

# CGE SUPPLEMENTARY TRAINING MATERIAL FOR THE TEAM OF TECHNICAL EXPERTS

## Module 2.2b

Background material:

*National greenhouse gas  
inventories – industrial processes  
sector*

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## ABBREVIATIONS

|                                   |  |
|-----------------------------------|--|
| <b>C<sub>2</sub>F<sub>6</sub></b> | carbon hexafluoride  |
| <b>CaCO<sub>3</sub></b>           | calcium carbonate  |
| <b>CaO</b>                        | calcium oxide  |
| <b>CF<sub>4</sub></b>             | carbon tetrafluoride   |
| <b>CH<sub>4</sub></b>             | methane  |
| <b>CO<sub>2</sub></b>             | carbon dioxide   |
| <b>EAF</b>                        | electric arc furnace   |
| <b>GHG</b>                        | greenhouse gas   |
| <b>GPG 2000</b>                   | Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories |
| <b>HFCs</b>                       | hydrofluorocarbons   |
| <b>IPCC</b>                       | Intergovernmental Panel on Climate Change  |
| <b>N<sub>2</sub>O</b>             | nitrous oxide  |
| <b>NH<sub>3</sub></b>             | ammonia  |
| <b>NO</b>                         | nitric oxide   |
| <b>ODS</b>                        | ozone depleting substances   |
| <b>PFCs</b>                       | perfluorocarbons   |
| <b>SF<sub>6</sub></b>             | sulphur hexafluoride   |



## 1. BACKGROUND AND COURSE OBJECTIVES

**This material was developed within the context of the process for international consultation and analysis (ICA) to further support the training for the team of technical experts (TTE) and to provide additional background knowledge and context.**

This module, prepared as supplementary training material to module 2.2 on technical analysis of greenhouse gas (GHG) inventories, aims to provide an overview of the methods and science involved in estimating emissions from the industrial processes sector. This is intended for **those experts nominated to the UNFCCC roster of experts with no or limited prior knowledge and wishing to enhance their technical knowledge on national GHG inventories.**

It is drawn from the most recent Consultative Group of Experts (CGE) training materials on national GHG inventories for Parties not included in Annex 1 to the Convention (non-Annex I Parties), which are based on *the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the Revised 1996 IPCC Guidelines), and *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (herein referred to as GPG 2000).

The information presented here should be further supplemented with that from the Revised 1996 IPCC Guidelines and GPG 2000 in order to address the complete length and breadth of the science and methods involved in estimating GHG emissions from the industrial processes sector.

## 2. SECTOR OVERVIEW

The Revised 1996 IPCC guidelines and the GPG 2000 provide guidance on categories of the industrial processes sector. They are the following: (2.A) mineral products; (2.B) chemical industry; (2.C) metal production; (2.D) other production; (2.E) production of halocarbons and sulphur hexafluoride (SF<sub>6</sub>); (2.F) consumption of halocarbons and SF<sub>6</sub>; and (2G) other.

Table 1  
Greenhouse gas source and sink categories

| GREENHOUSE GAS SOURCE AND SINK CATEGORIES                    | CO <sub>2</sub> | CH <sub>4</sub> | N <sub>2</sub> O | HFCs | PFCs | SF <sub>6</sub> | NO <sub>x</sub> | CO | NM VOC | SO <sub>2</sub> |
|--|-----------------|-----------------|------------------|------|------|-----------------|-----------------|----|--------|-----------------|
| <b>A. Mineral Products</b>                                   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 1. Cement Production   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 2. Lime Production   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 3. Limestone and Dolomite Use                                |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 4. Soda Ash Production and Use                               |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 5. Asphalt Roofing   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 6. Road Paving with Asphalt                                  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 7. Other (as specified in table 2(I).A-G)                    |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other non-specified  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| <b>B. Chemical Industry</b>                                  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 1. Ammonia Production  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 2. Nitric Acid Production                                    |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 3. Adipic Acid Production                                    |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 4. Carbide Production  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 5. Other (as specified in table 2(I).A-G)                    |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other non-specified  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| <b>C. Metal Production</b>                                   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 1. Iron and Steel Production                                 |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 2. Ferroalloys Production                                    |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 3. Aluminium Production                                      |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 4. SF <sub>6</sub> Used in Aluminium and Magnesium Foundries |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 5. Other (as specified in table 2(I).A-G)                    |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other non-specified  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| <b>D. Other Production</b>                                   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 1. Pulp and Paper  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 2. Food and Drink <sup>(2)</sup>                             |                 |                 |                  |      |      |                 |                 |    |        |                 |
| <b>E. Production of Halocarbons and SF<sub>6</sub></b>       |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 1. By-product Emissions                                      |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Production of HCFC-22  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 2. Fugitive Emissions  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 3. Other (as specified in table 2(II))                       |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other non-specified  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| <b>F. Consumption of Halocarbons and SF<sub>6</sub></b>      |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 1. Refrigeration and Air Conditioning Equipment              |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 2. Foam Blowing  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 3. Fire Extinguishers  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 4. Aerosols/ Metered Dose Inhalers                           |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 5. Solvents  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 6. Other applications using ODS <sup>(3)</sup> substitutes   |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 7. Semiconductor Manufacture                                 |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 8. Electrical Equipment                                      |                 |                 |                  |      |      |                 |                 |    |        |                 |
| 9. Other (as specified in table 2(II))                       |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other non-specified  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| <b>G. Other (as specified in tables 2(I).A-G and 2(II))</b>  |                 |                 |                  |      |      |                 |                 |    |        |                 |
| Other non-specified  |                 |                 |                  |      |      |                 |                 |    |        |                 |

Source: IPCC.

Note: The grey cells represent categories where emissions do not occur.

### 3. INDUSTRIAL PROCESSES SECTOR EMISSIONS

Greenhouse gas emissions from the industrial processes sector comprise carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and SF<sub>6</sub> from various industrial activities. The industrial processes sector emissions can generally be categorized into sources of generation, as follows:

- GHGs emitted during manufacturing value addition to mineral and metallurgical ores accounted for in categories 2.A and 2.C (e.g. CO<sub>2</sub> emissions from processing of limestone into clinker for cement production);
- Non-energy related GHG emissions from the use of fossil fuels used as feedstock (e.g. CO<sub>2</sub> emissions from the use of natural gas to produce ammonia, and coke in the reduction of iron ores in steel making);
- GHG emissions resulting from the use of various products that are GHGs (e.g. HFCs and PFCs as substitutes for ozone depleting substances in refrigeration and air conditioning).

#### 3.1. CARBON DIOXIDE EMISSION PROCESSES

The CO<sub>2</sub> emissions associated with industrial processes result from the use of carbonate raw materials in the production and use of a variety of mineral industry products. The two major pathways contributing significant CO<sub>2</sub> emissions are from calcination of carbonates and the acid-induced release of CO<sub>2</sub>, and the use of fossil carbon feedstock and fossil carbon as reducing agents in metal and mineral processing.

The thermal decomposition reactions that take place during the calcination process result in the release of CO<sub>2</sub> and the formation of a metallic oxide, while fossil carbon is oxidized into direct CO<sub>2</sub> emissions. Equation 1 represents a general calcination reaction for the mineral calcite or calcium carbonate decomposition (reaction equation A) and carbon oxidation (reaction equation B):

Equation 1

**Carbon dioxide from calcium carbonate decomposition and carbon oxidation**

*Reaction equation A:*



*Reaction equation B:*



The industrial processes sector accounts for CO<sub>2</sub> from chemical reactions. This is largely dependent on the purity of the carbonate content of the ore and the efficiency of the technology of conversion. The heat energy from various fuels such as coal,

coke and natural gas required to initiate and sustain the chemical reaction are accounted for in the energy sector. The three principal categories of calcination-related emissions processes in the mineral industry are cement production, lime production and glass production. These categories contribute significantly to the industrial processes sector emissions. Other source categories resulting from the consumption of carbonates in a variety of other mineral industries include ceramics, soda ash use and carbonate consumption for non-metallurgical magnesia production. Limestone and other carbonate materials are also consumed in a variety of other industries not covered in this section. Examples include carbonates used as fluxes, and slagging agents in metals smelting and refining (e.g. production of iron and steel and base metals, such as copper).

Another significant source of CO<sub>2</sub> in the industrial processes sector is the production of ammonia in the chemical industry from the use of fossil fuels, principally natural gas, coke from coal, coal, and petroleum coke. The CO<sub>2</sub> emissions result primarily from the consumption of blast furnace gas and coke oven gas in coke production; consumption of the reducing agent (e.g. coke from coal, coal, and petroleum coke) in metal production, including the reduction of iron ore in iron and steel production; reduction of alumina in aluminium production; the oxidation of carbon electrodes in scrap-charged electric arc furnaces; and consumption of natural gas and naphtha in the production of ammonia.

### 3.1.1. METHANE EMISSIONS

The potential sources of CH<sub>4</sub> emissions are from coke production, sinter production and direct reduced iron production in the integrated iron and steel industry. Although CH<sub>4</sub> and N<sub>2</sub>O may be emitted from some mineral industry categories, given current scientific knowledge, these emissions are assumed to be negligible.

### 3.1.2. NITROUS OXIDE AND NITRIC OXIDE

The production of nitric acid generates nitrous oxide (N<sub>2</sub>O) as a by-product of the high temperature catalytic oxidation of ammonia (NH<sub>3</sub>). Nitric oxide (NO), an intermediate in the production of nitric acid, however, readily decomposes to N<sub>2</sub>O and nitrogen dioxide (NO<sub>2</sub>) at high pressures and temperatures of 30–50°C. Most nitric acid is produced through the catalytic oxidation of ammonia. Emissions of N<sub>2</sub>O depend on the amount generated in the production process and the amount destroyed by abatement technologies used as pollution control systems. Abatement of N<sub>2</sub>O can be intentional, through the installation of equipment designed to destroy N<sub>2</sub>O, or unintentionally achieved in systems designed to abate other emissions such as nitrogen oxides (NO<sub>x</sub>).

### 3.1.3. HYDROFLUOROCARBONS AND PERFLUOROCARBONS

HFCs and PFCs are not controlled by the Montreal Protocol because they do not contribute to the depletion of the stratospheric ozone layer. Prior to the Montreal Protocol and the phase-out of various ozone depleting substances (ODS), the only HFCs produced were HFC-152a, and HFC-23. HFCs are now being used, among

other applications, as ODS substitutes. HFCs and PFCs have very high global warming potential.

The key GHGs are carbon tetrafluoride (CF<sub>4</sub>) and carbon hexafluoride (C<sub>2</sub>F<sub>6</sub>), generated from anode effects during the aluminium production process; while HFC-23 is produced during the production of HCFC-22. The other sources are physical release of HFCs, and to a very limited extent PFCs, from various applications as alternatives or substitutes for ODS in refrigeration and air conditioning, fire suppression and explosion protection, aerosols solvent cleaning, foam blowing and other applications.

