interval m, in nmol/mol;

Δt_m is the length of time interval m in the FTIR sampling period, in min; each time interval in the FTIR sampling period should be less than or equal to 60 min (e.g. an 8 h sampling period would consist of at least 8-time intervals);

$1/10^3$ is the conversion factor, (1 kg/1,000 g);

i is the input gas;

s is the stack system;

N is the total number of time intervals m in sampling period;

m is the time interval.

The total GHGs by-product emitted from stack system during sampling period is calculated according to Formula (10):

$$E_{ES,k,s} = W_k \cdot Q_s \cdot \frac{1}{V} \cdot \frac{1}{10^3} \cdot \sum_{m=1}^{N} \frac{X_{k,s,m}}{10^9} \cdot \Delta t_m \tag{10}$$

where

$E_{ES,k,s}$ is the emission of by-product k emitted from stack system s during the sampling period, in kg;

W_k is the molecular weight of by-product gas k, in g/g·mol;

Q_s is the flow rate of stack system s during the sampling period, in m^3/min;

V is the standard molar volume of gas, (0,024 0 m^3/ g·mol at 293,15 K and 101,325 kPa);

$X_{k,s,m}$ is average concentration of by-product gas k in stack system s during time interval m, in nmol/mol;

Δt_m is the length of time interval m in the FTIR sampling period, in min; each time interval in the FTIR sampling period should be less than or equal to 60 min (e.g. an 8 h sampling period would consist of at least 8-time intervals);

$1/10^3$ is the conversion factor, (1 kg/1,000 g);

k is the by-product gas;

s is the stack system;

N is the total number of time intervals m in sampling period;

m is the time interval.

After calculating $ES_{i,s}$ and $ES_{k,s}$, inventory compilers should calculate a facility-specific emission factor for each input gas consumed (in kg of FCs or N_2O emitted per kg of input gas i consumed) in the tools that vent to stack systems that are tested, as applicable, using Formula (11).

Input gas i gas specific emission factor is calculated according to Formula (11):

$$E_{\mathrm{EF},i,f} = \frac{\sum_s E_{\mathrm{ES},i,s}}{A_{i,f} \cdot \left(T_f + \frac{1 - T_f}{1 - \left(a_{i,f} \cdot d_i \right)} \right)} \tag{11}$$

where

$F_{\mathrm{E},i,f}$	is the emission factor for input gas i and facility f representing 100 % emissions control system uptime, in kg emitted / kg of input gas consumed;
$E_{\mathrm{ES},i,s}$	is the emission of input gas i from stack system s during the sampling period, in kg;
$A_{i,f}$	is the consumption of input gas i for facility f during the sampling period, in kg;
T_f	is the total uptime of all emissions control systems for facility f during the sampling period, as calculated in Formula 6.30 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*, (site-specific fraction);
$a_{i,f}$	is the estimate of the fraction of gas i emitted from process tools equipped with suitable emissions control technologies for facility f, (site-specific fraction, as determined in Formula 6.10 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*);
d_i	is the destruction removal efficiency (DRE) for gas i (fraction);
i	is the input gas;
s	is the stack system;
f	is the facility.

FC gas by-product specific emission factor is calculated according to Formula (12):

$$E_{\mathrm{EF},k,f} = \frac{\sum_s E_{\mathrm{ES},k,s}}{\sum_i A_{i,f} \cdot \left(T_f + \frac{1 - T_f}{1 - \left(a_{k,f} \cdot d_k \right)} \right)} \tag{12}$$

where

$E_{\mathrm{EF},k,f}$	is the emission factor for FC by-product gas k emitted from facility f, representing 100 % emissions control system uptime, in kg emitted / kg of all FC input gases i consumed;
$E_{\mathrm{ES},k,s}$	is the emissions of FC by-product gas k, emitted from stack system s during the sampling period, in kg;
$A_{i,f}$	is the consumption of FC input gas i for facility f during the sampling period, in kg;
T_f	is the total uptime of all emissions control systems for facility f during the sampling period, as calculated in Formula 6.30 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*, (site-specific fraction); if the stack system does not have emissions control systems on the tools vented to the stack system, the value of this parameter is zero;
$a_{k,f}$	is the estimate of the fraction of by-product emitted from process tools equipped with suitable emissions control technologies for facility f, (site-specific fraction, as determined in Formula 6.11 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*);
d_k	is the DRE for FC by-product k (fraction).

