CHAPTER 6

ELECTRONICS INDUSTRY EMISSIONS

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6.1 INTRODUCTION

Several advanced electronics manufacturing processes utilise fluorinated compounds (FCs) for plasma etching intricate patterns, cleaning reactor chambers, and temperature control. The specific electronic industry sectors discussed in this chapter include semiconductor, thin-film-transistor flat panel display (TFT-FPD), and photovoltaic (PV) manufacturing (collectively termed ‘electronics industry’).[1]

The electronics industry currently emits both FCs that are gases at room temperature and FCs that are liquids at room temperature. The gases include CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, nitrogen trifluoride (NF_3), and sulfur hexafluoride (SF_6), and are used in two important steps of electronics manufacturing: (i) plasma etching silicon containing materials and (ii) cleaning chemical vapour deposition (CVD) tool chamber-walls where silicon has deposited.[2] The majority of FC emissions results from limited utilisation efficiency (i.e., consumption) of the FC precursors during the etching or the cleaning process. In addition, a fraction of the fluorinated compounds used in the production process can be converted into by-product CF_4 and in some instances into C_2F_6, CHF_3 and C_3F_8.[3] Also, formation of CF_4 as a by-product of etching or cleaning carbon-containing low dielectric constant (low k) materials (or carbide) must be taken into account.[4] In addition, F_2, COF_2, and ClF_3 use may increase. These gases, although not in themselves contributors to global warming may lead to CF_4 formation under some conditions.

Electronics manufacturers use FCs for temperature control during certain processes. Also known as heat transfer fluids, these FCs are liquids at room temperature and have appreciable vapour pressures. Evaporative losses contribute to the total FC emissions. These evaporative losses occur during cooling of certain process equipment, during testing of packaged semiconductor devices and during vapour phase reflow soldering of electronic components to circuit boards. Evaporative losses do not appear to occur when liquid FCs are used to cool electronic components or systems during operation. In this application, the liquid FCs are contained in closed systems throughout the life of the product or system. More than 20 different liquid FCs are marketed, often as mixtures of fully fluorinated compounds, to the electronic sector.[5] Because the CO_2 equivalents of each liquid differ, each should be tracked and reported separately. The precise value of this conversion will be determined by the specific applicable reporting requirements.[6,7] In addition, liquid FCs are occasionally used to clean TFT-FPD panels during manufacture.

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[1] Recent comprehensive surveys of European and US PV manufacturers indicate that 40 to 50 percent of PV-manufacturers use relatively small quantities of FCs (predominantly CF_4 during etching of crystalline silicon wafers and C_2F_6 during chamber cleaning after deposition of SiNx films). Global usage, according to these surveys for 2004, was approximately 30 Mtonnes CF_4. While global FC use appears low in 2004, credible growth-forecasts of the PV industry are approximately 30 percent per year (and higher) for the foreseeable future. Morevoer, several reports extol the virtues of FC use as a means to increase manufacturing productivity and lower costs for silicon-based technologies (Shah *et al*., 2004; Maycock, 2005; Agostinelli *et al*., 2004 and Rentsch *et al*., 2005), Such expected growth rates and prospects for increase FC use motivate inclusion of FC emissions from PV manufacture in this chapter.

[2] Although C_5F_8 does not currently have a global warming potential (GWP) recognized by the IPCC, C_5F_8 emissions are discussed in this chapter. C_5F_8 is a direct greenhouse gas and emissions can be estimated using methods and data described in this chapter. C_5F_8’s atmospheric lifetime is approximately 1 year, resulting in a relatively low GWP (Sekiya, 2003).

[3] Emissions of C_2F_6 by-products have been observed from the decomposition of C_4F_6 molecules and may occur for other FC molecules with greater than two carbon atoms. Note that for most FC precursors, C_2F_6 formation as a by-product has not been observed. CHF_3 formation has been reported when c-C_4F_8 is used as an etchant in TFT-FPD manufacture and C_3F_8 by-product emissions have been reported when C_4F_8O is used in chamber cleaning.

[4] Low dielectric constant (low k) materials were first used as insulators for the interconnect structure of semiconductor chips at the 0.25μm node and below. Many low k materials contain carbon that may be removed as CF_4 during etching of thin films or the cleaning of the CVD reactors used for low k deposition. CF_4 may also be formed during cleaning of CVD reactors used for carbide deposition.

[5] A relatively recent review summarises the uses of liquid FCs (heat transfer fluids), their chemical composition, GWPs, among other things. See Burton (2004a).

[6] These materials are marketed under the trade names Fluorinert™ and Galden®. The Fluorinert™ materials are selected from fully fluorinated alkanes, ethers, tertiary amines and aminoethers and mixtures thereof to obtain the desired properties. The Galden® fluids span a range of fully fluorinated polyethers, called perfluoropolyethers (PFPEs), also selected for the desired properties.

6.2 METHODOLOGICAL ISSUES

6.2.1 Choice of method

6.2.1.1 ETCHING AND CVD CLEANING FOR SEMICONDUCTORS, LIQUID CRYSTAL DISPLAYS, AND PHOTOVOLTAICS

Emissions vary according to the gases used in manufacturing different types of electronic devices, the process used (or more roughly, process type (e.g., CVD or etch)), the brand of process tool used, and the implementation of emission reduction technology.

The choice of methods will depend on data availability and is outlined in the decision tree, see Figure 6.1, Decision Tree for Estimation of FC Emissions from Electronics Manufacturing. Emissions from liquid FCs are estimated using Tier 1, 2 and 3 approaches and are described separately in this section.[8]

Continuous (in-situ) emissions monitoring is currently considered a technically and economically unviable means to estimate emissions from this industry. FC emissions are periodically measured, however, during the development of new processes and tools, and after the establishment of commercial-ready process conditions (also known as centreline process conditions).[9] The industry seeks, prior to the introduction of high-volume manufacturing, centreline process designs that minimize FC emissions. However, it must be noted that FC emissions can be affected by changes in process variables (e.g., pressure, temperature, plasma power, FC gas flow, processing time). Thus, the accuracy of the methods used for estimating emissions will be affected by eventual differences between the process used in production and the reference centreline process. In addition, the efficacy of FC emission control equipment depends on operating and maintaining the equipment according to the manufacturer's specifications: Increased gas flows, improper temperature settings, and failure to perform required maintenance will individually and collectively negatively impact performance.

The accuracy of estimated emissions depends on the method used. The Tier 1 method uses default values for all parameters and does not account for the use of emission control technology. The Tier 2a method uses company-specific data on the proportion of gas used in processes with and without emission control technology, but does not distinguish between etching and cleaning, and uses default values for the other parameters. The Tier 2b method uses company-specific data on the proportion of gas used in *etching* versus *cleaning* and the proportion of gas used in processes with emission control technology, but relies on default values for some or all of the other parameters. The most rigorous method, Tier 3 method, requires a complete set of process-specific values rather than defaults.

Table 6.1 summarises the data requirements for the tiered emissions estimating methods for electronics manufacturing.

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[7] Where a commercial mixture is used inventory compilers will need to ensure that the conversion of the mass of the mixture to CO_2 equivalents uses the appropriate conversion factors.

[8] The logic depicted in Figure 6.1 does not show the possibility of combining tiers to improve estimates of emissions. For example, improved estimates of emissions might be achieved by using Tier 3 for a specific gas and process and Tier 2b for other gases and processes instead of using only the Tier 2b method. Similarly, the Tier 2a and 2b methods might be combined to produce an improved estimate compared to using only Tier 2a. However, the Tier 1 method should not be combined with any other method.

[9] Centreline conditions refer to the conditions under which equipment manufacturers standardise their equipment for sale. These are nominal specifications for gas flows, chamber pressure, processing time, plasma power, etc. It is common for semiconductor manufacturers to modify these conditions to optimise for particular needs.

TABLE 6.1
INFORMATION SOURCES NECESSARY FOR COMPLETING THE TIERED EMISSION ESTIMATING METHODS FOR ELECTRONICS MANUFACTURING

	Data	**Tier 1**	**Tier 2a**	**Tier 2b**	**Tier 3**
Process Gas Entering Tool	$FC_{i,p}$ = kg of gas *i* fed into specific process *p* or small set of common process tools (e.g., silicon nitride etch).				M
	$FC_{i,p}$ = kg of gas *i* fed into broad process category (e.g., etching or CVD chamber cleaning).		M	M(etch) & M(CVD)	
	h = Fraction of gas remaining in shipping container after use (heel).		D	D	M
Process Gas Reactions and Destruction in Tool	$U_{i,p}$ = Use rate (fraction destroyed or transformed) for each gas *i* and process *p*.		D	D(etch) & D(CVD) [a]	M
	$B_{CF4,i,p}$, $B_{C2F6,i,p}$, $B_{CHF3,i,p}$ and $B_{C3F8,i,p}$ = Emission factor for by-product emissions of CF_4, C_2F_6, CHF_3 and C_3F_8 respectively for gas *i* for each process.		D	D(etch) & D(CVD) [a]	M
Downstream FC Emission Control	$a_{i,p}$ = Fraction of gas *i* volume fed into processes with certified FC emission control technologies.		M	M	M
	$d_{i,p}$ = Fraction of gas *i* destroyed by the emission control technology.		D	D [a]	M
	$d_{CF4,p}$, $d_{C2F6,p}$, $d_{CHF3,p}$ and $d_{C3F8,p}$ = Fraction of CF_4, C_2F_6, CHF_3 and C_3F_8 by-products respectively destroyed by the emission control technology.[b]				M
Annual Production Capacity	C_d = Annual manufacturing design capacity in surface area of substrate processed (e.g., silicon, glass).	M			
	C_u = Fraction of annual capacity utilisation	D/M			