In relation to the fluorinated compounds, HFCs, PFCs and SF<sub>6</sub> are growing rapidly as primary substitutes for ODS, which are being phased-out under the Montreal Protocol on substances that deplete the ozone layer.

#### 3.1.4. SULPHUR HEXAFLUORIDE

SF<sub>6</sub> and PFCs are emitted from the manufacture and use of electrical equipment, and a number of other products. In most of these applications, the SF<sub>6</sub> and PFCs are used in the products due to one or more of the physical properties of the chemical: notably the high dielectric strength of SF<sub>6</sub> and the stability of PFCs; and SF<sub>6</sub> as an effective cover gas in foundries to prevent oxidation of molten magnesium. It is assumed that all SF<sub>6</sub> used as cover gas is emitted to the atmosphere.

#### 3.1.5. CARBON MONOXIDE, NON-METHANE VOLATILE ORGANIC COMPOUNDS AND AMMONIA EMISSIONS

The production and use of asphalt for road paving and roofing, as well as the use of solvents derived from petroleum and coal, are either not sources or are negligible sources of direct GHG emissions. They are, however, significant sources of non-methane volatile organic compounds and carbon monoxide emissions, which eventually oxidize to CO<sub>2</sub> in the atmosphere. NH<sub>3</sub> is emitted from ammonia production.

## 4. METHODS TO ESTIMATE GREENHOUSE GAS EMISSIONS FROM THE INDUSTRIAL PROCESSES SECTOR

### 4.1. INTRODUCTION

In the Revised 1996 IPCC Guidelines and GPG 2000, methods are generally referred to as ‘tiers’, with higher tier methods being more advanced. The GPG 2000 provides decision trees to help Parties in the selection of data and methods (i.e. tiers) for each individual category. These decision trees are intended to direct the Party to use the best method and data possible, given its national circumstances. In general, it is **good practice** for Parties to utilize higher tier methods, with their associated more detailed data, in particular for key categories. Parties are, however, permitted some flexibility in applying these decision trees as long as the choices they make result in estimates that are of equivalent quality to those described in the GPG 2000.

This flexibility is an important characteristic of the Revised 1996 IPCC Guidelines and the GPG 2000, because it recognizes that Parties have different national circumstances (e.g. availability of historical data). Although **good practice** is meant to direct Parties to use more rigorous methods and more detailed data, what is defined as ‘good practice’ can vary from Party to Party, depending on the national circumstances.

This section provides methods non-Annex I Parties are to apply in accordance with the Revised 1996 IPCC guidelines and GPG 2000 for estimating GHG emissions in the industrial processes sector. The section emphasizes the application of GPG 2000 decision tree guidance for the choice of methods (appropriate tier level) consistent with national circumstances, emission factors and activity data for the categories for which the GPG 2000 was developed.

However, the general methodology employed to estimate emissions associated with each industrial process involves activity level data, for example the amount of material produced or consumed, and an associated emission factor per unit of consumption or production, as shown in equation 2.

Equation 2

**General equation for greenhouse gas emissions**

$$\text{TOTAL}_{ij} = A_j \times \text{EF}_{ij}$$

where:

- TOTAL<sub>ij</sub> = process emission (tonnes) of gas i from industrial sector j
- A<sub>j</sub> = amount of activity or production of process material in industrial sector j (tonnes/yr)
- EF<sub>ij</sub> = emission factor associated with gas i per unit of activity in industrial sector j (tonne/tonne)

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.4.

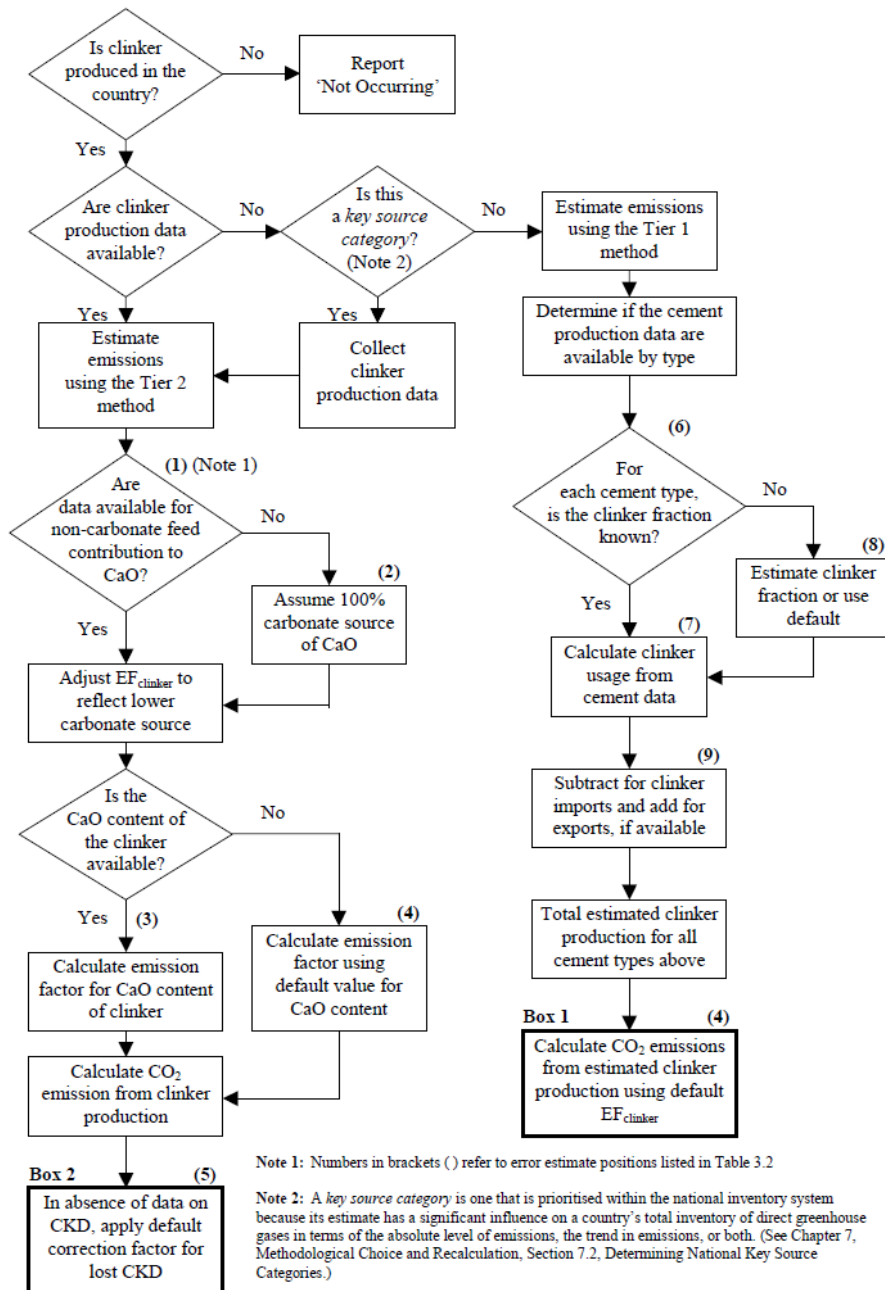
## 4.2. CARBON DIOXIDE EMISSIONS FROM CEMENT PRODUCTION

In the production of clinker, limestone, which is predominantly calcium carbonate ( $\text{CaCO}_3$ ), is heated in a cement kiln at a temperature of about  $1,300^\circ\text{C}$  ( $2,400^\circ\text{F}$ ), to produce lime ( $\text{CaO}$ ) and  $\text{CO}_2$  as a by-product. The  $\text{CaO}$  reacts with silica ( $\text{SiO}_2$ ), alumina ( $\text{Al}_2\text{O}_3$ ), and iron oxide ( $\text{Fe}_2\text{O}_3$ ) added in the kiln to form the clinker minerals (principally calcium silicates). The clinker is then allowed to cool, mixed with a small amount of gypsum, and used to make Portland cement. Cement kiln dust is generated during the manufacture of clinker and should be accounted for in the emissions estimation.

### 4.2.1. DECISION TREE FOR ESTIMATING CARBON DIOXIDE EMISSIONS FROM CEMENT PRODUCTION

The decision tree for  $\text{CO}_2$  emissions from cement production is provided in the GPG 2000.

Figure 1  
Decision tree for estimation of CO<sub>2</sub> emissions from cement production



Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 3.11.

#### 4.2.2. TIER 1 METHOD

Basic CO<sub>2</sub> emissions from industrial processes are estimated using equation 2. Estimating CO<sub>2</sub> emissions directly from cement production (i.e. using a fixed cement-based emission factor) is not consistent with good practice. Instead, in the absence of national clinker production data, cement production data may be used to estimate



clinker production taking into account the types of cement produced and including a correction for international clinker trade (exports, imports), where relevant.

Equation 3  
**Clinker production**

$$\text{Estimated Clinker Production} = \text{Cement Production} \cdot \text{Clinker Fraction} \\ - \text{Imported Clinker} + \text{Exported Clinker}$$

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 3.12.

The emission factors for clinker are based on stoichiometry, as shown below. In tier 1, it is good practice to use the same default CaO content of 65 per cent, resulting in an emission factor of 0.51 t CO<sub>2</sub> per tonne of clinker.

Equation 4  
**Emission factor for carbon dioxide from cement manufacture**

$$EF_{\text{clinker}} = 0.785 \cdot \text{CaO Content (Weight Fraction) in Clinker}$$

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 3.12.

### 4.2.3. HIGHER TIER METHODS

The most rigorous good practice method is to use aggregated plant or national clinker production data, instead of cement production statistics, and data on the CaO content in clinker.<sup>1</sup>

## 4.3. CARBON DIOXIDE EMISSIONS FROM LIME PRODUCTION

Lime is produced for different purposes (e.g. metallurgy, pulp and paper, construction materials, effluent treatment, water softening, pH control and soil stabilization). Lime production emits CO<sub>2</sub> during the thermal decomposition (calcination) of CaCO<sub>3</sub> in limestone to produce CaO; and also the decomposition of dolomite (CaCO<sub>3</sub>·MgCO<sub>3</sub>) to produce dolomitic 'quick' lime (CaO·MgO). The production of hydraulic lime (CaO + calcium silicates) is an intermediate substance. Hydrated (slaked) lime is also produced, using additional hydration operations.

