



MODULE 2
INDUSTRIAL PROCESSES



2. INDUSTRIAL PROCESSES

2.1 Introduction

Greenhouse gas emissions are produced from a variety of industrial activities which are not related to energy. The main emission sources are industrial production processes which chemically or physically transform materials. During these processes, many different greenhouse gases, including CO₂, CH₄, N₂O, and PFCs, can be released.

In some instances, industrial process emissions are produced in combination with fuel combustion emissions and it may be difficult to decide whether a particular emission should be reported within the energy or industrial emission sector. The criterion used to make this decision is discussed in the Section 2.1 of the Reference Manual.

All emissions, including evaporative emissions, which occur in energy transformation activities are discussed in the Energy Chapter. Emissions from petrochemical processes are, however, covered in this chapter. Emissions of NMVOC from use of solvents are discussed in the chapter “Solvents and other product use” even if they originate from an industrial process.

CO₂ from the use of biological carbon as feedstock and fermentation processes should not be reported under “Industrial Processes”, or any other sector of the IPCC Guidelines if they originate from sources of carbon that are from a closed cycle.

Non-combustion industrial processes resulting in N₂O emissions are recognised as important anthropogenic contributors to global N₂O emissions. It is estimated that this source category represents 10 to 50 per cent of anthropogenic N₂O emissions and 3 to 20 per cent of all global emissions of N₂O (IPCC, 1992).

HFCs, PFCs and SF₆ are also emitted from industrial processes, such as production of aluminium, magnesium and halocarbons (e.g., HCFC-22). In some countries PFC emissions from industrial processes could be an important contributor to national GHG emissions due to their high GWPs.

Current and expected applications of these compounds include refrigeration and air-conditioning, fire extinguishing, aerosols, solvents, and foam production. Consumption of HFCs, and to some extent PFCs and SF₆, is expected to grow substantially in the next decades due to their importance as substitutes for ozone-depleting substances.

It is essential for a full understanding of the methodologies presented in this workbook that inventory compilers read the related sections in Chapter 2 of the Reference Manual.

DOUBLE COUNTING

In situations where a country has difficulty in distinguishing whether an emission is energy, or industrial based, to avoid double counting of emissions, developers of emission inventories should take care not to include the same data in both categories.

2.2 General Methodology

The general methodology employed to estimate emissions associated with each industrial process involves the product of activity level data, e.g., amount of material produced or consumed, and an associated emission factor per unit of consumption/production according to:

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

where:

- TOTAL_{ij} = the process emission (tonnes) of gas i from industrial sector j
- A_j = the amount of activity or production of process material in industrial sector j (tonnes/yr)
- EF_{ij} = the emission factor associated with gas i per unit of activity in industrial sector j (tonne/tonne)

A number of mathematical steps may be involved in reducing more complex mathematical formulae to the simplified form of the equation above. In cases where mathematical transformations are involved, justifications are presented in the reference manual.

For certain industrial processes, more than one estimation methodology is presented here. The simplified approach is referred to as *Tier 1*, and the more detailed methodology as *Tier 2*. Recognising that data availability is often the main factor in estimating GHG emissions, several options are provided for certain industrial processes under *Tier 1*, as *Tier 1a*, *1b*, *1c*. More detailed discussion is given later.

Data Sources

Often process emissions from certain industrial sectors are caused by emissions from a few plants in each country for which measurement data exist or may be collected. In these cases, emission estimates should be based on such data instead of the more generalised methodology. Even if measurements are not available, it is preferable to base calculation on plant-specific data.

Many of the production data needed for emission estimation methods given in this workbook are available from the United Nations (1988) and from the US Bureau of Mines (1988) data sets. There is substantial overlap between US Bureau of Mines and the UN data sets, but the former is more complete. In some countries, national data may be available from appropriate government ministries. In Canada, for example, a national data base is maintained by Statistics Canada. Similar sources of standard production statistics may be available from national statistical publications.



2.3 Cement Production

Introduction

Carbon dioxide is produced during the production of clinker, an intermediate product from which cement is made. High temperatures in cement kilns chemically change raw materials into cement clinker. In a process called *calcination* or *calcining*, calcium carbonate is heated, forming lime and carbon dioxide.

SO₂ emissions will originate from sulphur in the fuel and in the clay raw material. The fuel emissions are counted as energy emissions while the SO₂ from the clay should be counted as non-combustion emissions.

Data Sources

International cement production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). A trade association, European Cement Associations (CEMBUREAU) also publishes information (see CEMBUREAU, 1990, World Cement Market in Figures and World Statistical Review). The Standard Nomenclature for Air Pollution (SNAP) numbers for cement are 30311 and 40612 (EMEP/CORINAIR, 1996).

2.3.1 Methodology for Estimating Emissions of CO₂

Because CO₂ is emitted during clinker production (rather than cement production itself), emission estimates should be based on the lime content and production of clinker. Clinker statistics, however, may not be readily available in some countries. If this is the case, cement production statistics can be used.

Estimation of CO₂ emissions from clinker production is accomplished by applying an emission factor, in tonnes of CO₂ released per tonne of clinker produced, to the annual clinker output.

2.3.2 Methodology for Estimating Emissions of SO₂

Estimation of SO₂ emissions from cement production is accomplished by applying an emission factor, in terms of SO₂ released per tonne of cement produced, to the annual cement output. A non-combustion emission factor of 0.3 kg SO₂/tonne cement has been calculated (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources).

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Use WORKSHEET 2-1 CEMENT PRODUCTION to enter data for this submodule.

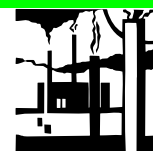
STEP 1 ESTIMATING CO₂ EMITTED

- 1 Enter the Quantity of Clinker Produced in column A in tonnes. If it is not available, estimate Quantity of Cement Produced.
- 2 For clinker production enter the Emission Factor of 0.5071 tonnes of CO₂ per tonne of clinker produced in column B. If the fraction (f) of lime in the clinker is known to be different from 0.646 then the emission factor can be converted as follows:
$$\text{Emission Factor (t CO}_2\text{/t clinker)} = 0.5701 \times (f) / 0.646$$

For cement production enter the Emission Factor of 0.4985 tonnes of CO₂ per tonne of cement produced in column B. If the fraction (f) of lime in the cement is known to be different from 0.635 then the emission factor can be converted as follows:
$$\text{Emission Factor (t CO}_2\text{/t cement)} = 0.4985 \times (f) / 0.635$$
- 3 Multiply column A by column B to obtain CO₂ Emitted in tonnes of CO₂, and enter this value in column C.
- 4 Divide column C by 10³ to convert to units of gigagrams CO₂, and enter this value in column D.