After calculating $F_{\mathrm{EF},i,f}$, inventory compilers should calculate annual facility-level emissions of each input gas i consumed during the year using Formula (13).

After calculating $E_{EA,i,f}$, inventory compilers should calculate annual facility-level emissions of each by-product k formed using Formula (14).

Tier 3b estimation of annual emission of input gas i is calculated according to Formula (13):

$$E_{EA,i,f} = E_{EF,i,f} \cdot C_{i,f} \cdot T_f + \frac{E_{EF,i,f}}{1 - a_{i,f} \cdot d_i} \cdot C_{i,f} \cdot (1 - T_f) \quad (13)$$

where

$E_{EA,i,f}$ is the annual emission of input gas i from the stack systems that are tested for facility f, in kg/year;

$E_{EF,i,f}$ is the emission factor for input gas i and facility f representing 100 percent emissions control system uptime, in kg emitted / kg of input gas consumed;

$C_{i,f}$ is the total consumption of input gas i for facility f for the reporting year, in kg/year;

T_f is the total uptime of all emissions control systems for facility f, during the reporting year, as calculated in Formula 6.27 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories* (site-specific fraction);

$a_{i,f}$ is estimate of the fraction of gas i emitted from process tools equipped with suitable emissions control technologies for facility f (site-specific fraction, as determined in Formula 6.10 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*);

d_i is the DRE for gas i (fraction).

Tier 3b estimation of annual emissions of FC gas by-product k is calculated according to Formula (14):

$$E_{EA,k,f} = E_{EF,k,f} \cdot \sum_i C_{i,f} \cdot T_f + \frac{E_{EF,k,f}}{1 - a_{k,f} \cdot d_k} \cdot \sum_i C_{i,f} (1 - T_f) \quad (14)$$

where

$E_{EA,k,f}$ is the annual emissions of FC by-product k from the stack systems that are tested for facility f, in kg/year;

$E_{EF,k,f}$ is the emission factor for by-product gas k, emitted from facility f representing 100 percent emissions control system uptime, as calculated in Formula 6.27 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*, in kg emitted/kg of all FC input gases consumed;

$C_{i,f}$ is the total consumption of FC input gas i for facility f for the reporting year, in kg;

T_f is the total uptime of all emissions control systems for facility f during the reporting year as calculated in Formula 6.27 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories* (fraction);

$a_{k,f}$ is the estimate of the fraction of FC by-product gas k emitted from process tools equipped with suitable emissions control technologies for facility f (site-specific fraction, as determined in Formula 6.11 of *2019 Refinement to the 2006 IPCC Guideline for National Greenhouse Gas Inventories*);

d_k is the DRE for FC by-product k (fraction).

7.3.8 Fluorinated liquids

7.3.8.1 General

Fluorinated liquids are used as heat transfer fluids (HTFs) for temperature control, device testing, cleaning substrate surfaces and other parts, and soldering in certain types of electronics manufacturing production processes. Leakage and evaporation of these fluids during use is a source of fluorinated greenhouse gas emissions.

7.3.8.2 Tier 1 — Fluorinated liquids

For fluorinated liquids Tier 1 method, “Tier 1 – Fluorinated liquids” in 6.2.1.2 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* shall be referred to.

Tier 1 factors for fluorinated liquids are not available for PV. Tier 1 factors are also not available for substrate cleaning. Thus, the Tier 2 approach should be used to estimate fluorinated liquid emissions from these sources.