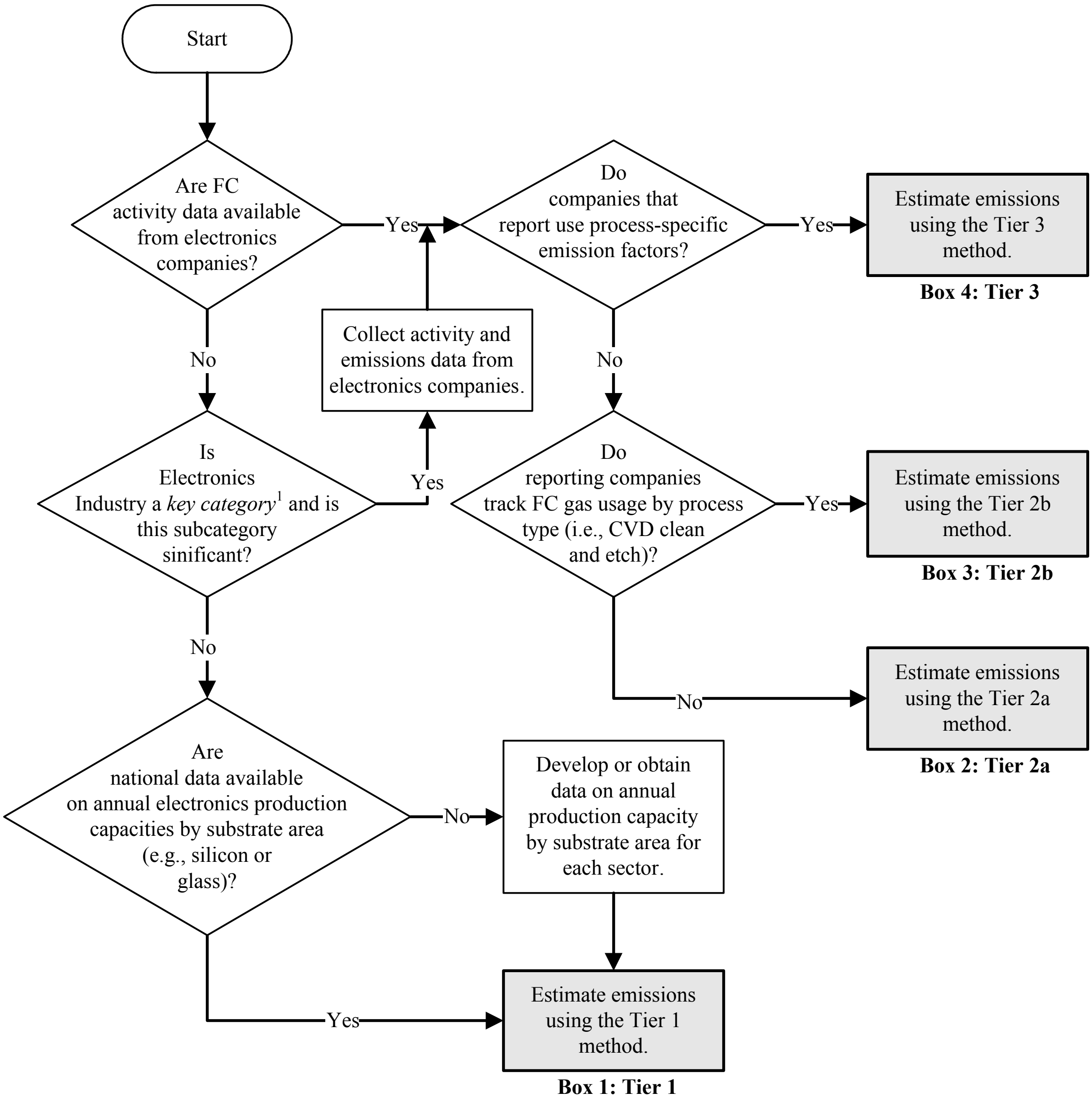
M = measure or acquire these values.

D = Use default factors from guidance.

[a] When available and supportable, M values may be substituted for D values for Tier 2a and 2b. See conditions in Table 6.6.

[b] There are no default values for Tier 2a and Tier 2b because the effect of by-products has been incorporated into the D-values for $d_{i,p}$ for gas *i*.

Figure 6.1 Decision tree for estimation of FC emissions from electronics manufacturing



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

TIER 1 METHOD – DEFAULT

The Tier 1 method is the least accurate estimation method and should be used only in cases where company-specific data are not available. The Tier 1 method, unlike the Tier 2 or 3 methods, is designed to give an aggregated estimate of FC emissions although its methodology appears to produce gas-specific emissions. Estimates are made simultaneously for all gases as listed in Table 6.2 and can only be used if reported as a complete set.

The calculation of emissions relies on a fixed set of generic emissions factors. The members of the set differ depending on the sector (or class) of electronic products being manufactured (semiconductors, TFT-FPDs or PV-cells). Each member of a set, which is a gas-specific emission factor, expresses an average emissions per unit of substrate area (e.g., silicon, TFT-FPD panel or PV-cell) consumed during manufacture. For any class of electronic products, the factors (members of the set) are multiplied by the annual capacity utilisation (C_u, a fraction) and the annual manufacturing design capacity (C_d, in units of giga square meters (Gm^2)) of substrate processes. The product ($C_u \bullet C_d$) is an estimate of the quantity of substrate consumed during electronics manufacture. The result is a set of annual emissions expressed in kg of the gases that comprise the set for each class of electronic products. Because the use of FCs varies widely during PV manufacture, a third factor to account for the proportion of PV manufacture that employs FC is needed to estimate FC emissions from the PV cells manufacturing. The Tier 1 formula is shown in Equation 6.1.

EQUATION 6.1
TIER 1 METHOD FOR ESTIMATION OF THE SET OF FC EMISSIONS

$$\{FC_i\}_{\mathbf{n}} = \{EF_i \bullet C_u \bullet C_d \bullet [C_{PV} \bullet \delta + (1-\delta)]\}_{\mathbf{n}} \qquad (i = 1, \ldots, n)$$

Where:

$\{FC_i\}_n$ = emissions of FC gas *i*, mass of gas *i*

Note: $\{\ \}_n$ denotes the set for each class of products (semiconductors, TFT-FPD or PV-cells) and *n* denotes the number of gases included in each set (six for semiconductors, three for TFT-FPD manufacture and two for PV-cells. See Table 6.2.). The estimates are only valid if made and reported for all members of the set using this Tier 1 methodology.

EF_i = FC emission factor for gas *i* expressed as annual mass of emissions per square meters of substrate surface area for the product class, (mass of gas i)/m^2

C_u = fraction of annual plant production capacity utilisation, fraction

C_d = annual manufacturing design capacity, $Gm^2$of substrate processed, except for PV manufacturing which is Mm^2

C_{PV} = fraction of PV manufacture that uses FCs, fraction

δ = 1 when Equation 6.1 is applied to PV industry and zero when Equation 6.1 is applied to either semiconductor or TFT-FPD industries, dimensionless

This method does not account for differences among process types (etching versus cleaning), individual processes, or tools. It also does not account for the possible use of atmospheric emission-control devices.

In using Tier 1, inventory compilers should not modify, in any way, the set of the FCs assumed in Table 6.2. Inventory compilers should not combine emissions estimated using Tier 1 method with emissions estimated using the Tier 2 or 3 methods. Neither may inventory compilers use, for example, the Tier 1 factor for CF_4 to estimate the emissions of CF_4 from semiconductors and combine it with the results of other FC gases from a Tier 2 or Tier 3 method. (See also Section 6.2.2.1.)

TIER 2a METHOD – PROCESS GAS-SPECIFIC PARAMETERS

This method calculates emissions for each FC used on the basis of company-specific data on gas consumption and on emission control technologies. It uses industry-wide default values for the 'heel' or fraction of the purchased gas remaining in the shipping container after use (h), the fraction of the gas 'used' (destroyed or transformed) in the semiconductor or TFT-FPD manufacturing process, and the fraction of the gas converted into CF_4 or C_2F_6 during the process. To use the Tier 2a method inventory compilers must have direct communication with industry (e.g., annual emissions reporting) to gather data and ensure that emission control technologies are installed and in use.

Total emissions are equal to the sum of emissions from the gas FC_i used in the production process plus the emissions of by-product CF_4, C_2F_6, CHF_3 and C_3F_8 resulting from use of the gas $FC_{i.}$, as shown in Equations 6.2, 6.3, 6.4, 6.5 and 6.6. Unlike the Tier 3 and 2b methods that are explained later in this section, the Tier 2a method does not distinguish between processes or process types (etching versus cleaning), individual processes or tools. The default emission factors represent weighted averages (based on expert judgments of weights), formed separately for each gas, over *all* etch *and* CVD processes.

As discussed below in the section on emission factors, the Tier 2a method uses the emission factor for the process type (CVD or etch) in which the individual FC is most frequently used in the particular electronics sector. This method reflects a current trend where individual FCs tend to be used predominantly in particular process types (CVD or etch) throughout each industry. However, in countries with companies or plants that depart significantly from the industry-wide pattern of usage (e.g., by using a gas primarily in etch while others primarily use it in CVD), inventory compilers should evaluate the potential to introduce error by using the Tier 2a method rather than the Tier 2b method.