STEP 2 ESTIMATING SO₂ EMITTED

- 1 Estimate Quantity of Cement Produced and enter this value in column A in tonnes.
- 2 Enter the Emission Factor in kg SO₂/tonne cement in column B. If no information on sulphur content and degree of absorption is available, enter a default of 0.3 kg SO₂/tonne cement.
- 3 Multiply column A by column B to obtain SO₂ Emitted in kg of SO₂, and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams SO₂, and enter this value in column D.



2.4 Lime Production

Introduction

The production of lime involves a series of steps comparable to those used in the production of Portland cement clinker. These include quarrying the raw materials, crushing and sizing, calcining (i.e., high temperature heat processing $\sim 1100^{\circ}\text{C}$) the raw materials to produce lime, hydrating the lime to calcium hydroxide followed by miscellaneous transfer, storage and handling operations.

Data Sources

International lime production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). The Standard Nomenclature for Air Pollution (SNAP) numbers for limestone and dolomite production are 30312 and 40613 (EMEP/CORINAIR, 1996).

2.4.1 Methodology for Estimating Emissions of CO_2

Estimation of CO_2 emissions from lime production is accomplished by applying an emission factor, in tonnes of CO_2 released per tonne of lime produced, to the annual lime output. The emission factors are tabulated in Table 2-1.

Process	Component	Emission Factor
Lime Kiln-Calcite Feed	CO_2	0.79 tonnes CO_2 /tonne quicklime produced
Lime Kiln-Dolomite Feed	CO_2	0.91 tonnes CO_2 /tonne dolomitic lime produced

Completing the Worksheet

Use WORKSHEET 2-2 LIME PRODUCTION to enter data for this submodule.

ESTIMATING CO_2 EMITTED

- 1 Estimate Quantity of Lime Produced by Lime Type and enter this value in column A in tonnes.
- 2 Enter the corresponding Emission Factor from Table 2-1 in column B in tonnes of CO_2 per tonne of quicklime or dolomitic lime produced.

DATA SOURCES

Note that SNAP codes and emission factors are correct at the time of publication of this *Workbook*. Readers should refer to the most recent edition of the UNECE/CORINAIR Guidebook for updated SNAP codes and emission factors.

EMISSION FACTORS

Emission factors assume pure lime, but in some cases the purity may range from 85 to 95 per cent). In these cases, the equations should be adjusted to account for the lime purity.

- 3 Multiply column A by column B to obtain CO₂ Emitted in tonnes of CO₂, and enter this value in column C.
- 4 Divide column C by 10³ to convert to units of gigagrams CO₂, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of the column to obtain the total CO₂ Emitted.

2.5 Limestone and Dolomite Use

Introduction

In industrial applications involving the heating of limestone or dolomite at high temperatures, CO₂ is generated.

Data Sources

International Limestone and Dolomite production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). Limestone and dolomite use is not included in the Standard Nomenclature for Air Pollution (SNAP) (EMEP/CORINAIR, 1996).

2.5.1 Methodology for Estimating Emissions of CO₂

Estimation of CO₂ emissions from limestone use is accomplished by applying an emission factor, in kilograms of CO₂ released per tonne of limestone, to the annual limestone use.

Consumption of limestone or dolomite in tonnes per year is assumed to equal material mined (or dredged) plus material imported minus material exported. Limestone or dolomite used for producing cement, lime and magnesium, agricultural activities and processes where CO₂ is not generated should be excluded from this calculation.

Completing the Worksheet

Use WORKSHEET 2-3 LIMESTONE AND DOLOMITE USE to enter data for this submodule.

ESTIMATING CO₂ EMITTED

- 1 Estimate Quantity of Limestone or Dolomite Used and enter these values in column A in tonnes.
- 2 For the calculation of CO₂ emissions from limestone use, enter the Emission Factor of 440 kg of CO₂ per tonne of limestone used in column B. If the fractional purity (f) of limestone in CaCO₃ per tonne of total raw material is known, the emission factor can be converted as follows:

LIMESTONE USE

CO₂ from liming of agricultural soils should be reported in the Land-use Change and Forestry Chapter. Limestone and dolomite used in cement and lime production should be reported under that industry sector. This section covers all other uses of limestone and dolomite which produce CO₂ emissions.



$$\text{Emission Factor (kg CO}_2\text{/t limestone)} = 440 \times (f)$$

For the calculation of CO₂ emissions from dolomite use, enter the emission factor of 477 kg of CO₂ per tonne of dolomite used in column B. If the fractional purity (f) of dolomite in CaCO₃·MgCO₃ per tonne of total raw material is known, the emission factor can be converted as follows:

$$\text{Emission Factor (kg CO}_2\text{/t dolomite)} = 477 \times (f)$$

- 3 Multiply column A by column B to obtain CO₂ Emitted in kilograms of CO₂, and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams CO₂, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total CO₂ emitted.

2.6 Soda Ash Production and Use

Introduction

Carbon dioxide is emitted from the use of soda ash, and may be emitted during production, depending on the industrial process used to manufacture it.

Emissions of CO₂ from the production of soda ash vary substantially with the manufacturing process. Four different processes may be used commercially to produce soda ash. Three of these processes, monohydrate, sesquicarbonate and direct carbonation, are referred to as natural processes. The fourth, the Solvay process, is classified as a synthetic process.

During the production process, trona (the principal ore from which natural soda ash is made) is calcined in a rotary kiln and chemically transformed into a crude soda ash. Carbon dioxide and water are generated as by-products of this process.

Data Sources

International soda ash production and use data are available from the United Nations (1988) and from the US Bureau of Mines (1988). Soda ash production and use is not included in the Standard Nomenclature for Air Pollution (SNAP) (EMEP/CORINAIR, 1996).

DOUBLE COUNTING

In order to avoid double counting, CO₂ emissions associated with the use of coke in soda ash production should be accounted for separately and those emissions associated with the non-energy use of coke subtracted from the totals in the combustion section.

Completing the Worksheet

Use WORKSHEET 2-4 SODA ASH PRODUCTION AND USE to enter data for this submodule. There is no methodology available to estimate CO₂ emission from the Solvay Process.

STEP 1 ESTIMATING CO₂ EMITTED FROM SODA ASH PRODUCTION [NATURAL PROCESS]

- 1 Estimate Quantity of Trona Utilised and enter this value in column A in tonnes.
- 2 Enter the Emission Factor of 0.097 tonnes of CO₂ per tonne of trona in column B.
- 3 Multiply column A by column B to obtain CO₂ Emitted in tonnes of CO₂, and enter this value in column C.
- 4 Divide column C by 10³ to convert to units of gigagrams CO₂, and enter this value in column D.