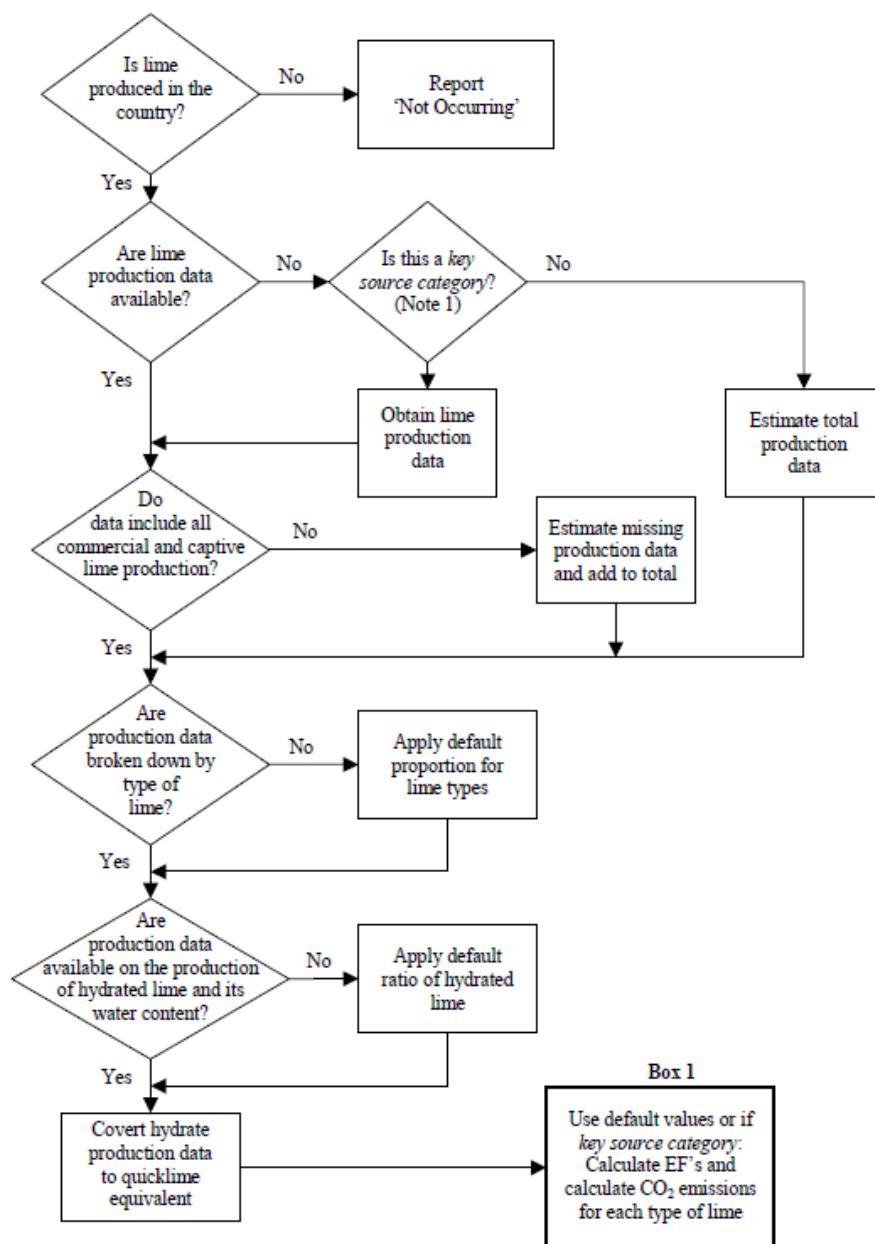
### 4.3.1. DECISION TREE FOR LIME PRODUCTION

The decision tree for CO<sub>2</sub> emissions from lime production is provided in the GPG 2000.

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<sup>1</sup> For more details, see GPG 2000, p. 3.10.

Figure 2  
Decision tree for lime production



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 3.21.

### 4.3.2. TIER 1 METHOD

The Revised 1996 IPCC Guidelines provide the following equation (equation 5) for estimating carbon dioxide emissions from lime production.

Equation 5  
**Lime production**

$$\text{CO}_2 \text{ Emissions} = \text{Emission Factor (EF)} \bullet \text{Lime Production}$$

Where:

EF = 785 kg CO<sub>2</sub> per tonne of high calcium quicklime, and  
913 kg CO<sub>2</sub> per tonne of dolomitic quicklime

*Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 3.20.*

### 4.3.3. HIGHER TIER METHODS

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000.

## 4.4. LIMESTONE AND DOLOMITE USE

Limestone (CaCO<sub>3</sub>) and dolomite (CaCO<sub>3</sub> • MgCO<sub>3</sub>) are basic raw materials having commercial applications in a number of industries including metallurgy (e.g. iron and steel), glass manufacture, agriculture, construction and environmental pollution control. In industrial applications involving the heating of limestone or dolomite at high temperatures, CO<sub>2</sub> is generated.

### 4.4.1. DECISION TREE FOR LIMESTONE AND DOLOMITE USE

No decision tree is provided in the GPG 2000 for this category.

## 4.4.2. TIER 1 METHOD

Equation 6

### Total carbon dioxide emissions from limestone and dolomite

The total CO<sub>2</sub> emission from limestone and dolomite use in Gg/yr calculated as:

$$\begin{aligned} \text{Total}_{ld} &= \{(A_{ls} \times EF_{ls}) + (A_d \times EF_d)\} / 10^6 \\ &= \{(440 \times f \times A_{ls}) + (477 \times f \times A_d)\} / 10^6 \end{aligned}$$

where:

Total<sub>ld</sub> is the process emission of CO<sub>2</sub> from limestone and dolomite use (Gg/yr)

A<sub>ls</sub> is the consumption of limestone (tonnes/yr). Consumption is assumed to equal material mined (or dredged) plus material imported minus material exported. The consumption entering this calculation excludes limestone used for producing cement and lime, agriculture and processes where CO<sub>2</sub> is not generated.

A<sub>d</sub> is the consumption of dolomite (tonnes/yr). Consumption is assumed to equal material mined plus material imported minus material exported. The consumption entering this calculation excludes limestone used for producing lime and magnesium, and processes where CO<sub>2</sub> is not generated.

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, p. 2.10.

## 4.4.3. HIGHER TIER METHODS

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000.

## 4.5. SODA ASH PRODUCTION AND USE

Soda ash (sodium carbonate, Na<sub>2</sub>CO<sub>3</sub>) is a white crystalline solid that is used as a raw material in a large number of industries including glass manufacture, soap and detergents, pulp and paper production and water treatment. Carbon dioxide is emitted from the use of soda ash, and may be emitted during production, depending on the industrial process used to manufacture soda ash.

### 4.5.1. DECISION TREE FOR SODA ASH PRODUCTION AND USE

No decision tree is provided in the GPG 2000 for this category.

## 4.5.2. TIER 1 METHOD

Equation 7

**General equation for greenhouse gas emissions**

$$\text{TOTAL}_{ij} = A_j \times \text{EF}_{ij}$$

where:

- TOTAL<sub>ij</sub> = process emission (tonnes) of gas i from industrial sector j
- A<sub>j</sub> = amount of activity or production of process material in industrial sector j (tonnes/yr)
- EF<sub>ij</sub> = emission factor associated with gas i per unit of activity in industrial sector j (tonne/tonne)

*Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.4.*

Where the emission factor for soda ash production is 0.097 t CO<sub>2</sub>/tonne of trona, and the emission factor for soda ash use is 415 kg CO<sub>2</sub>/tonne Na<sub>2</sub>CO<sub>3</sub>.

## 4.5.3. HIGHER TIER METHODS

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000.

## 4.6. AMMONIA PRODUCTION

Synthetic anhydrous ammonia is generally produced by catalytic steam reforming of natural gas or other fossil fuels. The primary release of CO<sub>2</sub> at the NH<sub>3</sub> plants, using the natural gas catalytic steam reforming process, occurs during regeneration of the CO<sub>2</sub> scrubbing solution, with relatively minor emissions resulting from condensate stripping. Part of the flux of CO<sub>2</sub> in the stripping gas may be used in production of urea from NH<sub>3</sub> or dry ice. Although less common, NH<sub>3</sub> is also produced using naphtha (a petroleum fraction) instead of CH<sub>4</sub> as a feedstock and through the electrolysis of brine at chlorine plants. Like the natural gas-based processes, the naphtha-based process produces CO<sub>2</sub> emissions; however, the brine electrolysis process does not lead to CO<sub>2</sub> emissions.

### 4.6.1. DECISION TREE FOR AMMONIA PRODUCTION

No decision tree is provided in the GPG 2000 for this category.

### 4.6.2. TIER 1 METHOD

Emissions of CO<sub>2</sub> will depend on the amount and composition of gas (or oil) used in the process. It is assumed that all carbon will be emitted to the air. It is recommended that inventory contributions are compiled using point source methods due to the

rather limited number of plants. Where greatest accuracy is desired, this will require direct contact with producers. Alternatively, total sector emissions may be determined on an area source basis using available emission factors and methods noted below.

Equation 8

**Carbon dioxide emissions from ammonia production**

The most accurate method of estimation will be:

$$\text{Emission (kt)} = \text{Consumption of gas (kt)} \times \text{carbon content} \times 44/12$$

If the gas consumption is not available, an alternative is to calculate the emissions from the ammonia production:

$$\text{Emission (kt)} = \text{Production of ammonia} \times \text{Emission factor}$$

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.16.

### 4.6.3. TIER 2 METHODS

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000.