7.3.8.3 Tier 2 — Fluorinated liquids

For fluorinated liquids Tier 2 method, “Tier 2 – Fluorinated liquids” in 6.2.1.2 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* shall be referred to.

There is one Tier 2 method for estimating actual emissions from the use of any and each fluorinated liquid, applicable to all electronics manufacturing sub-sector (semiconductor, display, MEMS and PV) and to each application (temperature control, device testing, cleaning substrate surfaces and other parts, and soldering). This Tier 2 method is a mass balance approach that accounts for fluorinated liquid usage over an annual period. It is appropriate when company-specific data are available; it is the only method applicable to the use of fluorinated liquids for cleaning substrates surfaces and other parts, and for the PV sub-sector.

8 Indirect emissions from imported energy and their determination

8.1 General

Indirect GHG emissions are emissions that are a consequence of the operations of the reporting entity, but occur at sources owned or controlled by another entity. The semiconductor and display manufacturing is associated with indirect GHG emissions from external production of electricity consumed during the process, which includes:

— electricity consumed for semiconductor and display manufacturing procedures by third parties;

— production and processing of conventional fossil and alternative fuels by third parties;

The definition of the boundaries for indirect emissions is included in 6.3.

8.2 GHG emissions from imported electricity

GHG emissions from external electricity production shall be calculated based on the measured delivery of grid electricity and, preferentially, emission factors obtained from the electricity supplier. Alternatively, it is recommended to use governmental data for the national power grid. If both data are not available, an average emission factor for the country may be used. Such factors are based on IEA data which are updated annually, (see Reference [7] for the latest update). Emissions associated with the consumption of electricity during transport and distribution (T&D) shall not be included in this calculation.

This document differentiates between the different power sources (purchase, production on-site) and paths of power usage: use for semiconductor and display production, consumption of power generation auxiliaries (difference between gross and net power production of the power plant) and power sold externally. Power given to other non-semiconductor and display installations within the same plant shall be treated like power sold externally.

The quantity of electricity consumed is calculated by subtracting the amount of resale electricity from the amount of purchased electricity.

The GHG emission from purchased electricity is calculated according to Formula (15):

$$E_{ELEC} = q_{ELEC} \cdot F_{E,ELEC} \quad (15)$$

where

E_{ELEC} is the GHG emissions from purchased, externally generated, electricity used at the plant, in tCO_2e;

q_{ELEC} is the quantity of electricity consumed, in MWh;

$F_{E,ELEC}$ is the emission factor of consumed electricity, in tCO_2e/MWh.

8.3 GHG emissions from external fossil and alternative fuels production and processing

GHG emissions from external fossil and alternative fuels production shall be calculated based on the amount of consumed steam or heat and, preferentially, emission factors obtained from the supplier. Alternatively, it is recommended to use governmental data for the national power grid. If both data sets are unavailable, an average emission factor for the country may be used.

The emission factor of consumed steam or heat can be determined in one of two ways.

a) Obtain the emission factor from the steam or heat supplier;

b) Calculate the emission factor using the amount of consumed fuel for steam or heat generated by the supplier and the amount of steam or heat generated by the supplier.

The GHG emission from purchased steam or heat is calculated according to Formula (16):

$$E_{SH} = q_{SH} \cdot F_{E,SH} \quad (16)$$

where

E_{SH} is the GHG emission from purchased, externally generated steam or heat used at the plant, in tCO_2e;

q_{SH} is the quantity of steam or heat consumed, in TJ steam or heat;

$F_{E,SH}$ is the emission factor of consumed steam, in tCO_2e/TJ steam.

Table 3 provides an example of the parameters required to determine the quantities of electricity and steam or heat consumed.

Table 3 — Parameters and data sources for the calculation of indirect GHG emissions

Emission source	Parameters	Frequency of measurement	Example for determining the activity data
Electricity	Electricity consumed	Annual	— Fiscal electricity meter — Invoices from the electricity supplier — Plant electricity submeter
Steam or heat	Steam or heat consumed	Annual	— Heat value meter — Plant steam or heat submeter (flowmeter) — Invoices from the steam or heat supplier

9 General requirements for identifying, calculating and reporting of GHG emissions

The reporting entity shall develop a monitoring plan to identify, calculate and report GHG emissions in accordance with ISO 19694-1.