EQUATION 6.2
TIER 2a METHOD FOR ESTIMATION OF FC EMISSIONS

$$E_i = (1-h) \bullet FC_i \bullet (1-U_i) \bullet (1-a_i \bullet d_i)$$

Where:

E_i = emissions of gas *i*, kg

FC_i = consumption of gas *i,*(e.g., CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, NF_3, SF_6), kg

h = fraction of gas remaining in shipping container (heel) after use, fraction

U_i = use rate of gas *i* (fraction destroyed or transformed in process), fraction

a_i = fraction of gas *i* volume used in processes with emission control technologies (company- or plant-specific), fraction

d_i = fraction of gas *i* destroyed by the emission control technology, fraction

EQUATION 6.3
BY-PRODUCT EMISSIONS OF CF_4

$$BPE_{CF4,i} = (1-h) \bullet B_{CF4,i} \bullet FC_i \bullet (1-a_i \bullet d_{CF4})$$

Where:

$BPE_{CF4,i}$ = by-product emissions of CF_4 from the gas *i* used, kg

$B_{CF4,i}$ = emission factor, kg CF_4 created/kg gas *i* used

d_{CF4} = fraction of CF_4 by-product destroyed by the emission control technology, fraction

EQUATION 6.4
BY-PRODUCT EMISSIONS OF C_2F_6

$$BPE_{C2F6,i} = (1-h) \bullet B_{C2F6,i} \bullet FC_i \bullet (1-a_i \bullet d_{C2F6})$$

Where:

$BPE_{C2F6,i}$ = by-product emissions of C_2F_6 from the gas *i* used, kg

$B_{C2F6,i}$ = emission factor, kg C_2F_6 created/kg gas *i* used

d_{C2F6} = fraction of C_2F_6 by-product destroyed by the emission control technology, fraction

EQUATION 6.5
BY-PRODUCT EMISSIONS OF CHF_3

$$BPE_{CHF3,i} = (1-h) \bullet B_{CHF3,i} \bullet FC_i \bullet (1-a_i \bullet d_{CHF3})$$

Where:

$BPE_{CHF3,i}$ = by-product emissions of CHF_3 from the gas *i* used, kg

$B_{CHF3,i}$ = emission factor, kg CHF_3 created/kg gas *i* used

d_{CHF3} = fraction of CHF_3 by-product destroyed by the emission control technology, fraction

EQUATION 6.6
BY-PRODUCT EMISSIONS OF C_3F_8

$$BPE_{C3F8,i} = (1-h) \bullet B_{C3F8,i} \bullet FC_i \bullet (1-a_i \bullet d_{C3F8})$$

Where:

$BPE_{C3F8,i}$ = by-product emissions of C_3F_8 from the gas *i* used, kg

$B_{C3F8,i}$ = emission factor, kg C_3F_8 created/kg gas *i* used

d_{C3F8} = fraction of C_3F_8 by-product destroyed by the emission control technology, fraction

After estimating the emission of gas *i* (E_i) and the CF_4, C_2F_6, CHF_3 and C_3F_8 by-product emissions for each gas ($BPE_{CF4,i}$, $BPE_{C2F6,i}$, $BPE_{CHF3,i}$ and $BPE_{C3F8,i}$), inventory compilers or companies should sum these emissions across all gases to estimate the total aggregate FC emissions.

TIER 2b METHOD – PROCESS TYPE-SPECIFIC PARAMETERS

The Tier 2b method requires data on the aggregate quantities of each gas fed into all etching processes and all cleaning processes ($FC_{i,p}$). Thus, it distinguishes only between broad process types (etching vs. CVD chamber cleaning), but it does not distinguish among the many possible individual processes or small sets of processes. Industry-wide default values can be used for any or all of the following:

- the fraction of the gas remaining in the shipping container after use termed the 'heel' (h);
- the fraction of the gas 'used' (destroyed or transformed) per process type ($U_{i,p}$);
- the emission factor for CF_4 by-product emissions in the process type ($B_{CF4,i,p}$);
- the emission factor for C_2F_6 by-product emissions in the process type ($B_{C2F6,i,p}$);
- the emission factor for CHF_3 by-product emissions in the process type ($B_{CHF3,i,p)}$); and
- the emission factor for C_3F_8 by-product emissions in the process type ($B_{C3F8,i,p}$).

Defaults are also presented (see Table 6.6) for the fraction of the gas destroyed by the emissions control technology by process type ($d_{i,p}$, $d_{CF4,p}$, $d_{C2F6,p}$, $d_{CHF3,p}$ and $d_{C3F8,p}$). Unless emission control technologies are installed, the default value for $a_{i,p}$, the fraction of gas volume fed into processes with emission control technologies, is zero. The default values for $U_{i,p}$, $B_{CF4,i,p}$, $B_{C2F6,i,p}$, $B_{CHF3,i,p}$ and $B_{C3F8,i,p}$ represent simple unweighted averages, formed separately for each gas, over *all* etch processes and over *all* CVD processes. Company or plant-specific emission factors may be substituted for default values when available. The equations account for the plant-specific use of emission-control devices, but do not account for differences among individual processes or tools or among manufacturing plants in their mix of processes and tools. Thus, Tier 2b estimates will be less accurate than Tier 3 estimates. Also, note that the Tier 2b method is applicable to semiconductor and TFT-FPD manufacture.

Emissions resulting from the use of a specific FC (FC_i) consist of emissions of FC_i itself *plus* emissions of CF_4, C_2F_6, CHF_3 and C_3F_8 created as by-products during use of FC_i. The following calculation should be repeated for each gas for each process type:

EQUATION 6.7
TIER 2b METHOD FOR ESTIMATION OF FC EMISSIONS

$$E_i = (1-h) \bullet \sum_p \left[FC_{i,p} \bullet (1-U_{i,p}) \bullet (1-a_{i,p} \bullet d_{i,p})\right]$$

Where:

E_i = emissions of gas *i*, kg

p = process type (etching vs. CVD chamber cleaning)

$FC_{i,p}$ = mass of gas *i* fed into process type *p* (e.g., CF_4, C_2F_6, C_3F_8, c-C_4F_8, c-C_4F_8O, C_4F_6, C_5F_8, CHF_3, CH_2F_2, NF_3, SF_6), kg

h = fraction of gas remaining in shipping container (heel) after use, fraction

$U_{i,p}$= use rate for each gas *i* and process type *p* (fraction destroyed or transformed), fraction

$a_{i,p}$ = fraction of gas *i* volume fed into process type *p* with emission control technologies (company-or plant-specific), fraction

$d_{i,p}$ = fraction of gas *i* destroyed by the emission control technology used in process type *p* (If more than one emission control technology is used in process type *p*, this is the average of the fraction destroyed by those emission control technologies, where each fraction is weighted by the quantity of gas fed into tools using that technology), fraction

EQUATION 6.8
BY-PRODUCT EMISSIONS OF CF_4

$$BPE_{CF4,i} = (1-h) \bullet \sum_p \left[B_{CF4,i,p} \bullet FC_{i,p} \bullet \left(1 - a_{i,p} \bullet d_{CF4,p}\right)\right]$$

Where:

$BPE_{CF4,i}$ = by-product emissions of CF_4 converted from the gas *i* used, kg

$B_{CF4,i,p}$ = emission factor for by-product emissions of CF_4 converted from gas *i* in process type *p*, kg CF_4 created/kg gas *i* used

$d_{CF4,p}$ = fraction of CF_4 by-product destroyed by the emission control technology used in process type *p* (e.g., control technology type listed in Table 6.6), fraction

EQUATION 6.9
BY-PRODUCT EMISSIONS OF C_2F_6

$$BPE_{C2F6,i} = (1-h) \bullet \sum_p \left[B_{C2F6,i,p} \bullet FC_{i,p} \bullet \left(1 - a_{i,p} \bullet d_{C2F6,p}\right)\right]$$

Where:

$BPE_{C2F6,i}$ = by-product emissions of C_2F_6 converted from the gas *i* used, kg

$B_{C2F6,i,p}$ = emission factor for by-product emissions of C_2F_6 converted from gas *i* in process type *p*, kg C_2F_6 created/kg gas *i* used

$d_{C2F6,p}$ = fraction of C_2F_6 by-product destroyed by the emission control technology used in process type *p* (e.g., control technology type listed in Table 6.6), fraction

EQUATION 6.10
BY-PRODUCT EMISSIONS OF CHF_3

$$BPE_{CHF3,i} = (1-h) \bullet \sum_p \left[B_{CHF3,i,p} \bullet FC_{i,p} \bullet \left(1 - a_{i,p} \bullet d_{CHF3,p}\right)\right]$$

Where:

$BPE_{CHF3,i}$ = by-product emissions of CHF_3 converted from the gas *i* used, kg

$B_{CHF3,i,p}$ = emission factor for by-product emissions of CHF_3 converted from gas *i* in process type *p*, kg CHF_3 created/kg gas *i* used

$d_{CHF3,p}$ = fraction of CHF_3 by-product destroyed by the emission control technology used in process type *p* (e.g., control technology type listed in Table 6.6), fraction

EQUATION 6.11
BY-PRODUCT EMISSIONS OF C_3F_8

$$BPE_{C3F8,i} = (1-h) \bullet \sum_p \left[B_{C3F8,i,p} \bullet FC_{i,p} \bullet \left(1 - a_{i,p} \bullet d_{C3F8,p}\right)\right]$$

Where:

$BPE_{C3F8,i}$ = by-product emissions of C_3F_8 from the gas *i* used, kg

$B_{C3F8,i,p}$ = emission factor for by-product emissions of C_3F_8 converted from gas *i* in process type *p*, kg C_3F_8 created/kg gas *i* used

$d_{C3F8,p}$ = fraction of C_3F_8 by-product destroyed by the emission control technology used in process type *p* (e.g., control technology type listed in Table 6.6), fraction

Note that in certain etching or cleaning recipes, multiple FC precursors can be used concurrently and emissions of CF_4, C_2F_6, CHF_3 or C_3F_8 as by-products may originate from each of the individual FC precursor decomposition. In such cases, emissions of CF_4, C_2F_6, CHF_3 or C_3F_8 by-products should be reported as originating from the FC gas with the largest mass flow.

TIER 3 METHOD – PROCESS-SPECIFIC PARAMETERS

The Tier 3 method also uses Equations 6.7, 6.8, 6.9, 6.10 and 6.11. However, this method requires company-specific or plant-specific values for all the parameters used in these equations for each individual process or for each of small sets of processes (e.g., silicon nitride etching or plasma enhanced chemical vapour deposition (PECVD) tool chamber cleaning). Therefore, when using Equations 6.7, 6.8, 6.9, 6.10 and 6.11, inventory compilers need to interpret 'p' in these equations as a specific 'Process' (e.g., silicon nitride etching or plasma enhanced chemical vapour deposition (PECVD) tool chamber cleaning), not as 'Process type'.

For purposes of transparency and comparability, the values used for these emission parameters should be well documented (see Section 6.2.2).