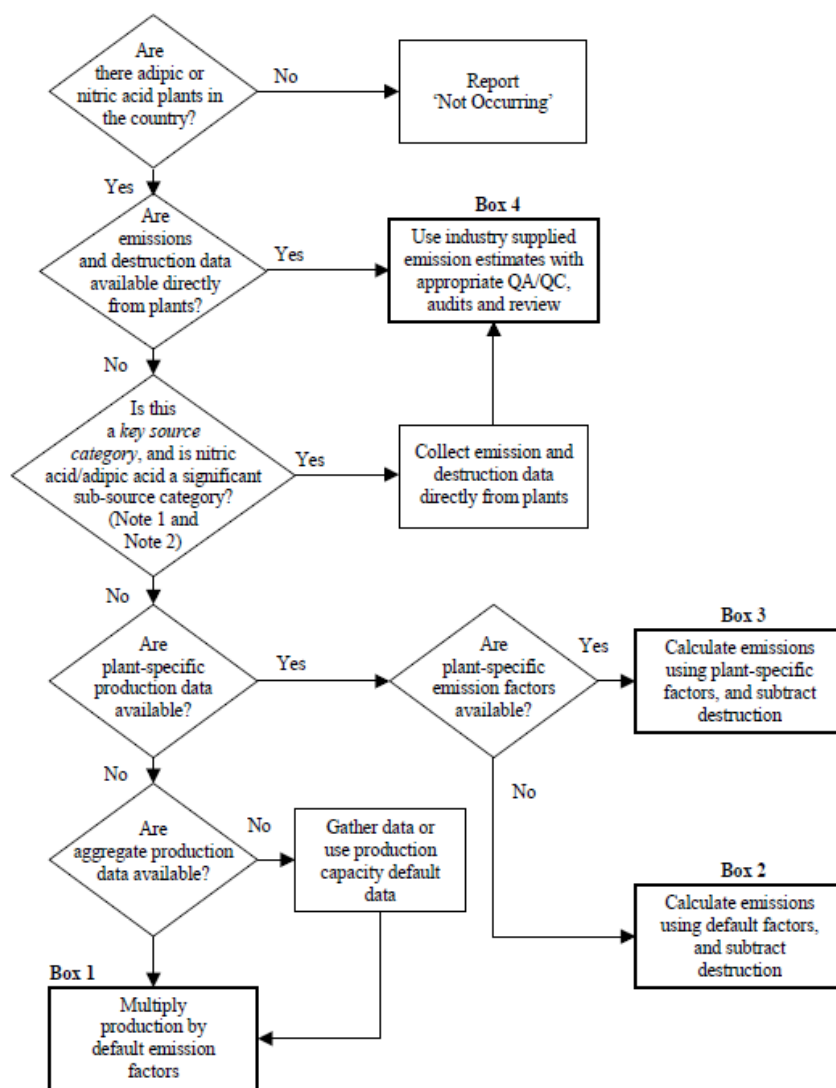
## 4.7. NITRIC ACID PRODUCTION AND ADIPIC ACID PRODUCTION

Nitric acid ( $\text{HNO}_3$ ) is used as a raw material mainly in the manufacture of synthetic nitrogen-based fertilizers. Nitric acid may also be used in the production of adipic acid and explosives (e.g. dynamite), for metal etching and in the processing of ferrous metals. The production of nitric acid generates  $\text{N}_2\text{O}$  as a by-product of the high temperature catalytic oxidation of  $\text{NH}_3$ .  $\text{NO}$ , an intermediate in the production of nitric acid, is also documented to readily decompose to  $\text{N}_2\text{O}$  and nitrogen dioxide  $\text{NO}_2$  at high pressures and temperatures of 30–50°C. Most nitric acid is produced through the catalytic oxidation of  $\text{NH}_3$ . Emissions of  $\text{N}_2\text{O}$  depend on the amount generated in the production process and the amount destroyed in any subsequent abatement process. Abatement of  $\text{N}_2\text{O}$  can be intentional, through installation of equipment designed to destroy  $\text{N}_2\text{O}$ , or unintentional in systems designed to abate other emissions, such as  $\text{NO}_x$ .

Adipic acid ( $\text{HOOC}(\text{CH}_2)_4\text{COOH}$ ) is used in the manufacture of a large number of products including synthetic fibres, coatings, plastics, urethane foams, elastomers and synthetic lubricants. The production of Nylon 6.6 accounts for the bulk of adipic acid use. Adipic acid is a dicarboxylic acid manufactured by a two-stage process. The first stage of manufacturing involves the oxidation of cyclohexane or cyclohexanone to form a cyclohexanone/cyclohexanol mixture. The mixture is then oxidized by nitric acid in the presence of a catalyst to form adipic acid.  $\text{N}_2\text{O}$  is generated as a by-product of the nitric acid oxidation stage.

### 4.7.1. DECISION TREE FOR NITRIC ACID AND ADIPIC ACID PRODUCTION

Figure 3  
Decision tree for N<sub>2</sub>O emissions from adipic acid and nitric acid production



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Note 2:** As a rule of thumb, a sub-source category would be significant if it accounts for 25-30% of emissions from the source category.

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.32.

### 4.7.2. TIER 1 METHOD

When no measured data exists, specific emission factors at the upper end of the appropriate range should be chosen.

Equation 9

**Nitrous oxide emissions from nitric acid**

$$\text{N}_2\text{O-emissions} = \text{Production level} \times \text{Specific Emission Factor}$$

*Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, p. 2.18.*

However, given the current and potential future use of N<sub>2</sub>O abatement technologies, particularly in adipic acid plants, the GPG 2000 included an additional term in the equation.

Equation 10

**Nitrous oxide emissions from adipic acid**

$$\text{N}_2\text{O Emissions} = \text{Specific Emission Factor} \bullet \text{Production Level} \bullet [1 - (\text{N}_2\text{O Destruction Factor} \bullet \text{Abatement System Utilisation Factor})]$$

*Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 3.31.*

### 4.7.3. HIGHER TIER METHOD

Higher tier methodologies are not described in the Revised 1996 IPCC Guidelines or GPG 2000.

## 4.8. IRON AND STEEL PRODUCTION

Steel is made from pig iron by the oxidation of the carbon in the iron in either basic oxygen furnaces or open heart furnaces. It is also common to produce steel by recycling scrap in an electric arc furnace (EAF). Pig iron (crude iron) is produced by the reduction of iron oxide ores, mostly in blast furnaces, using fossil carbon in coke or charcoal (sometimes supplemented with coal or oil) as both fuel and reductant. In most iron furnaces, the process is aided by the use of carbonate fluxes (limestone). Carbon plays the dual role of fuel and reducing agent. Except for a small amount of carbon retained in the crude iron, all the carbon in the coke and in the fluxes is emitted as the product of combustion and calcination. Emissions also occur to a much lesser extent during the production of steel by the process of oxidation of most of the carbon in the crude iron. The crude steel or pig iron contains about 3–5 per cent carbon by weight, which undergoes partial oxidation in the subsequent processes.

An integrated iron and steel plant typically operates a coke oven producing coke. Coke oven gas and coal tar are typical by-products of the coke manufacturing process. Coke oven gas is generally burned as a fuel in integrated primary iron and

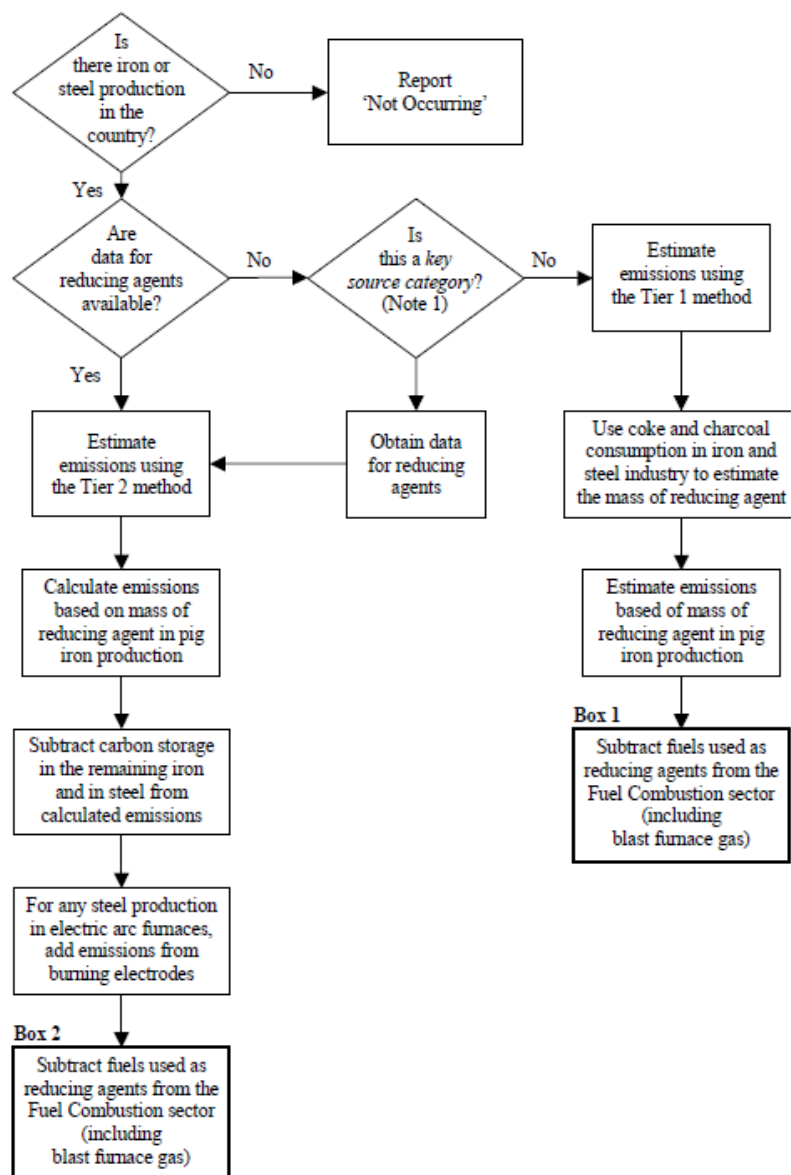


steel plants. Coal tar may be used as a raw material in the manufacture of anodes used for primary aluminium production or for other electrolytic processes.

When an EAF is used to produce steel, CO<sub>2</sub> emissions result from the consumption of carbon electrodes in the EAF. In most iron furnaces, the process also requires the use of carbonate fluxes (limestone); but these emissions are usually covered under the lime production and use category.

### 4.8.1. DECISION TREE FOR THE IRON AND STEEL INDUSTRY

Figure 4  
Decision tree for the iron and steel industry



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Note 2:** CO<sub>2</sub> emissions from limestone used as 'flux' in the reduction process are not included here since they are accounted for in the *IPCC Guidelines*, Vol. 3, section 2.5, on CO<sub>2</sub> emissions from limestone and dolomite use.

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.27.

## 4.8.2. TIER 1 METHOD

The Tier 1 method calculates emissions from the consumption of the reducing agent (e.g. coke from coal, coal, petroleum coke), using emission factors similar to those used to estimate combustion emissions. The Tier 1 method is rather simple and slightly overestimates emissions.

Equation 11

**Carbon dioxide emissions from iron and steel**

$$\text{Emissions} = \text{Mass of Reducing Agent} \bullet \text{Emission Factor}_{\text{reducing agent}}$$

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.26.

## 4.8.3. HIGHER TIER METHODS

Tier 2 method, emissions from iron production and steel production are calculated separately and data should be collected at the plant level.<sup>2</sup>

## 4.9. ALUMINIUM PRODUCTION

### 4.9.1. DECISION TREE FOR ALUMINIUM PRODUCTION

The production of primary aluminium results in process-related emissions of several GHGs, including CO<sub>2</sub> and two PFCs, namely perfluoromethane (CF<sub>4</sub>) and perfluoroethane (C<sub>2</sub>F<sub>6</sub>). Primary aluminium is produced in two steps. The manufacturing value chain processes involve calcination of bauxite to produce alumina (aluminium oxide, Al<sub>2</sub>O<sub>3</sub>) and electrolytic reduction of alumina to aluminium. The reduction of the alumina is an electrolysis process. The electrolyte is a molten bath of natural or synthetic cryolite (Na<sub>3</sub>AlF<sub>6</sub>). The reduction cells have carbon cathode blocks and anode carbon. The type of anode carbon depends on the technology. The two major forms are the prebaked carbon anodes and the Soderberg cell technologies.