STEP 2 ESTIMATING CO₂ EMITTED FROM SODA ASH USE

- 1 Estimate Quantity of Soda Ash Used and enter this value in column A in tonnes.
- 2 Enter the Emission Factor of 415 kilograms of CO₂ per tonne of soda ash used in column B.
- 3 Multiply column A by column B to obtain CO₂ Emitted in kilograms of CO₂, and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams CO₂, and enter this value in column D.

2.7 Production and Use of Miscellaneous Mineral Products

Introduction

Greenhouse gas emissions and ozone and aerosol precursor emissions resulting from asphalt roofing production, road paving with asphalt, the manufacture of other mineral products such as concrete pumice stone, and glass manufacture are addressed in this section.



Data Sources

International production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). The Standard Nomenclature for Air Pollution (SNAP) code for; asphalt roofing is 40610 (asphalt blowing is 60310); road paving is 40611; and flat and container glass are 33014 and 33015 respectively (EMEP/CORINAIR, 1996).

2.7.1 Asphalt Roofing Production

2.7.1.1 Methodology For Estimating Emissions of NMVOC and CO

Emissions from asphalt roofing production can be estimated from the national total mass of products. The emission factors in Table 2-2, given in the EMEP/CORINAIR Guidebook (SNAP 40610) are default factors.

	Emission Factor (Saturation with Spray)	Emission Factor (Saturation without Spray)
NMVOC	0.13 - 0.16	0.046 - 0.049
CO	NAV	0.0095
NAV = Not Available		
^a There are no data available for the emission of CO from a process in which the saturation includes a spray section. It was assumed that the emission would be the same as from a process with a dip saturator only.		

Asphalt blowing is the process of polymerising and stabilising asphalt to improve its weathering characteristics. This activity leads to emissions of NMVOC. The emission factors in Table 2-3, given in the EMEP/CORINAIR Guidebook, are default factors. It may be assumed that all of the asphalt used for non-paving use will be blown.

	Emission Factor (with Afterburners)	Emission Factor (No Control)
NMVOC	0.1	2.4

2.7.2 Road Paving with Asphalt

Introduction

Asphalt road surfaces are composed of compacted aggregate and asphalt binder. NMVOC is emitted from the asphalt plant during manufacture, the road surfacing operations and the subsequent road surface.

2.7.2.1 Methodology for Estimating Emissions of NMVOC

CONVERSION FACTOR

If the tonnes of asphalt paved is not known but rather the area paved, a conversion factor of 100 kg asphalt/m² road surface may be used.

The emissions of NMVOC depend on the type of asphalt (slow, medium or rapid cure) and the amount of diluent. A default emission factor of 320 kg of NMVOC per tonne of road surface is suggested (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources). The amount of diluent used is usually lower in warm countries than in colder ones, and hence lower emission factors may be expected in warm countries.

2.7.3 Production of Other Mineral Products

Introduction

There may be several other mineral production processes emitting pollutants. These are probably not significant sources on a global scale, but may be significant on a national or local scale. There is generally limited information on emissions available from these processes.

2.7.3.1 Methodology for Estimating Emissions from Other Mineral Products (NMVOC and SO₂)

Concrete Pumice Stone Production

The production of concrete pumice stone is similar to cement production in that SO₂ emissions will originate from the fuel use and the sulphur in clay. About 45 per cent of the SO₂ generated in the process will be sequestered in the product. An emission factor of approximately 0.5 kilograms SO₂/tonne product should be adopted where no plant specific information is available (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources).

Glass Production

NMVOC may be emitted from the production of glass. An emission factor of 4.5 kg per tonne of product has been derived (see the *Revised 1996 IPCC*



Guidelines for National Greenhouse Gas Inventories Reference Manual for sources).

Completing the Worksheet

Use WORKSHEET 2-5, PRODUCTION AND USE OF MISCELLANEOUS MINERAL PRODUCTS to enter data for this submodule.

STEP 1 ESTIMATING NMVOC EMITTED FROM ASPHALT ROOFING PRODUCTION

- 1 Estimate the Quantity of Asphalt Roofing Produced and enter this value in column A in tonnes.
- 2 For saturation processes, enter the corresponding Emission Factor from Table 2-2 in column B.

For asphalt blowing processes, enter the corresponding Emission Factor from Table 2-3 in column B
- 3 Multiply column A by column B to obtain NMVOC Emitted in kilograms of NMVOC, and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams NMVOC, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NMVOC Emitted.

STEP 2 ESTIMATING CO EMITTED FROM ASPHALT ROOFING PRODUCTION

- 1 Estimate the Quantity of Asphalt Roofing Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding Emission Factor from Table 2-2 in column B.
- 3 Multiply column A by column B to obtain CO Emitted in kilograms of CO, and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams CO, and enter this value in column D.

STEP 3 ESTIMATING NMVOC EMITTED FROM ROAD PAVING WITH ASPHALT

- 1 Estimate Quantity of Road Paving Material Used for each Emission Source in one year and enter this value in column A in tonnes.
- 2 Enter the Emission Factor of 320 kg NMVOC per tonne of asphalt paved in column B.
- 3 Multiply column A by column B to obtain NMVOC Emitted in kilograms of NMVOC, and enter this value in column C.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

- 4 Divide column C by 10^6 to convert to units of gigagrams of NMVOC Emitted, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NMVOC.

STEP 4 ESTIMATING NMVOC EMITTED FROM GLASS PRODUCTION

- 1 Estimate the Quantity of Glass Produced by Glass Type and enter this value in tonnes in column A.
- 2 Enter the corresponding Emission Factor for glass production (default 4.5 kg NMVOC per tonne of product) in column B in kilograms of NMVOC per tonne of product produced.
- 3 Multiply column A by column B to obtain NMVOC Emitted in kilograms of NMVOC and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams of NMVOC, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NMVOC Emitted.

STEP 5 ESTIMATING SO₂ EMITTED FROM CONCRETE STONE

- 1 Estimate the Quantity of Concrete Pumice Stone Produced and enter this value in tonnes in column A.
- 2 Enter the Emission Factor for concrete pumice stone production (default 0.5 kg SO₂ per tonne of product) in column B in kilograms of SO₂ per tonne of product produced.
- 3 Multiply column A by column B to obtain SO₂ Emitted in kilograms of SO₂ and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams SO₂ and enter this value in column D.