CF_4 formation from C-containing films during semiconductor manufacturing

The Tier 2a, Tier 2b and Tier 3 methods account for CF_4 emissions formed during removal via etching of carbon-containing low dielectric constant (k) materials or cleaning CVD reactors containing low k or carbide films during semiconductor manufacture. CF_4 may be formed even if the FC precursor does not contain carbon or if the FC precursor is not a greenhouse gas.

For example, cleaning low k CVD reactors with NF_3 will produce CF_4 as a by-product. In these cases, Equation 6.7 should be used to report NF_3 emissions and the result of Equation 6.8 should be used to reflect emissions of CF_4 from the process. In those situations where F_2, COF_2, or ClF_3 is used in chamber cleaning, CF_4 may also be formed. In this case, CF_4 emissions are estimated using Equation 6.8 and the results added to the total CF_4 emissions obtained from Equation 6.7. In both cases, $B_{CF4,i,p}$ should be measured as the fraction of the mass of CF_4 produced over the mass of clean or etch gas introduced in the reactor.

After estimating emissions of each FC gas and emissions of CF_4, C_2F_6, CHF_3 and C_3F_8 as by-products, inventory compilers or companies should sum these emissions across all gases to arrive at an estimate of aggregate FC emissions from a particular process.

BOX 6.1
EXAMPLE FOR SEMICONDUCTOR MANUFACTURE

For example, if a source used NF_3 (for chamber cleaning and etch), CHF_3 (etch) and CF_4 (etch), the total emissions, if low k films were used, are estimated using Equation 6.7 for NF_3, CHF_3 and CF_4 and Equation 6.8 for the formation of CF_4 formed when removing low k films with NF_3. In equation form, the total is:

$$\text{Total FC emissions} = E_{NF3} + E_{CHF3} + E_{CF4} + BPE_{CF4,NF3}$$

6.2.1.2 HEAT TRANSFER FLUIDS

There are two methods for estimating emissions from the use of heat transfer fluids. The choice of methods will depend on the availability of activity data on the use of heat transfer fluids, and is outlined in the decision tree (see Figure 6.2, Decision Tree for Estimation of FC Emissions from Heat Transfer Fluids, and see Section 1.5 of Chapter 1, Choosing between the Mass-Balance and Emission-Factor Approach).

TIER 1 – HEAT TRANSFER FLUIDS

Tier 1 is appropriate when company-specific data are not available on heat transfer fluids. It is the less accurate of the two methods for estimating emissions from losses of heat transfer fluids. The method, unlike the Tier 2 method, gives an estimate of aggregate emissions - a weighted average emission across all liquid FCs that is expressed as the mass of C_6F_{14}[10]. The calculation relies on a generic emission factor that expresses the average

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[10] In the absence of GWP estimates, the appropriate GWP for C_6F_{14} has been used as a proxy (to derive the default emission factor). (See the Inventory of U.S. Greenhouse Gas and Sinks: 1990-2003, the footnote to Table 4-58, page 166. (U.S. EPA, 2005))

aggregate emissions per unit of silicon consumed during semiconductor manufacturing. The formula is shown in Equation 6.12.

EQUATION 6.12
TIER 1 METHOD FOR ESTIMATION OF TOTAL FC EMISSIONS FROM HEAT TRANSFER FLUIDS

$$FC_{liquid,total} = EF_l \bullet C_u \bullet C_d$$

Where:

$FC_{liquid,\ total}$ = total FC emissions as expressed as the mass of C_6F_{14}, Mt C_6F_{14}

EF_l = emission factor (aggregate FC emissions per Gm^2 of silicon consumed during the period expressed as the mass of C_6F_{14} (See Table 6.2.)), Mt C_6F_{14}/Gm^2

C_u = average capacity utilisation for all semiconductor manufacturing facilities in the country during the period, fraction

C_d = design capacity of semiconductor manufacturing facilities in the country, Gm^2

TIER 2 METHOD – HEAT TRANSFER FLUIDS

There is one Tier 2 method for estimating actual emissions from the use of each FC fluid. This method is a mass-balance approach that accounts for liquid FC usage over an annual period. It is appropriate when company-specific data are available. Over the course of a year, liquid FCs are used to fill newly purchased equipment and to replace FC fluid loss from equipment operation through evaporation. The Tier 2 method neglects fluid losses during filling new or existing equipment or when decommissioning old equipment (which is reasonable for these costly fluids).[11] Inventory compilers should obtain from companies the chemical composition of the fluid(s) for which emissions are estimated. The method is expressed in Equation 6.13.

EQUATION 6.13
TIER 2 METHOD FOR ESTIMATION OF FC EMISSIONS FROM HEAT TRANSFER FLUIDS

$$FC_i = \rho_i \bullet \left[I_{i,t-1}(l) + P_{i,t}(l) - N_{i,t}(l) + R_{i,t}(l) - I_{i,t}(l) - D_{i,t}(l) \right]$$

Where:

FC_i = emissions of FC_i, kg

ρ_i = density of liquid FC_i, kg/litre

$I_{i,t-1}(l)$ = the inventory of liquid FC_i at the end of the previous period, litres

$P_{i,t}(l)$ = net purchases of liquid FC_i during the period (net of purchases and any returns), litres

$N_{i,t}(l)$ = total charge (or nameplate capacity) of new installed, litres

$R_{i,t}(l)$ = total charge (or nameplate capacity) of retired or sold equipment, litres

$I_{i,t}(l)$ = inventory of liquid FC_i at end of the period, litres

$D_{i,t}(l)$ = amount of FC_i recovered and sent offsite from retired equipment during the period, litres

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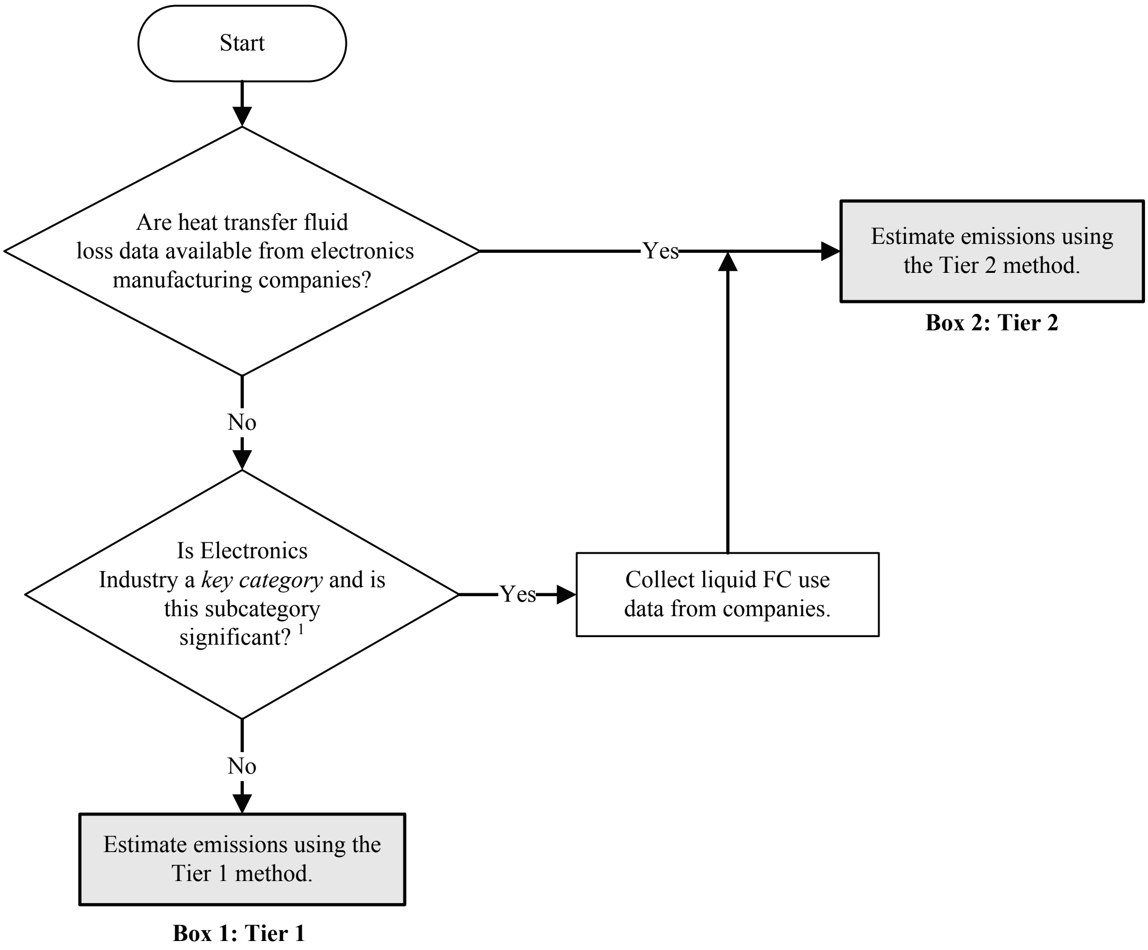
[11] Prices for heat transfer fluids vary from $55 – 130/litre. 3M, a manufacturer of a popular heat transfer fluid estimates that a vintage 2 000 manufacturing plant may loose 1 900 litres/year via evaporation. Manufactures of testing equipment that use heat transfer fluids report loss rates of approximately 30 litres/year/system for newer designs that reduce evaporative losses and 50 litres/year/system for older designs.

Figure 6.2 Decision tree for estimation of FC emissions from HT fluid loss from electronics manufacturing



Note:
1. See Volume 1 Chapter 4, Methodological Choice and Identification of Key Categories (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees

6.2.2 Choice of emission factors[12]

6.2.2.1 ETCHING AND CVD CLEANING FOR SEMICONDUCTORS, LIQUID CRYSTAL DISPLAYS, AND PHOTOVOLTAICS

TIER 1

The default emission factors for the Tier 1 method is presented in Table 6.2 below.