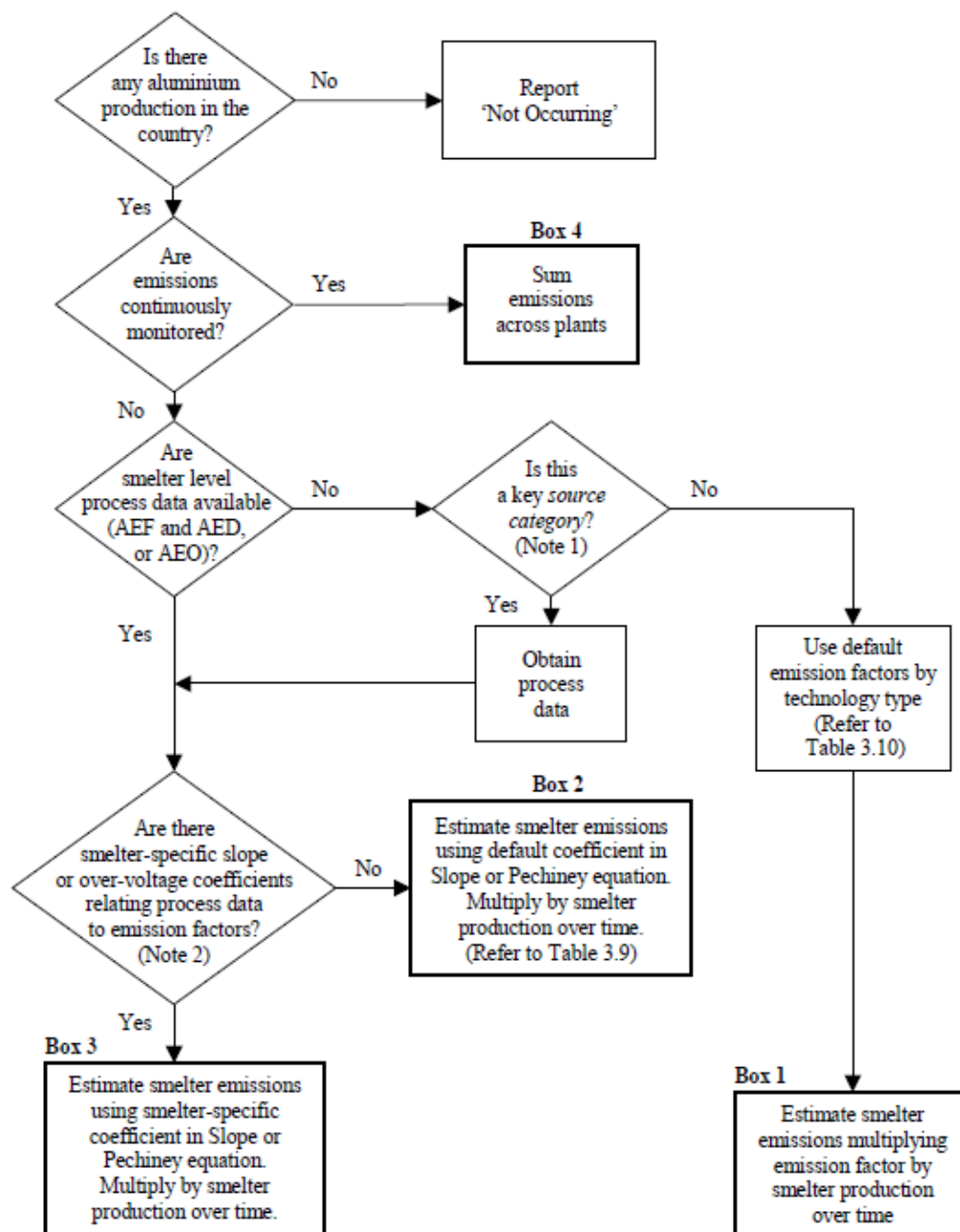
Carbon dioxide is emitted during the electrolysis. The carbon anode reacts with alumina (and other sources of oxygen such as air). These CO<sub>2</sub> emissions are accounted for as industrial processes emissions. During primary aluminium smelting, alumina is dissolved in a fluoride melt consisting primarily of cryolite. PFCs are formed as a result of phenomena known as the anode effect. This occurs when the alumina concentration in the electrolytic bath falls below critical levels. There is sudden increase in electrical resistance resulting in overvoltage. The anode effect causes carbon from the anode and fluorine from the dissociated molten cryolite bath to combine, thereby producing emissions of CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub>. In general, the magnitude of emissions for a given level of production depends on the frequency and duration of the anode effects and the over-voltage attained. The more frequent and long-lasting

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<sup>2</sup> For more information, see GPG 2000, p. 3.25.

the anode effects, or the larger the average over-voltage recorded, the greater the PFCs emissions.

Figure 5  
Decision tree for perfluorocarbons emissions from aluminium production



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

**Note 2:** In cases where a smelter has more than one distinct cell technology, a smelter must measure/use specific emission coefficients for each technology.

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.40.

## 4.9.2. TIER 1 METHOD

### **Carbon dioxide emissions**

Equation 12

**General equation for greenhouse gas emissions**

$$\text{TOTAL}_{ij} = A_j \times \text{EF}_{ij}$$

where:

$\text{TOTAL}_{ij}$  = process emission (tonnes) of gas *i* from industrial sector *j*

$A_j$  = amount of activity or production of process material in industrial sector *j* (tonnes/yr)

$\text{EF}_{ij}$  = emission factor associated with gas *i* per unit of activity in industrial sector *j* (tonne/tonne)

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.4.

Where the emission factor is 1.8 t CO<sub>2</sub>/tonne product for the Soderberg process and 1.5 tonnes CO<sub>2</sub>/tonne product.

### **Perfluorocarbons emissions**

Equation 13

**Perfluorocarbons emissions from aluminium production**

$$\text{CF}_4 \text{ emission (kg)} = \text{EF}_{(\text{tech})} \text{ (kg CF}_4\text{/tonne Al)} \times \text{pp}_{(\text{tech})} \text{ (tonnes)}$$

where:

$\text{EF}_{(\text{tech})}$  = emission factor by technology (from Table 2-20)

$\text{PP}_{(\text{tech})}$  = primary aluminium production by technology

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.37.

The default emission factor by technology type is set out in table 2 below.

Table 2  
**Estimated global carbon tetrafluoride emissions from smelters with various cell technologies**

| ESTIMATED GLOBAL CF <sub>4</sub> EMISSIONS FROM SMELTERS WITH VARIOUS CELL TECHNOLOGIES |                              |                              |
|---|------------------------------|------------------------------|
| Type of Cell Technology   | Per Cent of World Production | kg CF <sub>4</sub> /tonne Al |
| Modern Prebaked   | 20                           | 0.05                         |
| HS Søderberg  | 11                           | 1.0                          |
| "Older" Prebaked  | 40                           | 1.75                         |
| VS Søderberg  | 29                           | 2.0                          |
| Weighted average for all plants world-wide  | 100                          | 1.40                         |
| Source: Tabereaux, 1995.  |                              |                              |

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.36.

#### 4.9.3. HIGHER TIER METHODS

The most accurate method is either to monitor smelter emissions continuously (tier 3a), or to develop a smelter-specific long-term relationship between measured emissions and operating parameters and to apply this relationship using activity data (tier 3b). Where a smelter-specific relationship has not been developed, but information on operating parameters and production is available, default technology-specific slope and overvoltage coefficients may be used (tier 2).<sup>3</sup>

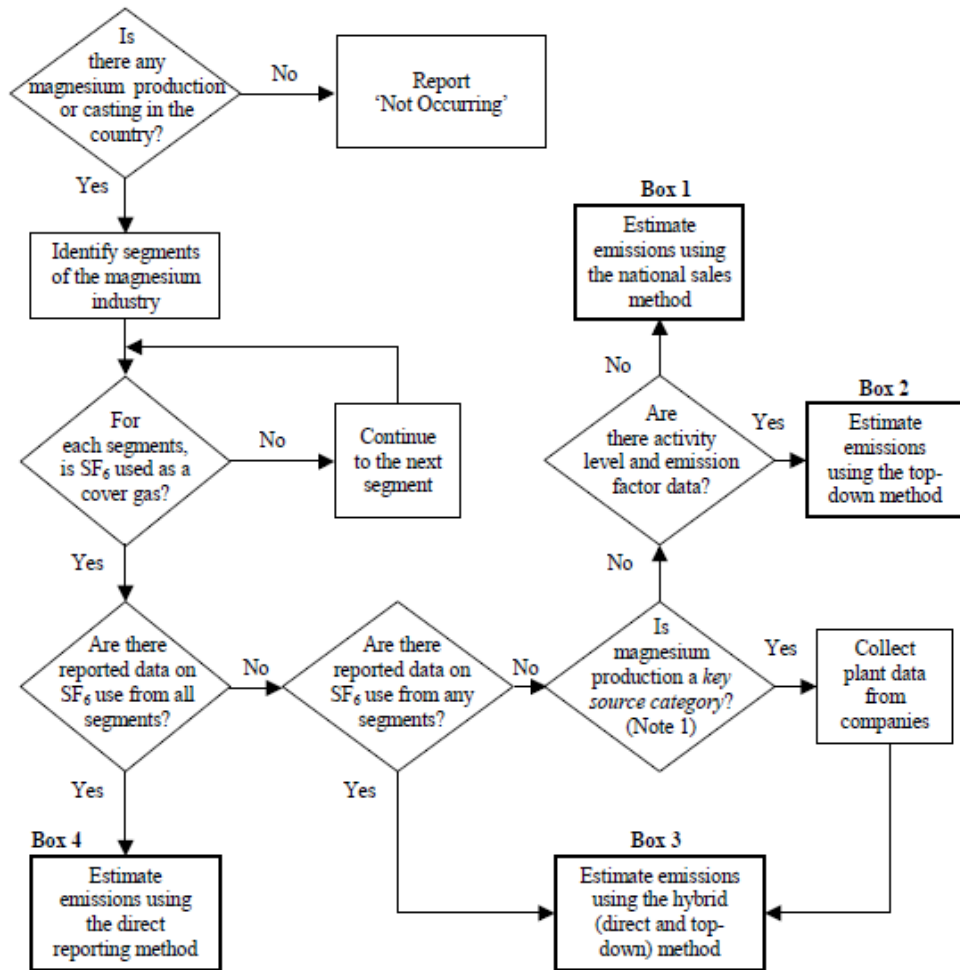
### 4.10. SUPHUR HEXAFLUORIDE EMISSIONS FROM MAGNESIUM PRODUCTION

In the magnesium industry, SF<sub>6</sub> is used as a cover gas in foundries to prevent oxidation of molten magnesium. It is assumed that all SF<sub>6</sub> used as cover gas is emitted to the atmosphere. Consumption figures are therefore used as emission estimates.

<sup>3</sup> For more information, see GPG 2000, p. 3.39.

### 4.10.1. DECISION TREE FOR SULPHUR HEXAFLUORIDE EMISSIONS FROM MAGNESIUM PRODUCTION

Figure 6  
Decision tree for sulphur hexafluoride emissions from magnesium production



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.49.

### 4.10.2. TIER 1 METHOD

Equation 14  
Sulphur hexafluoride emissions from magnesium production

|   |
|---|
| $\text{Emissions of SF}_6 = \text{Consumption of SF}_6 \text{ in Magnesium Smelters and Foundries}$ |
|---|

Source: *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual*, p. 2.39.