See Annex A for the content of the monitoring plan.

10 Baselines, acquisitions and disinvestments

GHG emissions performance is often measured relative to a past reference year (i.e. the “base year”). The “Kyoto base year” 1990 can be used as a default reference. However, in many cases, the lack of reliable and accurate historical data justifies the use of a more recent base year.

Acquisitions and divestitures, as well as the opening or closing of plants, will influence a company’s emissions performance, both in absolute and specific terms. To ensure consistency of baselines (i.e. the same quantity of emissions in and after the base year), companies shall apply the following rules in a consistent way:

— Adjustment of the baseline for change by acquisition and divestiture: Consolidated emissions reported for past years shall always reflect the current amount of shares held in a company. If a company is acquired, its past emissions shall be included in the consolidated emissions of the reporting company. This shall be done either back to the base year, or back to the year the acquired company came into existence, whichever is later. If a company is divested, past emissions shall be removed from the consolidated emissions. These adjustments shall be made in accordance with the consolidation rules in the GHG protocol[7].

— No baseline adjustment for “organic” change: In case of organic growth of production due to investment in new installations, capacity expansions or improved capacity utilization, the baseline shall not be adjusted. In the same sense, the baseline shall not be adjusted for organic negative growth; closure of process or decrease of production shall not result in a change of the baseline.

11 Reporting and performance assessment

11.1 General

GHG emissions monitoring and reporting have multiple goals, such as internal management of environmental performance, public environmental reporting, reporting for taxation schemes, voluntary or negotiated agreements, and emissions trading. Additional purposes can be, for example, performance benchmarking and product life cycle assessment.

This document has been designed as a flexible tool to satisfy these different reporting purposes. The information is structured in such a way that it can be aggregated and disaggregated according to different reporting scopes, such as shown in the following cases:

— Reporting to national GHG inventories should be compatible with IPCC guidelines. Hence, it should cover all direct GHG emissions, including GHG from fossil wastes. CO_2 from biomass fuels should be reported as a memo item.

— Reporting under CO_2 compliance and taxation schemes will have varying reporting requirements, depending on local conventions. This document allows reporting of gross and net emissions and indirect emissions, as appropriate.

This document does not define any threshold for excluding “immaterial” emission sources. In practice, the decision whether to include or exclude certain emission sources will also depend on the requirements of the respective reporting framework.

Reported GHG emissions shall include all relevant emissions as required by ISO 19694-1.

The following data shall be reported:

— the total GHG emissions (direct GHG emissions, energy indirect GHG emissions and other indirect GHG emission) associated with the manufacturing plant;

— the boundaries used for the assessment of the GHG emissions;

— the overall uncertainty (see Clause 11);

— process emissions shall be included in the total GHG gas emissions reported.

11.2 Corporate environmental reporting

The objective of voluntary environmental reporting is to provide the reader with a sufficiently accurate picture of the environmental footprint of the reporting company. This implies that the reporting of semiconductor and display device manufacturers shall cover all relevant emission components:

— gross direct GHG emissions of the reporting entity (etching, CVD cleaning, conventional fuels, alternative fuels, with biomass CO_2 as a memo item);

— net emissions (if applicable), calculated from gross emissions minus emissions from the use of alternative fuels;

— main indirect emissions (consumption of grid electricity).

Reporting shall be in absolute (Mt CO_2e/year) as well as specific (t CO_2e/ t consumed amount of FC) units. Reporting net emissions alone, omitting gross emissions is not acceptable.

In order to be complete, reporting shall include the CO_2 emissions (including indirect CO_2 emissions from consumption of grid electricity and accounting for own on-site power generation) from the different process steps.