In using Tier 1, it is not *good practice* to modify, in any way, the set of the FCs or the values of the emission factors assumed in Table 6.2. Inventory compilers should not combine emissions estimated using Tier 1 method with emissions estimated using the Tier 2 or 3 methods. For example, inventory compilers may not use the Tier 1 factor for CF_4 to estimate the emissions of CF_4 from semiconductors and combine it with the results of other FC gases from a Tier 2 or Tier 3 method. It should be also noted that the Tier 1 FC emission factors presented in Table 6.2 should not be used for any purpose other than estimating annual FC-aggregate emissions from semiconductor, TFT-FPD or PV manufacturing for compilation of the national greenhouse gas inventory.

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[12] Sources and methods for developing emissions factors, if not explicitly provided in Chapter 6, can be found in Burton (2006).

TABLE 6.2
TIER 1 GAS-SPECIFIC EMISSION FACTORS FOR FC EMISSIONS FROM ELECTRONICS MANUFACTURING

Electronics Industry Sector	Emission Factor (EF) (Mass per Unit Area of Substrate Processed)						
	CF_4	C_2F_6	CHF_3	C_3F_8	NF_3	SF_6	C_6F_{14}
Semiconductors, kg/m^2	0.9	1.	0.04	0.05	0.04	0.2	NA
TFT-FPDs, g/m^2	0.5	NA	NA	NA	0.9	4.	NA
PV-cells[a], g/m^2	5	0.2	NA	NA	NA	NA	NA
Heat Transfer Fluids[b], kg/m^2	NA	NA	NA	NA	NA	NA	0.3

[a] EFs adapted from unpublished work of Fthenakis, Alsema and Agostinelli. (Fthenakis ,2005) Note that factor is applicable only to silicon-specific technologies and is applied for abatement.

[b] EF assumes HTFs have the same GWP and C_6F_{14} represents a suitable proxy. The origin of this factor is described in Burton, 2004, and is based in part on the work of Tuma and Tousignant (2001).

TIER 2

As discussed above, emissions factors based on simple electronics production variables are not adequate to account for all of the factors that influence emissions. Data for each of the following parameters are necessary to prepare a reliable estimate:

- The gases used;
- The process type (CVD or etch) used;
- The brand of process tool used;
- Emission reduction technology.

Default values have been developed for the parameters used in Tier 2a and 2b methods (See Figure 6.1) on the basis of direct measurements, literature, and expert judgement (see Tables 6.3, 6.4, and 6.5 Tier 2 Default Emission Factors for FCs Emissions from Semiconductor[12], TFT-FPD[13], and PV[12] Manufacturing respectively). Given the difficulty in representing the diverse production conditions within the electronics industry, default emission parameters are inherently uncertain. While accuracy can be improved with larger sets of measured data and where factors are applied to similar processes using similar or identical chemical recipes, developing default factors necessarily involves some form of averaging across all of the data.

Electronics industry specialists expect that rapid technical innovation by chemical and equipment suppliers and electronics manufacturers will result in major emission reductions in the future (i.e., 2006 onwards). As a result, emission factors for these categories should evolve to reflect these changes. The semiconductor and TFT-FPD industries have established mechanisms through the World Semiconductor Council and the World LCD Industry Cooperation Committee, respectively, to evaluate global emission factors. The PV industry may be considering establishing a mechanism for tracking its PFC emissions during PV manufacture. (Fthenakis, 2006)

FC-use during PV manufacture may or may not increase. Existing evidence suggests that, should FC-use in this industry grow, efforts will be made to control their emissions (Agostinelli *et al*., 2004; Rentsch *et al*., 2005). Inventory compilers may wish to periodically consult with the industry to better understand global and national circumstances.

Tables 6.3 and 6.4 include two entries for NF_3: Remote-NF_3 and NF_3. The first refers to a cleaning method in which the film cleaning-agents formed from NF_3 (F-atoms) are produced in a plasma upstream (remote) from the chamber being cleaned. The last, denoted as simply NF_3, refers to an in-situ NF_3 cleaning process that is analogous to the process for other cleaning gases like C_2F_6 and C_3F_8.

The default value for the fraction of gas remaining in the shipping container (heel) is 0.10.

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[13] The emissions factors (EFs) for TFT-FPD manufacturing are simple (unweighted) averages developed from gas- and process-specific values published by Nishida *et al*. (2005).

TABLE 6.3
TIER 2 DEFAULT EMISSION FACTORS FOR FC EMISSIONS FROM SEMICONDUCTOR MANUFACTURING

	Greenhouse Gases with TAR GWP									**Greenhouse Gases without TAR GWP**			**Non-GHGs Producing FC By-products[‡]**	
Process Gas (i)	**CF_4**	**C_2F_6**	**CHF_3**	**CH_2F_2**	**C_3F_8**	**$c\text{-}C_4F_8$**	**NF_3 Remote**	**NF_3**	**SF_6**	**C_4F_6**	**C_5F_8**	**C_4F_8O**	**F_2**	**COF_2**
Tier 2a														
1-Ui	0.9	0.6	0.4	0.1	0.4	0.1	0.02	0.2	0.2	0.1	0.1	0.1	NA	NA
B_{CF4}	NA	0.2	0.07	0.08	0.1	0.1	0.02[†]	0.09	NA	0.3	0.1	0.1	0.02[†]	0.02[†]
B_{C2F6}	NA	NA	NA	NA	NA	0.1	NA	NA	NA	0.2	0.04	NA	NA	NA
B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.04	NA	NA
Tier 2b														
Etch 1-Ui	0.7[*]	0.4[*]	0.4[*]	0.06[*]	NA	0.2[*]	NA	0.2	0.2	0.1	0.2	NA	NA	NA
CVD 1-Ui	0.9	0.6	NA	NA	0.4	0.1	0.02	0.2	NA	NA	0.1	0.1	NA	NA
Etch B_{CF4}	NA	0.4[*]	0.07[*]	0.08[*]	NA	0.2	NA	NA	NA	0.3[*]	0.2	NA	NA	NA
Etch B_{C2F6}	NA	NA	NA	NA	NA	0.2	NA	NA	NA	0.2[*]	0.2	NA	NA	NA
CVD B_{CF4}	NA	0.1	NA	NA	0.1	0.1	0.02[†]	0.1[†]	NA	NA	0.1	0.1	0.02[†]	0.02[†]
CVD B_{C2F6}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.04	NA	NA

Notes: NA denotes not applicable based on currently available information

[‡] The default emission factors for F_2 and COF_2 may be applied to cleaning low-k CVD reactors with ClF_3.

[*] Estimate includes multi-gas etch processes

[†] Estimate reflects presence of low-k, carbide and multi-gas etch processes that may contain a C-containing FC additive

TABLE 6.4
TIER 2 DEFAULT EMISSION FACTORS FOR FC EMISSIONS FROM LCD MANUFACTURING

	Greenhouse Gases with TAR GWP									**Greenhouse Gases without TAR GWP**			**Non-GHGs Producing FC By-products**	
Process Gas (i)	**CF_4**	**C_2F_6**	**CHF_3**	**CH_2F_2**	**C_3F_8**	**c-C_4F_8**	**NF_3 Remote**	**NF_3**	**SF_6**	**C_4F_6**	**C_5F_8**	**C_4F_8O**	**F_2**	**COF_2**
Tier 2a														
1-Ui	0.6	NA	0.2	NA	NA	0.1	0.03	0.3	0.6	NA	NA	NA	NA	NA
B_{CF4}	NA	NA	0.07	NA	NA	0.009	NA	NA	NA	NA	NA	NA	NA	NA
B_{CHF3}	NA	NA	NA	NA	NA	0.02	NA	NA	NA	NA	NA	NA	NA	NA
B_{C2F6}	NA	NA	0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tier 2b														
Etch 1-Ui	0.6	NA	0.2	NA	NA	0.1	NA	NA	0.3	NA	NA	NA	NA	NA
CVD 1-Ui	NA	NA	NA	NA	NA	NA	0.03	0.3	0.9	NA	NA	NA	NA	NA
Etch B_{CF4}	NA	NA	0.07	NA	NA	0.009	NA	NA	NA	NA	NA	NA	NA	NA
Etch B_{CHF3}	NA	NA	NA	NA	NA	0.02	NA	NA	NA	NA	NA	NA	NA	NA
Etch B_{C2F6}	NA	NA	0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{CF4}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C2F6}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: NA denotes not applicable based on currently available information

TABLE 6.5
TIER 2 DEFAULT EMISSION FACTORS FOR FC EMISSIONS FROM PV MANUFACTURING

	Greenhouse Gases with TAR GWP									Greenhouse Gases without TAR GWP			Non-GHGs Producing FC By-products	
Process Gas (i)	CF_4	C_2F_6	CHF_3	CH_2F_2	C_3F_8	c-C_4F_8	NF_3 Remote	NF_3	SF_6	C_4F_6	C_5F_8	C_4F_8O	F_2	COF_2
Tier 2a														
1-Ui	0.7	0.6	0.4	NA	0.4	0.2	NA	0.2	0.4	NA	NA	NA	NA	NA
B_{CF4}	NA	0.2	NA	NA	0.2	0.1	NA	0.05	NA	NA	NA	NA	NA	NA
B_{C2F6}	NA	NA	NA	NA	NA	0.1	NA	NA	NA	NA	NA	NA	NA	NA
B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tier 2b														
Etch 1-Ui	0.7	0.4	0.4	NA	NA	0.2	NA	NA	0.4	NA	NA	NA	NA	NA
CVD 1-Ui	NA	0.6	NA	NA	0.1	0.1	NA	0.3	0.4	NA	NA	NA	NA	NA
Etch B_{CF4}	NA	0.2	NA	NA	NA	0.1	NA	NA	NA	NA	NA	NA	NA	NA
Etch B_{C2F6}	NA	NA	NA	NA	NA	0.1	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{CF4}	NA	0.2	NA	NA	0.2	0.1	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C2F6}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: NA denotes not applicable based on currently available information

TABLE 6.6
TIER 2a & 2b DEFAULT EFFICIENCY PARAMETERS FOR ELECTRONICS INDUSTRY FC EMISSION REDUCTION TECHNOLOGIES[a,b,e]

Emission Control Technology	CF_4	C_2F_6	CHF_3	C_3F_8	c-C_4F_8	NF_3[f]	SF_6
Destruction[c]	0.9	0.9	0.9	0.9	0.9	0.95	0.9
Capture/Recovery[d]	0.75	0.9	0.9	NT	NT	NT	0.9

[a] Values are simple (unweighted) averages of destruction efficiencies for all abatement technologies. Emission factors do not apply to emission control technologies which cannot abate CF_4 at destruction or removal efficiency (DRE) $\geq$ 85 percent when CF_4 is present as an input gas or by-product and all other FC gases at DRE $\geq$ 90 percent. If manufacturers use any other type of emission control technology, its destruction efficiency is 0 percent when using the Tier 2 methods.