2.8 Ammonia Production

Introduction

In most instances, anhydrous ammonia is produced by catalytic steam reforming of natural gas (mostly CH₄) or other fossil fuels. Natural gas is used as the feedstock in most plants, while other fuels (e.g., heavy oils) may be used with the partial oxidation process. Hydrogen is chemically separated from the fuel and combined with nitrogen to produce ammonia (NH₃). The remaining carbon is eventually emitted as CO₂.

Emissions of NO_x, NMVOC, CO and SO₂ may also occur during ammonia production.



Data Sources

There will usually be only a few ammonia plants in a country, and it is recommended that emissions be estimated based on plant specific data and/or point source methods. International production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). The Standard Nomenclature for Air Pollution (SNAP) number for ammonia production is 40403 (EMEP/CORINAIR, 1996).

2.8.1 Methodology for Estimating Emissions of CO₂

Emissions of CO₂ 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 atmosphere.

The most accurate method of estimation will be based on the consumption of gas. The carbon content of natural gas may vary, and it is recommended that this be determined for each plant. For example, data from Canada (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources) provide the values 812 m³ gas/tonne NH₃ and 0.525 kg carbon/m³ gas.

If the gas consumption is not available, an alternative is to calculate the emissions from the ammonia production. The recommended emission factor is 1.5 tonnes CO₂ per tonne NH₃ produced which excludes gas used as a fuel (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources). Gas used as a fuel must be excluded if other data are going to be used for emission factors. This figure depends on the carbon content in the feedstock.

The CO₂ from ammonia production may also be used for producing urea or dry ice. This carbon will only be stored for a short time. Therefore, no account should consequently be taken for intermediate binding of CO₂ in downstream manufacturing processes and products.

DOUBLE COUNTING

In order to avoid double counting, the quantities of oil or gas used must be subtracted from the quantity reported under energy and non-energy use in the Energy Chapter.

2.8.2 Methodology for Estimating Emissions of NMVOC, CO and SO₂

Default emission factors for uncontrolled emissions from the plant are found in Table 2-4.

TOC ^a	CO	SO ₂
4.7	7.9	0.03
^a Total organic compounds.		

The production of ammonia may be a source of NO_x . However, due to the lack of data for estimating NO_x emissions, a method for estimating emissions is not recommended here.

Completing the Worksheet

Use WORKSHEET 2-6 AMMONIA PRODUCTION to enter data for this submodule. Two methods are presented for estimating CO_2 Emitted: Tier 1a - Estimation from Gas Consumption and Tier 1b - Estimation from Ammonia Production.

Tier 1a - Based on Gas Consumption

STEP 1 ESTIMATING CO_2 EMITTED

- 1 Obtain an estimate of the Amount of Gas Consumed in m^3 during the production of ammonia and enter this value in column A. If these data are not available proceed to Tier 1b: Estimation from Ammonia Production.
- 2 Enter the Carbon Content of Gas, in units of kg carbon per m^3 gas, in column B.
- 3 Multiply column A by column B and the Conversion Ratio in column C (the ratio of molecular weights between CO_2 and carbon), to obtain CO_2 Emitted in kg of CO_2 , and enter this value in column D.
- 4 Divide column D by 10^6 to convert to units of gigagrams CO_2 , and enter this value in column E.

Tier 1b - Based on Ammonia Production

STEP 2 ESTIMATING CO_2 EMITTED

- 1 Obtain an estimate of the Amount of Ammonia Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor in column B in tonnes CO_2 per tonne of ammonia produced. The default emission factor is $1.5 \text{ t CO}_2/\text{t NH}_3$ produced.
- 3 Multiply column A by column B to obtain CO_2 Emitted in tonnes of CO_2 , and enter this value in column C.
- 4 Divide column C by 10^3 to convert to units of gigagrams CO_2 , and enter this value in column D.



STEP 3 ESTIMATING NMVOC, CO AND SO₂ EMITTED

- 1 Obtain an estimate of the Amount of Ammonia Produced in tonnes, and enter this value in column A for each pollutant, NMVOC, CO and SO₂.
- 2 Enter the corresponding Emission Factor for each pollutant NMVOC, CO and SO₂ as given in Table 2-4, in column B in kg per tonne of ammonia produced.
- 3 Multiply column A by column B to obtain Pollutant Emitted in kg, and enter the corresponding value for each pollutant NMVOC, CO and SO₂ in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams for each pollutant NMVOC, CO and SO₂, and enter this value in column D.

2.9 Nitric Acid Production

Introduction

The production of nitric acid (HNO₃) generates nitrous oxide (N₂O) as a by-product of the high temperature catalytic oxidation of ammonia (NH₃).

Data Sources

There are usually only a few plants in each country producing nitric acid, so measured data on emissions are often available. These data also take into account the effect of any abatement technology installed at the specific plants. The Standard Nomenclature for Air Pollution (SNAP) number for nitric acid production is 40402 (EMEP/CORINAIR, 1996).

2.9.1 Methodology for Estimating Emissions of N₂O

Emissions should be calculated from production data of nitric acid within a country, and specific emission figures based on the actual technology. Table 2-5 gives examples of emissions factors from nitric acid production plants, based on measurements. Emission rates depend upon technology and operating conditions.

EMISSION FACTORS

When no measured data exist, the emissions are estimated by multiplying the emission factor by the production quantity. The specific emission factors at the upper end of the appropriate range should be chosen.

	Emission Factor kg N ₂ O/tonne nitric acid
USA	2-9 ^a
Norway: - modern, integrated plants	<2
- atmospheric pressure plants	4-5
- medium pressure plants	6-7.5
Japan	2.2-5.7

^a Emission factors up to 19 kg N₂O/tonne nitric acid have been reported for plants not equipped with non-selective catalytic reduction technology (NSCR) (see *NGGI Reference in the Revised 1996 IPCC Guidelines Manual* for sources).

2.9.2 Methodology for Estimating Emissions of NO_x

Nitric acid is produced from the catalytic oxidation of ammonia. In addition to the N₂O emissions described previously, there may be non-combustion emissions of NO_x.

Emissions are estimated from the amount of nitric acid produced. The emission factor is multiplied by the production of nitric acid. Table 2-6 provides estimates of emission factors for NO_x. A value of 12.0 kg NO_x/tonne nitric acid should be used where the process and technology details are not known.

Process	Emission Factor kg NO _x /t nitric acid
Strong Acid Production	0.1 - 1
Low Pressure Process	10 - 20

Completing the Worksheet

Use WORKSHEET 2-7 NITRIC ACID PRODUCTION to enter data for this submodule.