Additional requirements for voluntary reporting include:

— Clearly state when GHG sources are excluded from the inventory. To this end, the standard spreadsheet requires companies to state the boundaries of their inventory.

— Clearly state that reporting is done in accordance with this document and any material deviations from it.

11.3 Reporting periods

Reporting GHG emissions can be based on calendar years or on financial years if it helps to reduce reporting costs. From a GHG perspective, a report can be based on financial years if it is done consistently over time with no gaps or overlaps. Changes in the reporting year should be clearly indicated.

11.4 Performance assessment

Performance assessment to benchmark or compare for internal or public reporting may also be undertaken on a voluntary basis using the outputs from this document. The nature of such voluntary reports can be highly dependent on the reporting context and purpose. System boundaries for such reporting depend on conventions and practical requirements as much as on scientific arguments.

In this document, performance indicators (PIs) are included that can be useful given the current business and policy environment, and associated reporting requirements. [For the process emission PIs, this document follows PIs from the normalized emission rate (NER) factors used by World Semiconductor Council (WSC)] Generally, this subclause on PIs is conceived as a flexible vessel where companies may introduce additional parameters according to their needs.

Basic unit of process emissions in the semiconductor and display industry are calculated according to Formula (17):

$$E_p = \frac{(E_i \cdot G_i) + (B_{\mathrm{BPE},k} \cdot G_k) + (E_{\mathrm{EAB},i,\mathrm{CF4}} \cdot G_{\mathrm{CF4}})}{s_{\mathrm{wafer}}} \quad (17)$$

where

$B_{BPE,k}$	is the emission of by-product *k* from Formulae (4) and (7);
$E_{EAB,i,CF4}$	is the emission of CF_4 from Formulae (5) and (8);
E_p	is the process emission, in tCO2e/m^2;
E_i	is the emission of unreacted input gas *i* from Formulae (2), (3) and (6), in tCO_2e/m^2;
G_{CF4}	is the GWP of CF_4;
G_i	is the GWP value of gas *i*;
G_k	is the GWP value of by-product *k*;
s_{wafer}	is the surface area of produce wafer, in m^2/annum.

Basic unit of total emissions in the semiconductor and display industry are calculated according to Formula (18):

$$E_{total} = E_{direct} + E_{indirect} + E_p \tag{18}$$

where

E_{total}	is the total emission in the semiconductor and display industry, tCO2e/m^2;
E_{direct}	is the direct combustion emission, tCO2e/m^2;
$E_{indirect}$	is the indirect combustion emission, tCO2e/m^2;
E_p	is the process emission, in tCO2e/m^2.

The PIs mentioned in Table 4 are voluntary and can be used to assess performance. Reporting entities can select the PI's most relevant to their circumstances.

Table 4 — PIs relating to GHG emissions

	Direct GHG emissions		Indirect GHG emissions
	Combustion emission	Process emission	
Semiconductor and display manufacturing processing	[tCO_2e / m^2]	[tCO_2e / m^2]	[tCO_2e / m^2]
Downstream processing	[tCO_2e / m^2]	—	[tCO_2e / m^2]
Total (semiconductor and display manufacturing process + downstream processing)	[tCO_2e / m^2]	[tCO_2e / m^2]	[tCO_2e / m^2]

12 Uncertainty of GHG inventories

12.1 General

The parameters required for determining GHG emissions involve uncertainty that can be expressed as an uncertainty range or confidence interval. The aggregate uncertainty of a GHG emissions estimate for a plant or organization will depend on the individual uncertainties of the underlying parameters.

Besides the uncertainty of parameters, there are other error sources that can contribute to the uncertainty of GHG emission estimates. These include model uncertainty – the question of how precisely a mathematical model reflects a specific context – and scientific uncertainty, for example related to the GWP to aggregate different GHG. This document is designed to reduce the model uncertainty inherent in semiconductor and display industry inventories to minimal levels. Addressing scientific uncertainty is beyond the scope of the industry inventories.