[b] Tier 2 emission control technology factors are applicable only to electrically heated, fuelled-combustion, plasma, and catalytic devices that

- are specifically designed to abate FCs,
- are used within the manufacturer's specified process window and in accordance with specified maintenance schedules and
- have been measured and has been confirmed under actual process conditions, using a technically sound protocol, which accounts for known measurement errors including, for example, CF_4 by-product formation during C_2F_6 as well as the effect of dilution, the use of oxygen or both in combustion abatement systems

[c] Average values for fuelled combustion, plasma, and catalytic abatement technologies.

[d] Average values for cryogenic and membrane capture and recovery technologies.

[e] Vendor data verified by semiconductor manufacturers. Factors should only be used when an emission control technology is being utilised and maintained in accordance with abatement manufacturer specifications.

[f] Use of NF_3 in the etch process is typically small compared to CVD. The aggregate emissions of NF_3 from etch and CVD under Tier 2b will usually not be greater than estimates made with Tier 2a or Tier 1 methods.

NT = not tested.

Process tool emission factors

The procedures for calculating process tool emission factors for Tier 2a and Tier 2b methods are identical. Process tool emission factors are defined as the amount of greenhouse gas emitted divided by the amount of greenhouse gas used in the process. The emission factors correspond to the '$(1 - U_i)$' term in the Tier 2 formulas. For example, the emission factor of 0.9 for CF_4 (see Table 6.3 above, Tier 2a value) means that 90 percent of the CF_4 used in the process is emitted as CF_4.

By-product emission factors were also calculated. The major by-product emission of significance is CF_4. While it is generally held that the only gases that emit significant amounts of CF_4 as a by-product are C_2F_6 and C_3F_8, the data provided by tool manufacturers and chemical suppliers showed that CF_4 is also formed from mixtures of gases (e.g., that contain CHF_3 or CH_2F_2) and c-C_4F_8. As a result of this discussion, CF_4 by-product emission factors were calculated for CHF_3, CH_2F_2, C_2F_6, C_3F_8, c-C_4F_8 and C_4F_8O. For example, a value of 0.1for C_3F_8 (taken from Table 6.3 above, Tier 2a value) means that 10 percent of the C_3F_8 used is converted into CF_4. However, C_2F_6 may also be emitted from the decomposition of molecules such as C_4F_6. As described previously, CF_4 may also be formed when etching or cleaning chambers where carbon-containing films are present.

In order to calculate the Tier 2b process tool emission factors, data were collected from process equipment and gas manufacturers. The data were collected according to process type (either Chemical Vapour Deposition (CVD) or etch) and also by type of gas (e.g. C_2F_6, CF_4). The methods used to conduct the emissions testing were real time Quadrupole Mass Spectrometry (QMS) and Fourier Transform Infrared Spectroscopy (FTIR), the best known methods for measuring process tool emissions. Calibration standards (usually 1 percent mixtures with a balance of N_2) were used to quantify the results. The measurement protocol and quality control requirements that were followed are outlined in the 'Guidelines for Environmental Characterisation of Semiconductor Equipment.' (Meyers *et al.*, 2001)[14] The emission factors for Tier 2b (see Tables 6.3 and 6.4 above) are the simple (unweighted) average of the data collected for each gas for etch and CVD, rounded to one significant figure.[12, 16]

In order to determine the Tier 2a process tool emission factors, knowledge of the amounts of gas used in typical semiconductor manufacturing processes is required. The Tier 2a emission factors were obtained using weights provided by industry experts for the proportion of each gas used in etching and cleaning processes. For example, the Tier 2b emission factors for C_2F_6 (Table 6.3) are 0.5 (etch) and 0.6 (CVD). The distribution of C_2F_6 usage between etching and CVD chamber cleaning processes during semiconductor manufacture is 20:80. Applying these weights to each of the emission factors gives 0.6 for the Tier 2a factor for C_2F_6 to one significant figure.

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[14] These guidelines have also been adopted by flat panel display manufacturers for measuring FC-emissions during flat panel device manufacture.

The corresponding distribution of SF_6 usage in TFT-FPD manufacture is 50:50, which gives 0.6 for corresponding Tier 2a emission factor (Table 6.4).[15]

For Tier 3 emission factors, semiconductor manufacturers use company or plant-specific values rather than using default values as listed in Table 6.1 above. In order to assure the quality of emission factors, emission testing should be conducted in accordance with accredited methods.[16] If a third-party supplier conducts the emissions testing, the semiconductor manufacturer should make sure that the third-party supplier is capable of meeting all of the requirements outlined in Revision 3.0 of the Equipment Environmental Characterisation Guidelines (SIA, 2000). Semiconductor manufacturers who use emission factors provided by the process tool equipment supplier should make sure that the emission factors are applicable to their specific manufacturing process. Manufacturing methods with process parameters (e.g., pressure, flow rate) that deviate from centreline conditions may have different emission factors than those provided by the tool manufacturer.

Emission control technology factors for Tier 2 methods

Emissions control technologies are developing at a rapid pace along with electronics manufacturing technology. Default control technology emission factors in Table 6.6 are based on tests of control devices that have been optimised for specific processes and tools. Results are expected to vary across tools and gas flow rates. Emission factors are not applicable to all tools or processes in semiconductor, liquid crystal display, or photovoltaic manufacturing facilities. The Tier 2 default destruction efficiency parameters presented in Table 6.6 are only applicable when the inventory compiler can demonstrate through communication with facility managers and subsequent documentation that emissions control technologies are operated and maintained in accordance with manufacturer specifications. If companies use any other type of abatement device, they should assume that its destruction efficiency is 0 percent under the Tier 2 a and b methods.

Assumptions for the emissions control technology emission factors for the Tier 2 (a & b) methods include:

(i) Specific emissions control technologies are not listed; emission factors for each chemical were established based on results achieved during testing of emissions control technologies in semiconductor manufacturing applications;

(ii) Emission factors should only be used when abatement is applied to emissions that fall within the operating range specified by the abatement manufacturer to meet or exceed the factors listed in Table 6.6;

(iii) Emission factors apply only to that portion of emissions that pass through a properly operating and maintained control device; emission factors should not be applied when control device is bypassed, not operating according to manufacturer specifications, or not maintained in accordance with specifications.

(iv) Emission factors do not apply to emission control technologies which cannot abate CF_4 at a destruction removal efficiency (DRE) $\geq$ 85 percent when CF_4 is present as an input gas or by-product and all other FC gases at DRE $\geq$ 90 percent. If manufacturers use any other type of emission control technology, its destruction efficiency is 0 percent when using the Tier 2 methods.

The default Tier 2 emission control factors in Table 6.6, Default Efficiency Parameters for Electronics Industry FC Emission Reduction Technologies were calculated from data received from equipment suppliers, abatement technology suppliers and electronic device manufacturers. It should be noted that only data from abatement devices that were specifically designed to abate FCs were used in the calculation. Data were received from combustion abatement devices (all of which used some type of fuel), plasma abatement devices, electrically heated abatement devices, and catalytic abatement devices.

The values presented in Table 6.6, Default Efficiency Parameters for Electronics Industry FC Emission Reduction Technologies, are the results of all of the data received for optimized technologies and for each input gas, rounded down to the next 5 percent (e.g., an average of 98 percent would be rounded down to 0.95). The averages were rounded down to reflect that (i) emissions control devices vary in their efficacy depending upon what gas they are optimised to destroy, and (ii) the efficacy of emission control devices depends on the type of tool they are installed on (150, 200 or 300mm wafers) and the amount of FC gas flown through that particular tool, and total exhaust flow through the emissions control device. An emission control device that can destroy 99 percent of a FC when it is optimised to destroy that FC on a certain tool may destroy less than 95 percent of that FC when it is optimised to destroy something else or when it is used on a tool for which it was not designed, or if the FC or total exhaust flow exceeds a certain limit. Electronics manufacturers and abatement tool manufacturers

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[15] The 50:50 SF_6 usage rates represent an average for the leading TFT-FPD manufacturing regions of Japan, Republic of Korea and Taiwan. That proportion was provided by Nishida (2006) and Kim (2006).

[16] One example of an internationally accredited testing method is Meyers *et al.* (2001).

should ensure that the abatement system installed is properly sized and maintained and that the emission control device can meet or exceed the default emission factor highlighted in Table 6.6.

6.2.2.2 HEAT TRANSFER FLUIDS

The emission factor for the Tier 1 method is presented in Table 6.2. There is no emission factor for the Tier 2 method for estimating emissions from evaporation of heat transfer fluids.

6.2.3 Choice of activity data

Activity data for the electronics industry consists of data on gas sales and use or the annual amount of electronics substrate processed (e.g., m^2 of silicon processed for semiconductors). For the more data-intensive Tier 2 methods, gas purchase data at the company or plant-level are necessary. For the Tier 1 methods, inventory compilers will need to determine the total surface area of electronic substrates processed for a given year. Silicon consumption may be estimated using an appropriate edition of the World Fab Watch (WFW) database, published quarterly by Semiconductor Equipment & Materials International (SEMI)[17]. The database contains a list of plants (production as well as R&D, pilot plants, etc.) worldwide, with information about location, design capacity, wafer size and much more. Similarly, SEMI's 'Flat Panel Display Fabs on Disk' database provides an estimate of glass consumption for global TFT-FPD manufacturing.