ESTIMATING N₂O AND NO_x EMITTED

- 1 Obtain an estimate of the Amount of Nitric Acid Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor for each pollutant in kg pollutant per tonne of nitric acid produced in column B. For the appropriate emission factor see Table 2-5 for N₂O and Table 2-6 for NO_x.



- 3 Multiply column A by column B to obtain Pollutant Emitted in kg and enter this value in column C for each pollutant.
- 4 Divide column C by 10^6 to convert to units of gigagrams for each pollutant, and enter this value in column D.

2.10 Adipic Acid Production

Introduction

Adipic acid is a dicarboxylic acid manufactured from a cyclohexanone/cyclohexanol mixture oxidised by nitric acid. N_2O is generated as a by-product of the oxidation stage.

Adipic acid production also results in emissions of NO_x , NMVOC and CO. Process emissions from the production of adipic acid vary substantially with the level of emission control employed.

Data Sources

International production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). The Standard Nomenclature for Air Pollution (SNAP) number for adipic acid production is 40521 (EMEP/CORINAIR, 1996).

2.10.1 Methodology for Estimating Emissions of N_2O

Adipic acid production produces N_2O at a rate (for unabated emissions) of 300g N_2O /kg adipic acid produced.

2.10.2 Methodology for Estimating Emissions of NO_x , NMVOC and CO

The EMEP/CORINAIR Guidebook indicates that there may be emissions of NO_x , NMVOC and CO in addition to N_2O , but does not propose emission factors at present. US EPA emission factors are given in Table 2-7 (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources).

TECHNOLOGY ABATEMENT

There is a range of abatement efficiencies attainable with currently available technologies. Any reduction in N_2O emissions due to the installation of abatement systems should be assessed on a plant-specific basis where possible.

NO_x	NMVOC	CO
8.1	43.3	34.4

Completing the Worksheet

Use WORKSHEET 2-8 ADIPIC ACID PRODUCTION to enter data for this submodule.

ESTIMATING N₂O, NO_x, NMVOC AND CO EMITTED

- 1 Obtain an estimate of the Amount of Adipic Acid Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor, in kg pollutant per tonne of adipic acid produced, in column B. For N₂O, a default value of 300 kg N₂O/t adipic acid produced can be used. For NO_x, NMVOC and CO, see Table 2-7 for default emission factors.
- 3 Multiply column A by column B to obtain Pollutant Emitted in kg and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams of pollutant, and enter this value in column D for each pollutant.

2.11 Carbide Production

Introduction

The production of carbide can result in emissions of CO₂, CH₄, CO and SO₂.

Data Sources

International production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). Carbide manufacturing is not included in the Standard Nomenclature for Air Pollution (SNAP) (EMEP/CORINAIR, 1996).

2.11.1 Methodology for Estimating Emissions of CO₂ and CH₄ from Silicon Carbide Production

CO₂ Emissions

In the production of silicon carbide, CO₂ is released as a by-product from a reaction between quartz and carbon. Petrol coke is used as a carbon source. A typical emission factor based on Norwegian plants, is 2.3 tonnes CO₂/tonne coke.



CH₄ Emissions

The petrol coke used in this process may contain volatile compounds which will form CH₄. Some of this CH₄ will escape to the atmosphere, particularly during start up. Measurements at Norwegian plants suggest emission factors of 10.2 kg CH₄/tonne petrol coke or 11.6 kg CH₄/tonne carbide product.

2.11.2 Methodology for Estimating Emissions of CO₂ from Calcium Carbide Production

Calcium carbide is made by heating calcium carbonate (CaCO₃) and subsequently reducing lime (CaO) with carbon (e.g., petrol coke). Both steps lead to emissions of CO₂.

The emission factors in Table 2-8 are suggested for estimating emissions.

Emissions may be calculated from the use of raw materials (limestone and coke). Limestone contains about 98 per cent CaCO₃. 1750 kg limestone (or 950 kg CaO) and 640 kg reducing agent (including 20 kg carbon electrodes) are required to produce 1 tonne of carbide.

Limestone	0.76	tonnes CO ₂ /tonne carbide
Reduction	1.090	tonnes CO ₂ /tonne carbide
Use of product	1.100	tonnes CO ₂ /tonne carbide

CALCIUM CARBIDE

Note that the CaO (lime) might not be produced at the carbide plant. In this case, the emissions from the CaO step should be reported as emissions from lime production (Section 2.4) and only the emissions from the reduction step and use of the product should be reported as emissions from calcium carbide manufacture.

Completing the Worksheet

Use WORKSHEET 2-9 CARBIDE PRODUCTION - to enter data for this submodule. If the quantity of coke consumed is not known, CO₂ emissions can be estimated from carbide production data. See method presented for calcium carbide production.

For CH₄ emissions from Silicon Carbide, two methods are presented:

- Tier 1a which is based on consumption of petrol coke; and,
- Tier 1b which is based on carbide production data for silicon.

Silicon Carbide

STEP 1 ESTIMATING CO₂ EMITTED FROM SILICON CARBIDE PRODUCTION

- 1 Obtain an estimate of the Consumption Of Coke in tonnes and enter this value in column A.
- 2 Enter the Carbon Content in Coke (in per cent) in column B. A default value of 97 per cent can be used.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

- 3 Enter the Carbon Input Sequestered in Product (in per cent) in column C. If no other data are available, a value of 35 per cent can be used.
- 4 Multiply column A by column B and by 100 minus column C, and the factor 3.67×10^{-4} to obtain CO₂ Emitted in tonnes, and enter this value in column D.
- 5 Divide column D by 10^3 to convert to units of gigagrams CO₂, and enter this value in column E.

Tier Ia - Based On Petrol Coke Consumption

STEP 2 ESTIMATING CH₄ EMITTED FROM SILICON CARBIDE PRODUCTION - TIER Ia

- 1 Obtain an estimate of the Amount of Petrol Coke Consumed in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor, in kg CH₄ per tonne of petrol coke consumed, in column B. The suggested emission factor is 10.2 kg CH₄/tonne petrol coke if no other information is available.
- 3 Multiply column A by column B to obtain CH₄ Emitted in kg and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams CH₄, and enter this value in column D.