The general principles in ISO 19694-1 apply for the determination of uncertainty according to the requirements of the Guidance on Uncertainty Assessment and ISO/IEC Guide 98-3.

Where standards for measurement of specific materials, energy consumption or any other emissions include the analysis of uncertainty, Guidance on Uncertainty Assessment and ISO/IEC Guide 98- shall be applied.

12.2 Assessment of uncertainty of the mass balance based method

12.2.1 Major sources of uncertainty

The overall uncertainty of the mass balance based method depends on the uncertainty of the measurement and analytical methods used. The main sources of uncertainty normally being associated with:

a) measurement of activity data (including production volume and fuel quantities);

b) determination of analytical parameters (including chemical composition, emissions factors);

c) representativeness of sampling.

Quantifying parameter uncertainties is demanding in terms of data and procedures. As a result, statements about the aggregate uncertainty of emissions estimates are inherently uncertain themselves and often involve a subjective component. Nevertheless, there are clear incentives to assess and minimize uncertainty:

— companies may wish to rank the sources of uncertainty in their inventory in order to identify priority areas to focus on when improving inventory quality;

— some GHG reporting schemes, for example the monitoring guidelines for the EU ETS, set quantitative limits for the uncertainty of key parameters used to estimate emissions from semiconductor and display plants;

— wherever monetary values are assigned to GHG emissions, uncertainty in emissions estimates can have financial consequences.

12.2.2 Uncertainty of activity data

The information on the uncertainty of a measuring instrument can be found in different sources including:

— certificates on calibration under national metrological control (where the operational error limits the uncertainty under normal operational conditions);

— the specification from the manufacturer of the measuring device and estimate of the additional uncertainty under operational conditions concerning relevant influences, or;

— an individual uncertainty assessment under operational conditions (e.g. via regular testing and adjustment of the measuring device).

Activity data for the electronics industry consists of data on gas consumption and/or production figures (surface area of substrate used during the production of electronic devices). Activity data uncertainty originates from multiple variables and particular attention should be taken to minimize the uncertainty and the potential bias of the measurements or of the models used to estimate activity data. For the activity data uncertainty of the semiconductor and display industry, see “Activity data uncertainty” in 6.3.2 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

For an individual uncertainty assessment of a measuring device used to determine activity data of materials or fuels, the 95 % confidence interval should be calculated from the deviations of the measuring device observed within regular maintenance and control calibrations using check weights or other methods recommended by the manufacturer.

12.2.3 Aggregated uncertainties of activity data

In accordance with ISO/IEC Guide 98-3, if the activity data are determined by using the mass balance based method, the aggregated uncertainty for the activity data has to be calculated via error propagation considering the diverse uncertainties of each parameter of the mass balance according to the expanded uncertainty of the weighing/measuring methods involved in the calculation of activity data.

For the assessment of the scales uncertainty, the 95 % confidence interval has to be calculated from the deviations of the scale.[5] The associated uncertainty is determined by calculating the standard deviation and then assessing it in terms of the normal measurements made, according to Formulae (19) and (20):

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{19}$$

where

$\bar{x}$	is the arithmetic mean of observed deviations with x_i;
x_i	is the independent value of observed deviations;
n	is the number of deviations.

$$S(x_i) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{20}$$

where

$S(x_i)$	is the experimental standard deviation;
x_i	is the independent value of observed deviations;
$\bar{x}$	is the arithmetic mean of observed deviations with x_i;
n	is the number of deviations.

The calculation of the 95 % confidence interval according to the t-distribution is given in Formula (21):

$$U(x_i) = \bar{x} \pm t_{\varphi,\alpha} \cdot \frac{S(x_i)}{\sqrt{n}} \tag{21}$$

$U(x_i)$	is the relative expanded uncertainty;
$S(x_i)$	is the experimental standard deviation;
n	is the number of deviations;
$\frac{S(x_i)}{\sqrt{n}}$	is the standard uncertainty;
$\bar{x}$	is the arithmetic mean of observed deviations with x_i;
$t_{\varphi,\alpha}$	is the t-distribution, (degree of freedom $\varphi = n - 1$, probability of error $\alpha = 1 - p$, probability $p = 0{,}95$ in case of a 95 % confidence interval).