#### 4.10.3. HIGHER TIER METHODS

If direct data on SF<sub>6</sub> consumption from all individual users of the gas in the magnesium industry can be collected, a higher tier method can be applied using the tier 1 method as a basis.<sup>4</sup>

#### 4.11. EMISSIONS RELATED TO PRODUCTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE

Chemical by-products of industrial processes, substances which are different from the desired end-product, may be released into the atmosphere. HFC-23 is produced along with HCFC-22 and it is estimated that the HFC-23 released from this source is currently equivalent to 4 per cent of the production of HCFC-22 assuming no abatement measures.

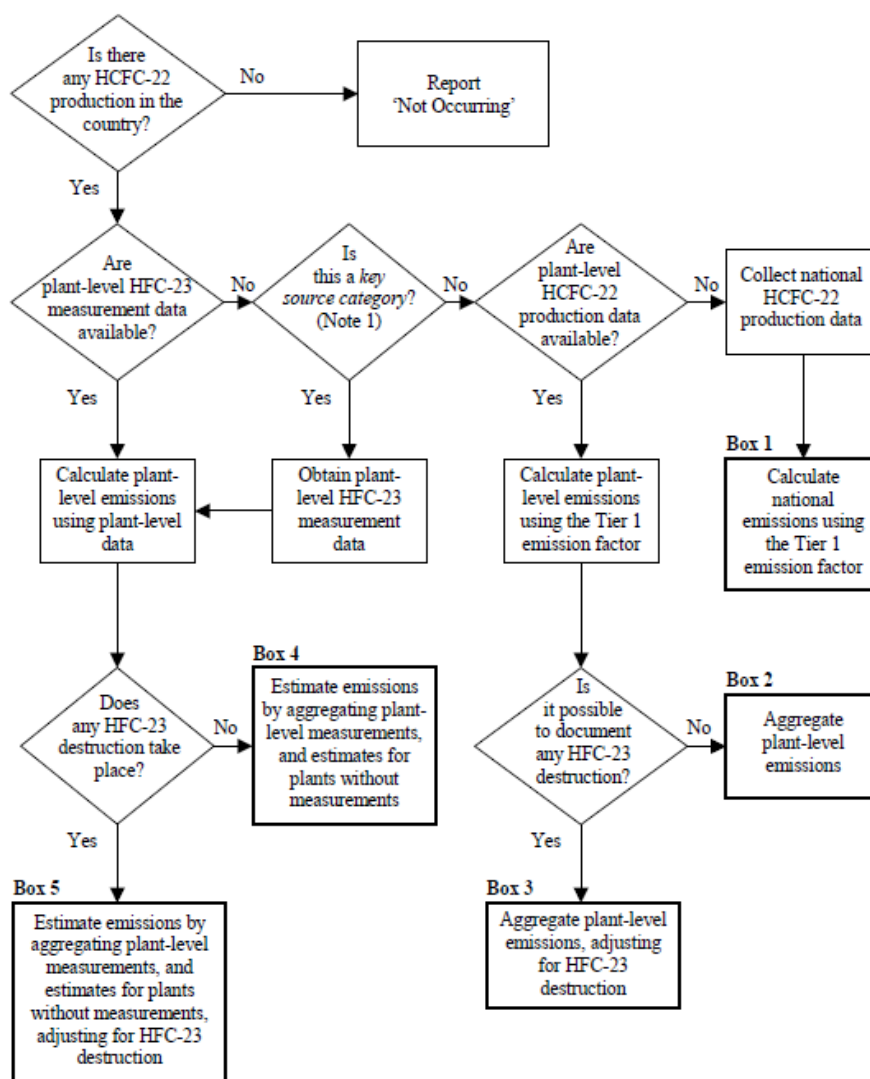
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<sup>4</sup> For more information, see GPG 2000, p. 3.48.



### 4.11.1. DECISION TREE FOR HFC-23 EMISSIONS FROM HCFC-22 PRODUCTION

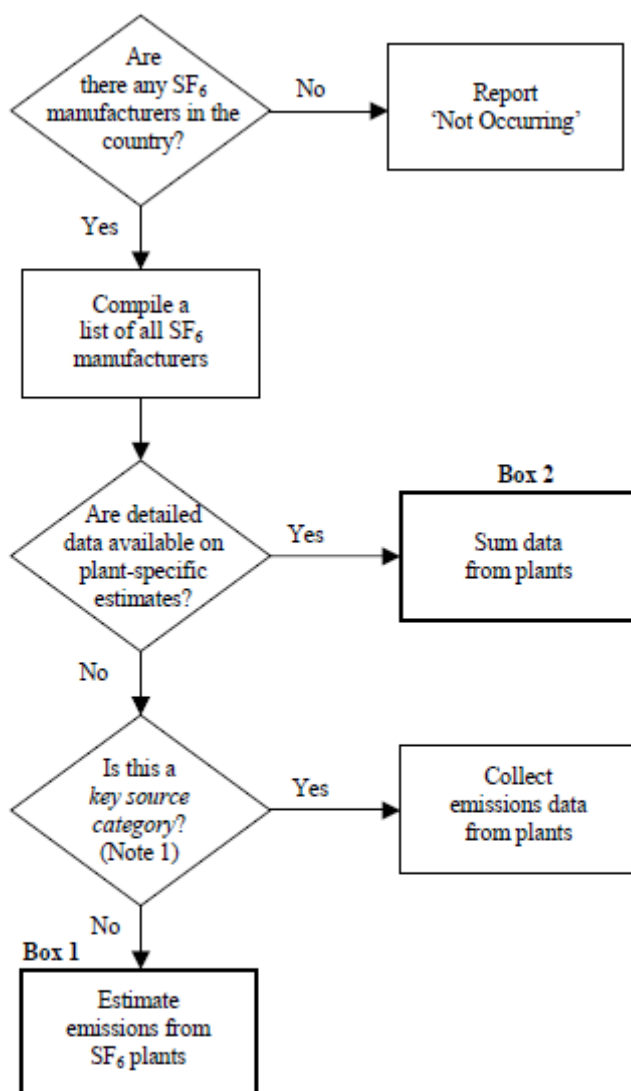
Figure 7  
Decision tree for HFC-23 emissions from HCFC-22 production



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.124.

Figure 8  
Decision tree for sulphur hexafluoride production



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.68.

#### 4.11.2. TIER 1 METHOD

Equation 15

**By-product emissions from production of hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride**

$$\text{By-product Emissions (tonnes)} = \text{By-product Factor (tonnes/tonne)} \\ \times \text{Total HCFC-22 Production (tonnes)}$$

*Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.42.*

The default emission factor is assumed to be 4 per cent for HCFC-22 production.

A default emission factor of 0.2 per cent of the total quantity of SF<sub>6</sub> produced is suggested for those countries in which the predominant end use does not require highly purified SF<sub>6</sub> gas (e.g. electrical equipment, insulated windows). In countries where the major uses require highly purified SF<sub>6</sub> gas (e.g. semiconductor manufacturing), the default value should be 8 per cent.

#### 4.11.3. HIGHER TIER METHODS

The tier 2 method is based on measurement of the concentration and flow-rate from the condenser vent at individual plants. The product of HFC-23 concentration multiplied by the volumetric flow-rate gives the mass rate of HFC-23 emissions.<sup>5</sup>

Reporting the sum of all plant level measurements is considered higher tier for SF<sub>6</sub> production.

### 4.12. EMISSIONS RELATED TO CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE

#### 4.12.1. OVERVIEW

Partially fluorinated hydrocarbons, PFCs and SF<sub>6</sub> are used as alternatives to ozone depleting substances (ODS) being phased out under the Montreal Protocol. Ozone depleting substances including chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl chloroform, and HCFCs are used in a variety of industrial applications including refrigeration and air-conditioning equipment, solvent cleaning, foam production, sterilization, fire extinguishing and aerosols.

The emissions from this category occur as leaks from different types of equipment and also releases due to the destruction or decommissioning of such equipment after use. As CFCs, halons, carbon tetrachloride, methyl chloroform, and, ultimately,

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<sup>5</sup> For more information, see GPG 2000, p. 3.123.

HCFCs are being phased out, HFCs are selectively used as replacements. HFCs use is expected to continue to grow at least in the short term.

#### 4.12.2. REFRIGERATION AND AIR CONDITIONING

Refrigeration and air-conditioning systems may be classified in up to six sub-application domains or categories,<sup>6</sup> although less sub-applications are typically used at a single country level. These categories are: (i) domestic (i.e. household) refrigeration; (ii) commercial refrigeration, including different types of equipment, from vending machines to decentralized refrigeration systems in supermarkets; (iii) industrial processes including chillers, cold storage and industrial heat pumps used in the food, petrochemical and other industries; (iv) transport refrigeration, including equipment and systems used in refrigerated trucks, containers, reefers and wagons; (v) stationary air conditioning including air-to-air systems, heat pumps and chillers for building and residential applications; and (vi) mobile air-conditioning systems used in passenger cars, truck cabins, buses and trains.

For all these sub-applications, different HFCs are progressively replacing CFCs and HCFCs. For example, in developed and several developing countries, HFC-134a has replaced CFC-12 in domestic refrigeration, high-pressure chillers and mobile air-conditioning systems, and blends of HFCs such as R-407C (HFC-32/HFC-125/HFC-134a) and R-410A (HFC-32/HFC-125) are replacing HCFC-22 mainly in stationary air conditioning. HFC blends R-404A (HFC-125/HFC-143a/HFC-134a) and R-507A (HFC-125/HFC-143a) have replaced R-502 (CFC-22/CFC-115) and HCFC-22 in commercial refrigeration. Other, non-HFC substances are also used to replace CFCs and HCFCs such as isobutane (HC-600a) in domestic refrigeration or ammonia in industrial refrigeration. A large number of blends containing HFCs and/or PFCs are being used in refrigeration and air conditioning applications.

#### 4.12.3. FOAM BLOWING AGENTS

HFCs are being used increasingly as replacements for CFCs and HCFCs in foams, and particularly in insulation applications. Compounds that are being used include HFC-245fa, HFC-365mfc, HFC-227ea, HFC-134a and HFC-152a.<sup>7</sup> For open-cell foam, emissions of HFCs used as blowing agents are likely to occur during the manufacturing process and shortly thereafter. Open-celled foams are used for applications such as household furniture cushioning, mattresses, automotive seating and for moulded products, such as car steering wheels and office furniture. Closed-cell foams, on the other hand, are primarily used for insulating applications where the gaseous thermal conductivity of the chosen blowing agent (lower than air) is used to contribute to the insulating performance of the product throughout its lifetime.

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<sup>6</sup> UNEP-RTOC, 2003.

<sup>7</sup> See GPG 2000, table 3.20, page 3.98.