Tier Ib - Based On Silicon Carbide Production

STEP 3 ESTIMATING CH₄ EMITTED FROM SILICON CARBIDE PRODUCTION - TIER Ib

- 1 Obtain an estimate of the Amount of Silicon Carbide Produced in tonnes and enter this value in column A.
- 2 Enter an Emission Factor, in kg CH₄ per tonne of carbide produced, in column B. An emission factor of 11.6 kg CH₄/tonne carbide product can be used if no other information is available.
- 3 Multiply column A by column B to obtain CH₄ Emitted in kg, and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams CH₄, and enter this value in column D.



Calcium Carbide

STEP 4 ESTIMATING CO₂ EMITTED FROM CALCIUM CARBIDE PRODUCTION

- 1 Obtain an estimate of the Amount of Carbide Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor, in tonnes CO₂ per tonne of chemical produced, in column B. For calcium carbide the emission factor must include all necessary components, such as heating of calcium carbonate, reduction of lime and/or use of product (see Table 2-8 for emission factors). Do not include emissions from lime production, if lime is produced at a different plant from the calcium carbide.
- 3 Multiply column A by column B to obtain CO₂ Emitted in tonnes and enter this value in column C.
- 4 Divide column C by 10³ to convert to units of gigagrams CO₂, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total CO₂ Emitted.

2.12 Production of Other Chemicals

Introduction

The production of other chemicals such as carbon black, styrene, polyvinylchloride, sulphuric acid, etc. can be sources of CH₄, N₂O, NO_x, NMVOC, CO and SO₂.

Data Sources

International production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). The Standard Nomenclature for Air Pollution (SNAP) (EMEP/CORINAIR, 1996) codes for the processes are given in the tables.

2.12.1 Methodology for Estimating Emissions of CH₄

Although most CH₄ sources from industrial processes individually are small, collectively they may be significant.

Few data on emission factors are presently available. These are presented in Table 2-9 (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources).

Carbon black	11
Ethylene	1
Dichloroethylene	0.4
Styrene	4
Methanol	2
Coke	0.5

Emissions are determined by multiplying an emission factor by the annual production.

2.12.2 Methodology for Estimating Emissions of N₂O

Production of chemicals other than nitric acid and adipic acid may be sources of N₂O, but more studies are needed to determine whether they represent significant sources.

2.12.3 Methodology for Estimating Emissions of NO_x, NMVOC, CO and SO₂

This section is concerned with emissions from small point sources. Total national emissions from these sources may be important and a simple methodology is suggested here.

A summary of default emission factors, as well as emission factor ranges where applicable, is provided in Table 2-10. Ranges given for NMVOC emissions from many processes are quite large. Emission factors are likely to be quite process specific.



SOURCE	SNAP	NO _x	NM VOC	CO	SO ₂
Acrylonitrile	40520	-	1 (0.4-100)	-	-
Acrylonitrile Butadiene Styrene (ABS) Resins	40515	-	27.2 (1.4-27.2)	-	-
Carbon black	40409	0.4	40 (5-90)	10 (5-14)	3.1
Ethylbenzene	40518	-	2 (0.1-2)	-	-
Ethylene and propylene	40501/40502	-	1.4	-	-
Formaldehyde	40517	-	5 (0-8)	-	-
Graphite	40411	-	NAV	-	-
Phtalic anhydride	40519	-	6.0 (1.3-6.0)	-	-
Polypropylene	40509	-	12 (0.35-12)	-	-
Polystyrene	40511	-	5.4 (0.2-5.4)	-	-
Polyethene - Low density	40506	-	3	-	-
Polyethene - Linear low density	-	-	2	-	-
Polyethene - High density	50507	-	6.4	-	-
Polyvinylchloride	40508	-	8.5 (0.14-8.5)	-	-
Styrene	40510	-	18 (0.25-18)	-	-
Styrene butadiene	40512-14	-	NAV	-	-
1,2, dichloroethane	40503	-	7.3 (0.2-7.3)	-	-
Sulphuric acid	40401	-	-	-	17.5 (1-25)
Titanium dioxide	40410	-	-	-	14.6 (0.9-14.6)
Urea	40408	NAV	NAV	NAV	NAV
Vinyl chloride ^a	40504				
1,2, dichloroethane	40505	-	2.2	-	-

Note: Ranges in brackets
See the Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories Reference Manual for sources.
^a Emission factors should be used for the monomer and polymer separately even if they are produced at the same plant unless otherwise specified.

Completing the Worksheet

Use WORKSHEET 2-10 PRODUCTION OF OTHER CHEMICALS to enter data for this submodule.

STEP 1 ESTIMATING CH₄ EMITTED

- 1 Obtain an estimate of the Amount of Chemical Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor from Table 2-9, in kg CH₄ per tonne of chemical produced, in column B.
- 3 Multiply column A by column B to obtain CH₄ Emitted in kg and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams CH₄, and enter this value in column D.

- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total CH₄ emitted.

STEP 2 ESTIMATING NO_x EMITTED

- 1 Obtain an estimate of the Amount of Chemical Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor from Table 2-10, in kg NO_x per tonne of chemical produced, in column B.
- 3 Multiply column A by column B to obtain NO_x Emitted in kg and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams NO_x, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NO_x emitted.

STEP 3 ESTIMATING NMVOC EMITTED

- 1 Obtain an estimate of the Amount of Chemical Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor from Table 2-10, in kg NMVOC per tonne of chemical produced, in column B.
- 3 Multiply column A by column B to obtain NMVOC Emitted in kg and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams NMVOC, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NMVOC emitted.

STEP 4 ESTIMATING CO EMITTED

- 1 Obtain an estimate of the Amount of Chemical Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor from Table 2-10, in kg CO per tonne of chemical produced, in column B.
- 3 Multiply column A by column B to obtain CO Emitted in kg and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams CO, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total CO emitted..



STEP 5 ESTIMATING SO₂ EMITTED

- 1 Obtain an estimate of the Amount of Chemical Produced in tonnes and enter this value in column A.
- 2 Enter the corresponding Emission Factor from Table 2-10, in kg SO₂ per tonne of chemical produced, in column B.
- 3 Multiply column A by column B to obtain SO₂ Emitted in kg and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams SO₂, and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total SO₂ emitted.

2.13 Metal Production

Introduction

The preferred methodology (Tier 1a) for the estimation of emissions of CO₂ from all types of metal production is given in Section 2.13.1. This method requires information on the quantity of reducing agent used. If this information is not available, methodologies (Tier 1b) for estimating emissions of CO₂ based on the metal production quantities are given in the following sections pertaining to particular metals.