The activity data in Table 6.7 reflect design capacity figures. Semiconductor and TFT-FPD manufacturing plants are not operated at design capacities for sustained periods, such as a full year. Instead, the capacity fluctuates depending on product demand. For semiconductor manufacturing, publicly available industry statistics show that the global annual average capacity utilisation during the period 1991 – 2000 varied between 76 and 91 percent, with an average value of 82 percent and most probable value of 80 percent. When country-specific capacity utilisation data are not available, the suggested capacity utilisation for semiconductor manufacturing is 80 percent. This should be used consistently for a time series of estimates. For TFT-FPD manufacturing, publicly available capacity utilisation data are not available. The TFT-FPD manufacturing industry, like the semiconductor manufacturing industry, lowers product prices to maintain the highest practical plant capacity utilisation. By analogy, therefore, it is suggested to use 80 percent to estimate substrate glass consumption using the design capacities provided in Table 6.7 for country TFT-FPD manufacturers. For PV manufacturing, published capacity utilisation data ranges between 77 – 92 percent, with the average for the years 2003 and 2004 of 86 percent. Therefore, 86 percent is the recommended default figure for C_u (see Equation 6.1) to use.

When estimating emissions during PV manufacture, one should account for the fraction of the industry that actually employs FCs (C_{PV} in Equation 6.1). Because recent surveys indicate that between 40 – 50 percent of PV manufacture actually uses FC, and the usage trend may be increasing, the recommended default value for C_{PV} is 0.5.

Table 6.7 summarises the capacity for 2003, 2004 and 2005 for countries, which in total, account for more than 90 percent of world capacity in 2003.

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[17] The term 'fab' is synonymous with clean room/manufacturing facility. Semiconductor and flat panel display manufacturing plants are often called fabrication plants, from which the abbreviation 'fab' follows.

TABLE 6.7
COUNTRY TOTAL SILICON (Si) AND GLASS DESIGN CAPACITIES (Mm^2) FOR 2003, 2004 AND 2005

	Annual Si design capacities, Mm^2			**Annual Glass design capacities, Mm^2**		
Country Totals	**2003[1]**	**2004[2]**	**2005[2]**	**2003[1]**	**2004[2]**	**2005[2]**
Australia	0.0008	0.0008	0.0008	NA	NA	NA
Austria	0.0201	0.0201	0.0201	NA	NA	NA
Belgium	0.0040	0.0040	0.0040	NA	NA	NA
Canada	0.0041	0.0041	0.0041	NA	NA	NA
China	0.1436	0.1982	0.3243	0.0432	0.0432	0.8154
Czech Republic	0.0057	0.0057	0.0057	NA	NA	NA
France	0.0653	0.0674	0.0674	NA	NA	NA
Germany	0.1622	0.1622	0.1622	NA	NA	NA
China, Hong Kong	0.0059	0.0059	0.0059	NA	NA	NA
Hungary	0.0006	0.0006	0.0006	NA	NA	NA
India	0.0128	0.0128	0.0128	NA	NA	NA
Ireland	0.0175	0.0430	0.0430	NA	NA	NA
Israel	0.0310	0.0310	0.0564	NA	NA	NA
Italy	0.0431	0.0431	0.0609	NA	NA	NA
Japan	0.9091	0.9235	0.9639	4.5746	5.3256	6.9201
Latvia	0.0019	0.0019	0.0019	NA	NA	NA
Malaysia	0.0284	0.0284	0.0284	NA	NA	NA
Netherlands	0.0301	0.0301	0.0301	0.0209	0.0209	0.0209
Republic of Belarus	0.0077	0.0077	0.0077	NA	NA	NA
Russia	0.0250	0.0250	0.0325	NA	NA	NA
South Korea	0.3589	0.3742	0.3937	5.8789	9.4679	12.4857
Singapore	0.1730	0.1730	0.1985	0.2821	0.2821	0.2821
Slovakia	0.0043	0.0043	0.0043	NA	NA	NA
South Africa	0.0021	0.0021	0.0021	NA	NA	NA
Sweden	0.0019	0.0019	0.0019	NA	NA	NA
Switzerland	0.0098	0.0098	0.0098	NA	NA	NA
Thailand	0.0000	0.0000	0.0094	NA	NA	NA
Turkey	0.0000	0.0000	0.0000	NA	NA	NA
United Kingdom	0.0597	0.0597	0.0936	NA	NA	NA
United States of America	0.6732	0.6921	0.7190	0.0000	0.0000	0.0000
Vietnam	0.0000	0.0000	0.0000	NA	NA	NA
Global Total	3.3206	3.4972	3.8849	15.0572	23.9959	33.7459

[1] Country totals include fab in production

[2] Country totals include fabs under construction and announced.

NA = not applicable.

Sources: Extractions from World Fab Watch Database, January 2004 Edition for Semiconductor Manufacturing and Flat Panel Display Fabs on Disk Database (Strategic Marketing Associates, 2004a), October 2004 Edition for TFT-FPD Manufacturing (Strategic Marketing Associates, 2004b).

TABLE 6.8
COUNTRY TOTAL PV PRODUCTION CAPACITY[a] FOR 2003, Mm^2

Australia	0.135
Austria	0.0307
Canada	0.0154
Denmark	0.00254
France	0.162
Germany	0.817
Italy	0.100
Japan	3.72
Norway	0.0138
Portugal	0.115
S. Korea	0.462
Spain	0.715
Sweden	0.377
Switzerland	0.00238
United Kingdom	0.0269
United States	1.02

[a]Capacities for all PV manufacturing technologies, includes those that may not use FCs during PV manufacture; World average capacity utilisation for 2003 = 86%.

Source: IEA, 2004. PV participating survey countries.

6.2.4 Completeness

Complete accounting of emissions from the semiconductor industry should be achievable in most countries because there are a limited number of companies and plants. There are four issues related to completeness that should be addressed:

- **Other by-products:** A number of transformation by-products are generated as a result of FC use for chamber cleaning and etching. As highlighted above, formation of CF_4 and C_2F_6 can result from the decomposition of other FC gases. Also, CF_4 formation has been observed in the cleaning of low k CVD chambers. In this case, the Tier 3 method should be used to accurately estimate emissions.
- **New chemicals:** Completeness will be an issue in the future as the industry evaluates and adopts new chemical processes to improve its products. Industry-wide efforts to reduce FC emissions are also accelerating the review of new chemicals. Consequently, *good practice* for this industry is to incorporate a mechanism that accounts for greenhouse gases not listed in the IPCC Third Assessment Report (e.g., C_4F_6, C_5F_8, Fluorinerts™, and Galdens®). These new FC materials have high GWPs or may produce high GWP by-product emissions.
- **Other sources:** A small amount of FCs may be released during gas handling (e.g. distribution) and by sources such as research and development (e.g. university) scale plants and tool suppliers. These emissions are not believed to be significant (e.g., less than 1 percent of this industry's total emissions).
- **Other products or processes:** FC use has been identified in the electronics industry in emissive applications including: micro-electro-mechanical systems (MEMS),[18] hard disk drive manufacturing, device testing (FC liquids), vapour phase reflow soldering,[19] and precision cleaning.[20]

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[18] Emissions from micro-electro-mechanical systems (MEMS) manufacturing may be estimated using methods similar to those used for the other electronic sub sectors. Company-specific emission and abatement factors are required. Very small amounts of FCs are also used in and research and development laboratories/facilities.

6.2.5 Developing a consistent time series

Use of FCs by the semiconductor industry began in the late 1970s and accelerated significantly beginning in the early 1990s. Determining a base year emissions level may present difficulties because few data are available for emissions occurring before 1995. If historical emissions estimates were based on simple assumptions (e.g., use equals emissions), then these estimates could be improved by applying the methods described above. If historical data are not available to permit use of a Tier 3 or 2 method, then the Tier 1 method using default emission parameters can be used retrospectively. Both Tier 1 and Tier 2 could then be applied simultaneously for the years in which more data become available to provide a comparison or benchmark. This should be done according to the guidance provided in Volume 1, Chapter 5.

In order to ensure a consistent emissions record over time, an inventory compiler should recalculate FC emissions for all years reported whenever emissions calculation procedures are changed (e.g., if an inventory compiler changes from the use of default values to actual values determined at the plant level). If plant-specific data are not available for all years in the time series, the inventory compiler will need to consider how current plant data can be used to recalculate emissions for these years. It may be possible to apply current plant-specific emission parameters to sales data from previous years, provided that plant operations have not changed substantially. Such a recalculation is required to ensure that any changes in emission trends are real and not an artefact of changes in procedure.

6.3 UNCERTAINTY ASSESSMENT

Use of the Tier 3 method will result in the least uncertain inventory. Given the limited number of plants and the close monitoring of production processes at the plant level, collection of data for use in Tier 2b or Tier 3 methods should be technically feasible. Inventory compilers should seek the advice of the industry on uncertainties, using the approaches to obtaining expert judgement outlined in Volume 1, Chapter 3.

Of all the methods, Tier 1 is the most uncertain. Using a single factor to account for the FC emissions from the diversity of semiconductor products is a glaring simplification. The factors presented in Table 6.2 are heavily weighted toward the manufacture of advanced vintage-late-1990s memory and logic products, having 3 to 5 layers, respectively, manufactured on the silicon wafer. The factors for countries that are currently manufacturing products at the leading-edge of technology (and are not using measures to reduce FC emissions) would be larger, while countries that manufacture products that use older technologies or manufacture simpler devices would use the same or an even smaller factor.

The Tier 1 emissions factors for TFT-FPD manufacturing represents a weighted average of the estimated aggregate PFC emissions per unit area of substrate glass consumed during TFT-FPD manufacture for the area where data were available (Burton, 2004b). The estimated emissions reported for Japan used Tier 2b factors for semiconductor manufacturing from *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC, 2000) in semiconductor manufacturing (Nishida *et al*., 2004). For emissions from Taiwan's TFT-FPD manufacturers, the method for estimating emissions was not reported (Leu *et al*., 2004). However, subsequently Leu (2004) reported an aggregate emission factor having a similar magnitude to that developed by Burton (2004b). The uncertainty in the Tier 1 emissions factor for TFT-FPD manufacture is probably large, but not known at this time.