#### 4.12.4. FIRE PROTECTION

There are two general types of fire protection (fire suppression) equipment that use HFCs and/or PFCs as partial replacements for halons: portable (streaming) equipment, and fixed (flooding) equipment. HFCs, PFCs and more recently a fluoroketone are mainly used as substitutes for halons, typically halon 1301, in flooding equipment. While actual emissions from the fire protection sub-sector are expected to be quite small, the use is normally non-emissive in provision of stand-by fire protection and is growing. This results in an accumulating bank of future potential emissions.

#### 4.12.5. AEROSOL AS PROPELLANTS AND SOLVENTS

Most aerosol packages contain hydrocarbons as propellants; but in a small fraction of the total. HFCs and PFCs may be used as propellants or solvents. Emissions from aerosols usually occur shortly after production, on average six months after sale. However, the period between manufacture and sale could vary significantly depending on the sub-application involved. The five main sub-applications are: (i) metered dose inhalers; (ii) personal care products (e.g. hair care, deodorant, shaving cream); (iii) household products (e.g. air-fresheners, oven and fabric cleaners); (iv) industrial products (e.g. special cleaning sprays such as those for operating electrical contact, lubricants, pipe-freezers); and (v) other general products (e.g. silly string, tire inflators, klaxons). The HFCs currently used as propellants are HFC-134a, HFC-227ea and HFC-152a. The substances HFC-245fa, HFC-365mfc, HFC-43-10mee and a PFC, perfluorohexane, are used as solvents in industrial aerosol products. Of these, HFC-43-10mee is the most widely used. HFC-365mfc is also expected to be used within aerosols in the near future.

#### 4.12.6. SOLVENT APPLICATIONS

HFCs are now used in solvent applications to replace CFC-113. PFCs are only very rarely used. HFC and PFC solvent uses occur in four main areas: (i) precision cleaning; (ii) electronics cleaning; (iii) metal cleaning; and (iv) deposition applications. HFCs are typically used in the form of an azeotrope or other blend for solvent cleaning. The most commonly used HFC solvent is HFC-43-10mee, with some use of HFC-365mfc and HFC-245fa (as an aerosol solvent).

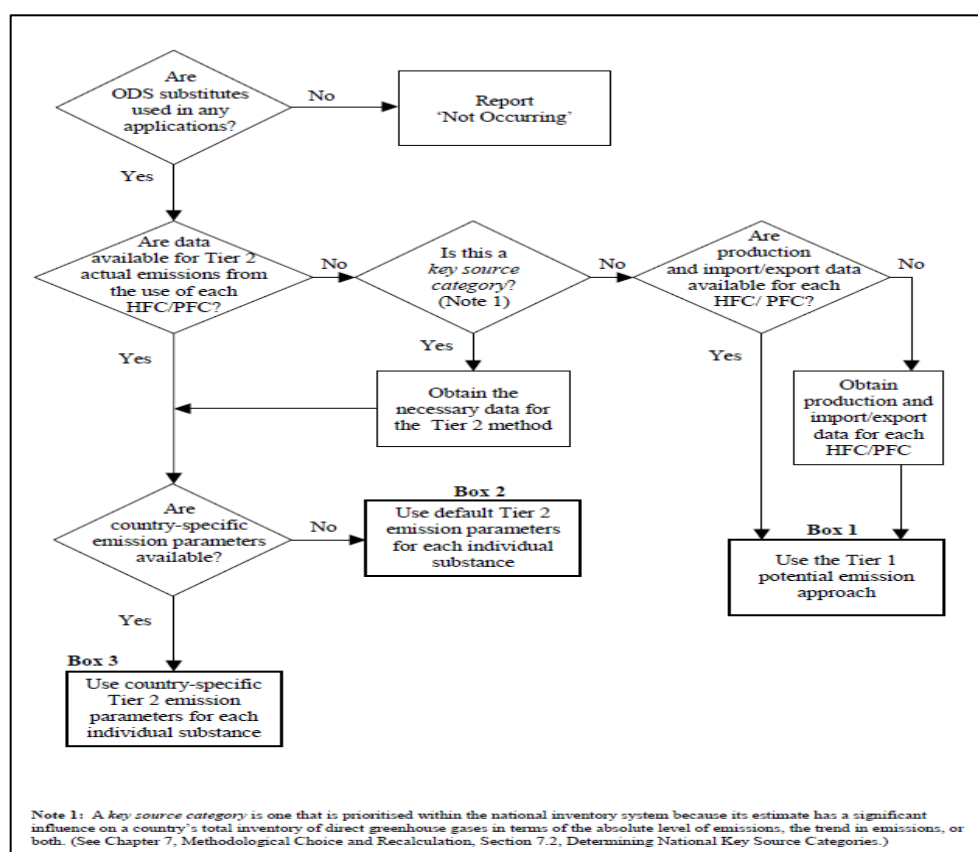
#### 4.12.7. OTHER APPLICATIONS

HFCs and PFCs represent a large range of gases whose properties make them attractive for a variety of niche applications. These include electronics testing, heat transfer, dielectric fluid, medical applications and potentially many new applications not yet developed. ODS phase-out (both CFCs and HCFCs) is moving towards completion in developed countries; the number of new applications emerging is expected to be very limited. However, in theory at least, new applications could emerge right up until the final global phase-out of ODS in 2040.

#### 4.12.8. GENERAL METHODOLOGY FOR ALL OZONE DEPLETING SUBSTANCES SUBSTITUTES CATEGORIES

The generalized decision tree for consumption of HFCs and PFCs as substitutes for ODS is presented in figure 9.

Figure 9  
Generalized decision tree for all substitutes for ozone depleting substances



Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.80.

#### 4.12.9. TIER 1 METHOD

The GPG 2000 tier 1 method estimates potential emissions assuming that they occur during the year in which the chemical is produced or sold into a particular end-use application, while tier 2 estimates actual emissions. For potential emissions, where adopted, the method requires information for the mass balance approach using domestic production, imports, exports and stock change. The tier 1 method requires less data; but it may produce very inaccurate estimates over the short term because, for many long-lived sources, such as refrigerators, chemicals are emitted over a period of several years. The greater the length of time over which the chemical is released, the greater the possible inaccuracy of the 'potential' method. If, as is the case in most countries, equipment sales are increasing each year, the total amount of chemical stored in end-use equipment must also be increasing. Therefore, the potential method is likely to overestimate emissions.

Equation 16

**Potential emissions of fluorinated gases**

$$\text{Potential Emissions} = \text{Production} + \text{Imports} - \text{Exports} - \text{Destruction}$$

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.47.

There are two versions of tier 1 (a and b) depending upon whether HFCs and PFCs in products are taken into account. In tier 1a, chemicals contained in products are not considered. In tier 1b, chemicals contained in products are considered. The reason for two versions is that it is expected that there may be difficulties in many countries with the availability of data regarding imports and exports of HFCs and PFCs in products, at least in the short term. The tier 1b methodology is preferred if relevant data are available.

### **Tier 1a**

The quantities of HFCs and PFCs contained in various products imported into or exported from a country may be difficult to estimate. In tier 1a, only chemicals imported or exported in bulk are considered in the calculation of potential emissions, which is similar to the approach presently used to report ODS under the Montreal Protocol. Equation 15 sets out the definitions of imports and exports.

Equation 17

**Imports and exports of hydrofluorocarbons and perfluorocarbons**

$$\begin{aligned} \text{Imports} &= \text{Imported HFC/PFC in bulk} \\ \text{Exports} &= \text{Exported HFC/PFC in bulk} \end{aligned}$$

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.47.

### **Tier 1b**

Tier 1b is an extension of tier 1a and includes HFCs and PFCs contained in various products which are imported and exported.

Equation 18

**Imports and exports of hydrofluorocarbons and perfluorocarbons including those contained in products**

$$\begin{aligned} \text{Imports} &= \text{Imported chemical in bulk} + \text{quantity of chemical imported in} \\ &\quad \text{HFC/PFC containing products} \\ \text{Exports} &= \text{Exported chemical in bulk} + \text{quantity of chemical exported in} \\ &\quad \text{HFC/PFC containing products} \end{aligned}$$

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 2.48.

#### 4.12.10. HIGHER TIER METHODS

Tier 2 contains actual emission calculations for each individual chemical. This is the preferred method if input data are available. Some countries may already have the relevant information available to apply the tier 2 methodology. However, countries that do not are recommended to establish routines to report HFC and PFC emissions according to tier 2.

The tier 2 methodology:

- a) estimates the consumption of each individual HFC and PFC chemical at a rather detailed level, e.g. refrigerators, other stationary refrigeration and air-conditioning equipment, soft foam, hard foam etc., to establish the volume basis for emission calculations;
- b) estimates emissions on the basis of the consumption distribution from (a), and emission characteristics related to various processes and equipment, also taking current service and recovery practices into account.<sup>8</sup>

#### 4.13. SEMICONDUCTOR MANUFACTURE

The semiconductor industry currently emits fluorocarbons ( $\text{CF}_4$ ,  $\text{C}_2\text{F}_6$ ,  $\text{C}_3\text{F}_8$ ,  $\text{c-C}_4\text{F}_8$ ,  $\text{CHF}_3$ ), nitrogen trifluoride ( $\text{NF}_3$ ) and  $\text{SF}_6$  from its manufacturing process. These gases, collectively referred to as fluorinated compounds, are used in two important steps of semiconductor manufacturing: (i) plasma etching thin films and (ii) cleaning chemical vapour deposition (CVD) tool chambers. In addition, a fraction of the fluorocarbons used in the production process are converted into  $\text{CF}_4$ .