Data Sources

International production data are available from the United Nations (1988) and from the US Bureau of Mines (1988). The Standard Nomenclature of Air Pollution (SNAP) number for reheating furnaces iron and steel is 30302; gray iron foundries is 30303; production processes - iron & steel industries & collieries is 40200; coke oven is 40201; blast furnace charging is 40202; pig iron tapping is 40203; solid smokeless fuel is 40204; open hearth furnace steel plant is 40205; basic oxygen furnace is 40206; electric furnace steel plant is 40207; rolling mills is 40208; ferroalloys is 40302; ferroalloy production is 40302; aluminium production is 40301; non-ferrous metal industry is 40300 (EMEP/CORINAIR, 1996).

2.13.1 Preferred Methodology for Estimating Emissions of CO₂

This preferred methodology requires knowledge of the quantity of reducing agent used in metal manufacturing. If this information is unavailable, refer to Sections 2.13.2 to 2.13.6.

Table 2-11 gives suggested default emission factors for various mass reducing agents.

Reducing Agent	Emission Factor ^a
Coal ^b	2.5
Coke from coal ^b	3.1
Petrol coke	3.6
Prebaked anodes and coal electrodes	3.6

^a If better information on actual carbon content is not available nationally or cannot be calculated from data in the Energy Chapter.

^b Derived from data in the Energy Chapter

2.13.2 Iron and Steel

2.13.2.1 Methodology for Estimating Emissions of CO₂

Tier 1a

See Section 2.13.1 if quantity of reducing agent is known.

Tier 1b

Parsons (1977) and ORTECH (1994) have studied the consumption of carbon at iron and steel production facilities. These results have been summarised by Environment Canada 1996. A CO₂ emission factor is shown in Table 2-12.

DOUBLE COUNTING

Additional emissions occur as the limestone flux gives off carbon dioxide during reduction of pig iron in the blast furnace. This source is covered as emissions from limestone use in Section 2.5. Care should be taken not to double count these emissions.

Country	Description	Emission Factor	Reference
Canada ^a	Integrated facility ^b (coke plus iron and/or steel production).	1.6	Environment Canada 1996

^a Includes CO₂ produced by coke and coke oven gas consumption. It does not include any form of conventional energy consumption. The emission factor applies to both iron or iron plus steel production, since uncertainty in the estimates overshadow the incremental difference in CO₂ emissions.

^b Environment Canada has reported an emission factor of approximately 1.5 tonnes CO₂/tonne iron or steel for a non-integrated facility. This is, however, a rather uncertain value.

Note: Figures exclude CO₂ from flux (CaCO₃) consumption.



2.13.2.2 Methodology for Estimating Emissions of NO_x, NMVOC, CO and SO₂

Emissions from iron and steel may originate from various stages of the production process. These are described in the tables below. Most of the emissions from rolling mills are from the fuel used to heat the process. However, cold-rolling will emit a range of gases in addition to the emissions from fuel combustion.

The following Tables 2-13 to 2-16 summarise the emission factors reported in the *Revised 1996 IPCC Guidelines for Greenhouse Gas Inventories Reference Manual* for NO_x, NMVOC, CO and SO₂, respectively:

TABLE 2-13 REPORTED NO _x EMISSION RATES FOR THE IRON AND STEEL SECTOR (G NO _x /TONNE IRON OR STEEL PRODUCED)		
Source	Emission Factor (g/tonne produced)	Reference
Iron Production - Pig iron tapping	76	CASPER 1995
Steel Processing - rolling mills	40	EMEP/CORINAIR Guidebook

TABLE 2-14 REPORTED NMVOC EMISSION RATES FOR THE IRON AND STEEL SECTOR (G NMVOC/TONNE IRON OR STEEL PRODUCED)		
Source	Emission Factor (g/tonne produced)	Reference
Iron Production - Blast furnace charging	100	CASPER 1995
Iron Production - Pig iron tapping	20	CASPER 1995
Steel Processing - rolling mills	30	EMEP/CORINAIR Guidebook

TABLE 2-15 REPORTED CO EMISSION RATES FOR THE IRON AND STEEL SECTOR (G CO/TONNE IRON OR STEEL PRODUCED)		
Source	Emission Factor (g/tonne produced)	Reference
Iron Production - Blast furnace charging	1300	CASPER 1995
Iron Production - Pig iron tapping	112	CASPER 1995
Steel Processing - rolling mills	1	EMEP/CORINAIR Guidebook

TABLE 2-16 REPORTED SO₂ EMISSION RATES FOR THE IRON AND STEEL SECTOR (G SO₂/TONNE IRON OR STEEL PRODUCED)		
Source	Emission Factor (g/tonne produced)	Reference
Iron Production - Blast furnace charging	1000-3000	Environment Canada
Iron Production - Pig iron tapping	30	CASPER 1995
Steel Processing - rolling mills	45	EMEP/CORINAIR Guidebook

Emission factors for steel production (open hearth furnace, basic oxygen furnace steel plant and electric furnace steel plants) are not provided.

2.13.3 Ferroalloys

Introduction

Ferroalloy production involves a metallurgical reduction process which results in significant carbon dioxide emissions.

Primary emissions in covered arc furnaces consist almost entirely of CO as opposed to CO₂, due to the strong reducing environment (ORTECH, 1994). All CO is assumed, however, to be converted to CO₂, within days afterwards.

2.13.3.1 Methodology for Estimating Emissions of CO₂

Tier 1a

See Section 2.13.1 if quantity of reducing agent is known.



Tier 1b

The suggested emission factors (Table 2-17) assume (if not otherwise specified) that all carbon is fossil, and are derived from a material balance made by SINTEF (SINTEF 1991a) and Streibel, 1974.

Type Ferroalloy	Emission Factor (tonnes/tonne product)
Ferrosilicon - 50%Si	2-2.7
Ferrosilicon - 75%Si	3.9
Ferrosilicon - 90%Si	4.8-6.5
Silicon metal ^a	4.3
Ferromanganese	1.6
Silicon manganese	1.7
Ferrochromium	1.3
Ferrochromium-silicon	NAV

^a All producers probably use some biocarbon in order to obtain the desired product properties. 1.6 tonne bio-CO₂/tonne silicon may be considered as a minimum value and is not included in the emission factor in the table.

2.13.4 Aluminium

Introduction

Primary aluminium is produced in two steps. First bauxite ore is ground, purified and calcined to produce alumina. Following this, the alumina is electrically reduced to aluminium by smelting in large pots.

Most carbon dioxide is evolved from the reaction of the carbon anode with alumina, but some is formed as the anode reacts with other sources of oxygen (especially air). This occurs during cell operation and, in the case of prebaked electrodes, during anode production at the aluminium plant.