When using Tier 3 method for semiconductor and TFT-FPD manufacturing, the resulting estimates of emissions will be more accurate than the Tier 2a, 2b or Tier 1 methods, on the order of ± 30 percent (95 percent confidence interval). Uncertainty in the efficacy of emission control technology appears to contribute most to this uncertainty, especially the variability in the uptime of emission control devices and in flow rates to emission control devices that may exceed device design limits.

Estimates of emissions from using heat transfer fluids using the Tier 2 method will be more accurate than Tier 1 method, of the order of ± 20 percent (95 percent confidence interval).

6.3.1 Emission factor uncertainties

The uncertainties in the emission factors suggested for the Tier 2b and 2a methods are shown in Table 6.9 for semiconductor manufacturing and Table 6.10 for TFT-FPD manufacturing. The factors were developed

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[19] Emissions from vapour phase reflow soldering may be estimated to equal annual net FC purchases for maintaining vapour phase reflow soldering equipment.

[20] Emissions from precision cleaning are to be accounted for in Section 7.2 (Solvents) of this Volume.

specifically for this guidance. For Tier 2b, relative errors for each entry (process and gas in the case of Tier 2b) were estimated as the standard deviation of the factors provided by an expert group, normalised to the simple (unweighted) average, rounded to one significant figure.[12] The estimate for each value was then doubled to estimate the 95 percent confidence interval. The same procedure was used to estimate the relative errors for product-formation factors (B). The corresponding estimates for the Tier 2a method were derived for the Tier 2b estimates, using the estimates of gas usage employed in development of the emission factors (see Section 6.2.2 Tier 2).

Tier 1 emission factors will have an uncertainty range that is skewed towards values close to zero extending up to 200 percent (95 percent confidence interval for semiconductor and TFT-FPD manufacture). Uncertainty estimates for PV manufacturing are not available.

6.3.2 Activity data uncertainties

Gas consumption constitutes the unit of activity to estimate emissions during semiconductor, TFT-FPD and PV manufacture for the Tier 2a and 2b methods. Gas consumption can be either measured or estimated from data on gas purchases, and requires knowledge of h, the unused gas returned to gas suppliers in the shipping containers. The uncertainties (95 percent confidence interval) in gas consumption and h, whether measured or estimated using expert judgment are shown in Table 6.10, Relative Errors (95 percent confidence interval) for Activity Data for Tier 2a and 2b Methods for Semiconductor and TFT-FPD Manufacture.

For Tier 1 method, the unit of activity is substrate consumption. Uncertainties in the Tier 1 activity data are attributed principally to missing data entries in the WFW and FPD databases. An estimate of the reliability of entries derived from the WFW in Table 6.7 is ± 10 percent (95 percent confidence interval), which reflects errors due to missing and incorrect entries in the database. The 95 percent confidence interval in capacity utilisation over the 1991-2000 period is ± 12 percentage points (i.e., from 70 percent utilisation to 94 percent utilisation). The corresponding entries for TFT-FPD and PV manufacture are assumed to be similar to those for semiconductor manufacturing.

TABLE 6.9
TIER 2 DEFAULT ESTIMATES OF RELATIVE ERRORS (%) FOR EMISSION FACTOR FOR FC EMISSIONS FROM SEMICONDUCTOR MANUFACTURING, 95 PERCENT CONFIDENCE INTERVALS[*]

	Greenhouse Gases with TAR GWP									**Greenhouse Gases without TAR GWP**			**Non-GHGs Producing FC By-products**	
Process Gas (i)	**CF_4**	**C_2F_6**	**CHF_3**	**CH_2F_2**	**C_3F_8**	**$c\text{-}C_4F_8$**	**NF_3 Remote**	**NF_3**	**SF_6**	**C_4F_6**	**C_5F_8**	**C_4F_8O**	**F_2**	**COF_2**
Tier 2a														
1-Ui	15	30	100	400	20	80	400	70	300	300	80[†]	40	NA	NA
B_{CF4}	NA	90	300	200	60	100	200	200	NA	200	100[†]	80	200	200
B_{C2F6}	NA	NA	NA	NA	NA	200	NA	NA	NA	200	200	NA	NA	NA
B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	40	NA	NA
Tier 2b														
Etch 1-Ui	60	100	100	700	NA	200	NA	300	300	300	200[†]	NA	NA	NA
CVD 1-Ui	10	30	NA	NA	0.4	30	400	70	NA	NA	30[†]	40	NA	NA
Etch B_{CF4}	NA	200	300	200	NA	200	NA	NA	NA	200	200[†]	NA	NA	NA
Etch B_{C2F6}	NA	NA	NA	NA	NA	200	NA	NA	NA	200	200[†]	NA	NA	NA
CVD B_{CF4}	NA	80	NA	NA	60	60	200	200	NA	NA	60[†]	80	200	200
CVD B_{C2F6}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	40	NA	NA

Notes: NA denotes not applicable based on currently available information

[*] Values that exceed 100% imply a distribution that is skewed towards values close to zero extending up to the value given.

[†] Estimate relies on an analogy to $c\text{-}C_4F_8$ as the data for C_5F_8 were insufficient to estimate a confidence interval.

TABLE 6.10
TIER 2 DEFAULT ESTIMATES OF RELATIVE ERRORS (%) FOR EMISSION FACTOR FOR FC EMISSIONS FROM LCD MANUFACTURING, 95 PERCENT CONFIDENCE INTERVALS

	Greenhouse Gases with TAR GWP									Greenhouse Gases without TAR GWP			Non-GHGs Producing FC By-products	
Process Gas (i)	**CF_4**	**C_2F_6**	**CHF_3**	**CH_2F_2**	**C_3F_8**	**$c\text{-}C_4F_8$**	**NF_3 Remote**	**NF_3**	**SF_6**	**C_4F_6**	**C_5F_8**	**C_4F_8O**	**F_2**	**COF_2**
Tier 2a														
1-Ui	50	NA	8	NA	NA	5	70	20	20	NA	NA	NA	NA	NA
B_{CF4}	NA	NA	30	NA	NA	40	NA	NA	NA	NA	NA	NA	NA	NA
B_{CHF3}	NA	NA	NA	NA	NA	20	NA	NA	NA	NA	NA	NA	NA	NA
B_{C2F6}	NA	NA	40	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tier 2b														
Etch 1-Ui	50	100	8	NA	NA	5	NA	60	NA	NA	NA	NA	NA	NA
CVD 1-Ui	NA	NA	NA	NA	NA	NA	70	20	6	NA	NA	NA	NA	NA
Etch B_{CF4}	NA	NA	30	NA	NA	40	NA	NA	NA	NA	NA	NA	NA	NA
Etch B_{CHF3}	NA	NA	NA	NA	NA	20	NA	NA	NA	NA	NA	NA	NA	NA
Etch B_{C2F6}	NA	NA	40	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{CF4}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C2F6}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CVD B_{C3F8}	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes: NA denotes not applicable based on currently available information

6.4 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC), REPORTING AND DOCUMENTATION

6.4.1 Quality Assurance/Quality Control (QA/QC)

It is *good practice* to conduct quality control checks as outlined in Volume 1, Chapter 6, and an expert review of the emissions estimates. Additional quality control checks as outlined in Volume 1 and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. Inventory compilers are encouraged to use higher tier QA/QC for *key categories* as identified in Volume 1, Chapter 4.

Additional general guidance for higher tier QA/QC procedures is also included in Volume 1, Chapter 6. Due to the highly competitive nature of the semiconductor industry, provisions for handling confidential business information should be incorporated into the verification process. Methods used should be documented, and a periodic audit of the measurement and calculation of data should be considered. A QA audit of the processes and procedures should also be considered.

6.4.2 Reporting and Documentation

Care should be taken not to include emissions of HFCs used as ODS substitutes with those used in semiconductor manufacturing. It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Section 6.11. It is not practical to include all documentation in the national inventory report. However, the inventory should include summaries of methods used and references to source data such that the reported emissions estimates are transparent and steps in their calculation may be retraced.

Explicit reporting on emissions in this industry would improve the transparency and comparability of emissions. As a number of FCs gases are emitted by this industry, reporting by individual gas species rather than by chemical type would also improve the transparency and usefulness of this data. Efforts to increase transparency should take into account the protection of confidential business information related to specific gas use. Country-level aggregation of gas-specific emissions data should protect this information in countries with three or more manufacturers. Table 6.11, Information Necessary for Full Transparency of Estimates of Emissions from Semiconductor Manufacturing, shows the supporting information necessary for full transparency in reported emissions estimates.

Good practice for Tier 3 is to document the development of company-specific emission factors, and to explain the deviation from the generic default values. Given confidentiality concerns, inventory compilers may wish to aggregate this information across manufacturers. In cases where manufacturers in a country have reported different emission or conversion factors for a given FC and process or process type, inventory compilers may provide the range of factors reported and used.

TABLE 6.11
INFORMATION NECESSARY FOR FULL TRANSPARENCY OF ESTIMATES OF EMISSIONS FROM ELECTRONICS MANUFACTURING

Data	Tier 1	Tier 2a	Tier 2b	Tier 3
Total surface area of electronics substrate processed (e.g., m^2 silicon, m^2 glass)	X			
Capacity utilisation for semiconductor, TFT-FPD and PV manufacturing	X			
Fraction of PV manufacturing capacity that uses FC gases	X			
Emissions of each FC (rather than aggregated for all FCs)		X	X	X
Sales/purchases of each FC		X		
Mass of each FC used in each process or process type			X	X
Fraction of each FC used in processes with emission control technologies		X	X	X
Use rate for each FC for each process or process type (This and following information is necessary only if default value is not used)				X
Fraction of each FC transformed into CF_4 for each process or process type				X
Fraction of gas remaining in shipping container				X
Fraction of each FC destroyed by emission control technology				X
Fraction of CF_4 by-product destroyed by emission control technology				X

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