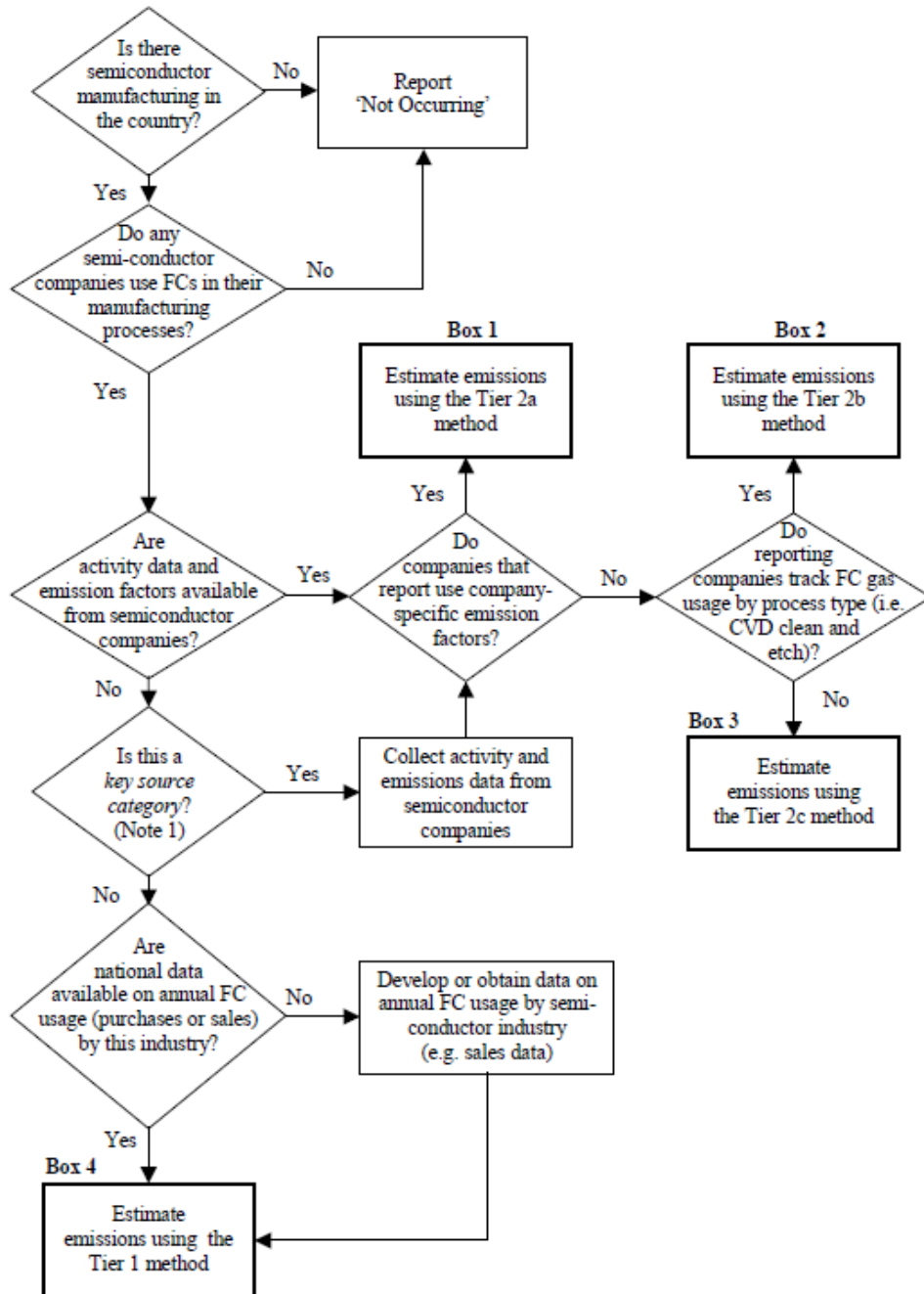
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<sup>8</sup> For more information, see Revised 1996 IPCC Guidelines, Reference Manual, p. 2.51 and GPG 2000, p. 3.81.



### 4.13.1. DECISION TREE FOR FLUORINATED COMPOUND EMISSIONS FROM SEMICONDUCTOR MANUFACTURING

Figure 10  
Decision tree for fluorinated compound emissions from semiconductor manufacturing



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.70.

#### 4.13.2. TIER 1 METHOD

Emissions are equal to the sum of emissions from the gas  $FC_i$  used in the production process plus the by-product emissions of  $CF_4$  resulting from use of the gas  $FC_i$ , as shown in equations 17 and 18.

Equation 19

**$FC_i$  emissions from semiconductor manufacturing**

$$\text{Emissions of } FC_i = (1 - h) \cdot [FC_i \cdot (1 - C_i)]$$

Where:

$FC_i$  = Sales/purchases of gas  $i$  in kg ( $CF_4$ ,  $C_2F_6$ ,  $C_3F_8$ ,  $c-C_4F_8$ ,  $CHF_3$ ,  $NF_3$ ,  $SF_6$ )

$h$  = Fraction of gas remaining in shipping container (heel) after use

$C_i$  = Use rate of gas (fraction destroyed or transformed in process)

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.72.

Equation 20

**Carbon tetrafluoride emissions from semiconductor manufacturing**

$$\text{Emissions of } CF_4 \text{ for } FC_i = (1 - h) \cdot (B_i \cdot FC_i)$$

Where:

$B_i$  = kg  $CF_4$  created per kg of gas  $i$

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.73.

#### 4.13.3. HIGHER TIER METHOD

Higher tier methods can be applied only when country-specific information on the emissions is known.<sup>9</sup>

### 4.14. EMISSIONS OF SULPHUR HEXAFLUORIDE FROM ELECTRICAL EQUIPMENT AND OTHER SOURCES

Sulphur hexafluoride is used for electrical insulation, arc quenching, and current interruption in equipment used in the transmission and distribution of electricity. Most of the  $SF_6$  used in electrical equipment is used in gas insulated switchgear and circuit breakers, though some  $SF_6$  is used in high-voltage gas-insulated transmission lines

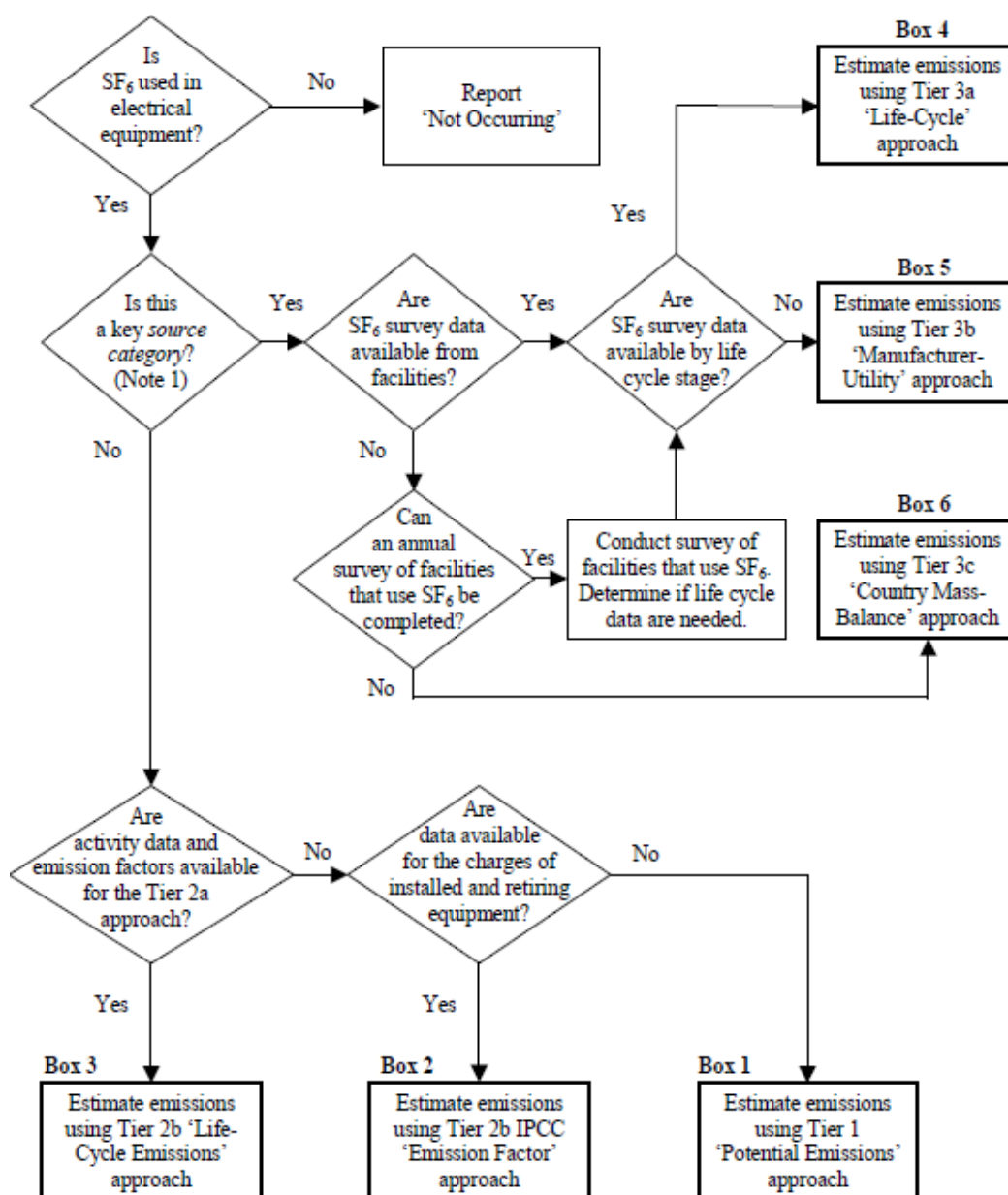
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<sup>9</sup> For more information, see GPG 2000, p. 3.69.

and other equipment. SF<sub>6</sub> emissions from electrical equipment are the largest global source category of SF<sub>6</sub> emissions.

#### 4.14.1. DECISION TREE FOR SULPHUR HEXAFLUORIDE FROM ELECTRICAL EQUIPMENT

Figure 11  
Decision tree for sulphur hexafluoride from electrical equipment



**Note 1:** A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.54.

#### 4.14.2. TIER 1 METHOD

The simplest estimation method in the Revised 1996 IPCC Guidelines estimates potential emissions of SF<sub>6</sub> from all uses by equating emissions to total consumption of SF<sub>6</sub>.

Equation 21

**Potential sulphur hexafluoride emissions from electrical equipment**

$$\text{Potential SF}_6 \text{ Emission} = \text{Production} + (\text{Imports} - \text{Exports}) - \text{Destruction}$$

Source: *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, p. 3.57.

#### 4.14.3. HIGHER TIER METHOD

Higher tier methods can be applied only when country-specific information on the emissions is known.<sup>10</sup>

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<sup>10</sup> For more information, see GPG 2000, p. 3.55.

## 5. SECTOR SPECIFIC ISSUES (ALLOCATION ISSUES)

The Revised 1996 IPCC Guidelines acknowledge that the separation of non-energy use of feedstock and energy uses, and the identification of any fuel by-products from processes, have been identified as a particularly difficult area of energy emissions accounting statistics. A careful examination of energy and industry processes emissions should compare the basic fuel use data and the energy balance of the Party (where available) for appropriate industrial processes sector allocations. There is always the tendency to allocate all the energy and non-energy emissions to the energy sector. While the practice does not affect the national total emissions, it under-reports the industrial processes contribution, and therefore makes the sector appear to have a relatively lower share of emissions.

The energy and non-energy emissions allocation is rather difficult when Parties do not have an energy balance. Hence, a close cooperation is particularly important for the iron and steel industry, where coke (or coal) consumption is considered to be industrial. This is because the primary purpose of coke (or coal) oxidization is to produce pig iron, and not to produce process heat.

Coke oven, or blast furnace gas, may also be used for energy purposes. There is the potential for double counting here – carbon in these gases is coming basically from the coke – and therefore particular attention should be paid to the estimation reported by the Party. If this is a key category, it is important that the national inventory report includes a tracking of carbon through the production process (carbon balance), identifying the origins of carbon (coke, coal, limestone, fuels), storage in intermediate and final products (carbon in iron and steel), and the intermediate products containing carbon and used as fuels (e.g. coke oven gas and blast furnace gas).