For a significant number of samples, the expanded uncertainty $U(x_i)$ and the 95 % confidence interval can be estimated using a coverage factor $k = 2$ instead of $t_{\varphi,\alpha}$. In any case, the number of samples n and the coverage factor k should be stated with any estimate of the expanded uncertainty.

12.2.4 Application of default values instead of analytical results

If default values are used in the GHG inventory, the uncertainty of those default values shall be considered when assessing a GHG inventory.

For the uncertainty assessment of emission factors, see "Emission factor uncertainties" in 6.3.1 of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

12.2.5 Evaluation of the overall uncertainty of a GHG inventory

In order to determine the overall uncertainty of a GHG inventory, the assessed uncertainties of activity data and analytical parameters shall be aggregated by the error propagation laws in accordance with the GUM and IPCC.

12.3 Assessment of the uncertainty for the stack-measurement method

When using the stack-measurement method, the uncertainty assessment shall take account of the general guidance on uncertainty assessment provided in ISO 19694-1 and shall be in accordance with ISO/IEC Guide 98-3.

Annex A
(informative)

Content of the monitoring plan

An operator shall develop a monitoring plan i.e. GHG determination and reporting plan based on this document for the semiconductor and display industry type of installation.

The monitoring plan shall consist of detailed, complete and transparent documentation of the monitoring methodology of a specific installation and shall at least contain the following elements:

a) general information:

1) a description of the organization and activities for the scope considered,

2) a description of the procedure for managing the assignment of responsibilities,

3) a description of the written procedures of the data flow activities,

4) a description of the written procedures for the control activities established,

5) the version number and date of the monitoring plan;

b) a description of the semiconductor and display industry methodologies consisting of:

1) a detailed description of the mass balance based methodologies applied,

2) where applicable and where the operator intends to make use of simplification for small source streams, a categorization of the source streams referring to the sector-specific standards,

3) a description of the measurement systems/processes used,

4) where applicable, the default values used for calculation factors indicating the source of the factor,

5) where applicable, a list of the chemical analysis methods to be used,

6) where applicable, a description of the procedure underpinning the sampling plan for the sampling of fuel and materials to be analysed;

c) a description of the measurement-based methodologies for stack emissions, where applied, including the following:

1) any calculation formulae used for data aggregation and used to determine the emissions from each emission source as well as the method for determining whether valid hours or shorter reference periods for each parameter may be calculated, and for substitution of missing data,

2) a list of all relevant emission points,

3) where flue gas flow is derived by calculation, a description of the written procedure for these emission sources,

4) a list of all relevant measurement equipment,

5) a description of how CO_2 arising from biomass is to be determined and subtracted from the measured total CO_2 emissions.

Together with the monitoring plan, the operator shall include the following supporting information: evidence for each source stream and emission source demonstrating compliance with the uncertainty thresholds for activity data and calculation factors, where applicable, as defined in Clause 8.

Annex B
(informative)

Default emission factors

Default emission factors are according to 6.2.2 “Choice of emission factors” of *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Table B.1 — Tier 1 gas-specific emission factors for process emissions from electronic manufacturing

Electronics industry sub-sector	Semiconductors kg/m²	Display g/m² (array input glass area)	PV g/m²	MEMS kg/m²
CF_4	0,36	0,65	5	0,015
C_2F_6	0,12		0,2	
C_3F_8	0,03			
C_4F_6	0,03			
c-C_4F_8	0,01	0,001		0,076
C_4F_8O	0,000 07			
C_5F_8	0,001			
CHF_3	0,001	0,002 4		
CH_2F_2	0,003			
NF_3	0,15	1,29		
SF_6	0,05	4,14		1,86
N_2O	1,01	17,06		