2.13.4.1 Methodology for Estimating Emissions of CO₂

Tier 1a

See Section 2.13.1 if quantity of reducing agent is known.

Tier 1b

If information on quantity of reducing agent is not known, the emissions of CO₂ may be estimated from the production volume of primary metal and the specific consumption of carbon. Emissions factors for CO₂ are suggested in Table 2-18 based on SINTEF 1991b and ORTECH 1994.

TABLE 2-18 EMISSION FACTORS FOR CO ₂ FROM PRIMARY ALUMINIUM PRODUCTION (TONNE/TONNE PRODUCT)		
Pollutant	Soderberg Process	Prebaked Anode Process
CO ₂	1.8	1.5

2.13.4.2 Methodology for Estimating Emissions of PFCs

Introduction

Two PFCs, carbon tetrafluoride (CF₄) and carbon hexafluoride (C₂F₆), are known to be emitted from the process of primary aluminium smelting.

Tier 1a - Measured Emission Data

TIER 1a

Tier 1a is the preferred methodology. Every effort should be made to obtain measurement data.

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* gives details on the variability of emissions of PFCs. Since emissions of CF₄ and C₂F₆ vary so significantly from one aluminium smelter to the next, depending on cell type and anode effects (AE) parameters, the estimations will be highly uncertain unless actual emission measurements have been made.

Tier 1b - Calculation of Emission Data

It is recognised that measurements are both expensive and time-consuming. It may, however, be much easier to make a limited survey of AE frequency and duration at smelters. In such cases, it is recommended that specific CF₄ emissions for anode effects longer than 2 minutes are calculated as follows (based on the method developed by Tabereaux 1995):



$$\text{kg CF}_4/\text{tonne Al} = 1.698 \times (p / \text{CE}) \times \text{AEF} \times \text{AED}$$

where:

p	=	average fraction amount of CF ₄ in the pot gas during anode effects
Prebaked: p	=	0.08 (8%)
Söderberg: p	=	0.04 (4%)
CE	=	current efficiency expressed as a fraction, rather than a percentage
AEF	=	number of anode effects per pot day
AED	=	anode effect duration in minutes

It is recommended that the default rate for C₂F₆ emissions be 1/10 that of CF₄.

Type of Cell	CF ₄		C ₂ F ₆	
	Equation Constant	Average fraction of CF ₄ in the pot gas during anode effects	Equation Constant	Average fraction amount of C ₂ F ₆ in the pot gas during anode effects
Prebake	1.698	0.08	0.1698	0.08
Söderberg	1.698	0.04	0.1698	0.04

Tier 1c - Estimated Emission Data

PFC emissions estimates have been reported in several studies. These are briefly discussed in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual*.

The estimates should be used only when no measured data exist. Specific emission factors should be chosen according to the type of technology used as shown in Table 2-20 and applied to national primary aluminium production data for each technology. The following equation may then be used to give an estimate of the annual CF₄ emissions from a smelter with a given cell technology.

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

where:

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

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

Type of Cell Technology	Per Cent Of World Production	kg CF ₄ /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

See the *Revised 1996 IPCC 1996 Guidelines for Greenhouse Gas Inventories Reference Manual* for sources.

It is recommended that the default rate for C₂F₆ emissions be 1/10 that of CF₄.

2.13.4.3 Methodology for Estimating Emissions of NO_x, CO and SO₂

Emissions of NO_x, CO and SO₂ can be estimated from the amount of aluminium produced. Emissions may originate from the production process and baking of anodes. No distinction between the Søderberg and prebaked method is given in the EMEP/CORINAIR Guidebook (SNAP 40301). The suggested emission factors are shown in Table 2-21. No information is given about the degree of control.



TABLE 2-21 EMISSION FACTORS FOR NO _x , CO AND SO ₂ FROM ALUMINIUM PRODUCTION (KG/TONNE PRIMARY ALUMINIUM PRODUCED)			
Pollutant	Process	Emission Factor (Default)	Emission Factor (Range)
NO _x	Electrolysis	2.15	1.3-3.0
	Anode baking	NE	NE
CO	Electrolysis	135	27-680
	Anode baking	400	NAV
SO ₂	Electrolysis	14.2	10-17.5
	Anode baking	0.9	0.8-1.0

NE = negligible. NAV = not available.

2.13.5 Other Metal Production

2.13.5.1 Methodology for Estimating Emissions of CO₂

Tier 1a

See Section 2.13.1 if quantity of reducing agent is known.

Tier 1b

This includes production of all non-ferrous metals except aluminium. The metals may be produced using carbon as reducing agents or by other methodologies.

Whether carbon is emitted or not depends on the production process. Some ores are not reduced with carbon. Hence, CO₂ emissions from these processes are low. The general methodology suggested where emissions are calculated from the consumption of reducing agents and the carbon content of ores is recommended. An overview of production processes is given in Table 2-22. Some metals may be produced from alternative production methods.

CARBONATE ORES

In the case of *magnesium* and other metals in a carbonate ore, the carbon emitted from the ore should be taken into account in addition to the coke reducing agent.

Metal	Main Ore(s)	Carbon reduction	Electrolysis (without carbon)	Other (non-CO ₂)
Chromium ^a	FeCr ₂ O ₄ , PbCrO ₄	x		
Copper	Cu ₂ S, CuFeS ₂ , Cu ₂ O, carbonate		x	x (SO ₂)
Gold	Element		x	x
Lead	PbS	x		x (SO ₂)
Magnesium	Carbonate	x	x	
Mercury	HgS			x (SO ₂)
Molybdenum	MoS ₂			x (SO ₂)
Nickel	NiS, NiO	x	x	x (SO ₂)
Platinum	Element, PtS			x
Silicon ^b	SiO ₂ , Si-O-alkali	x		
Silver	Ag ₂ S, element			x
Tin	SnO ₂	x		
Titanium	TiO ₂ , FeTiO ₃	x ^c		
Tungsten	WO ₃			x
Uranium	U _x O _y			x
Zinc	ZnS, ZnCO ₃	x	x	x (SO ₂)

^aSee also ferroalloy production
^b See also ferroalloy production and carbide production
^cTwo step reduction process, involving first C + Cl₂, then Mg
 Note: The appearance of (SO₂) in the final column indicates that the production process is a major world-wide source of SO₂ emissions.

2.13.6 SF₆ Used in Aluminium and Magnesium Foundries

2.13.6.1 Methodology for Estimating Emissions of SF₆

In the aluminium industry SF₆ is used as a cover gas only for special foundry products. Since SF₆ is assumed to be inert, SF₆ emissions should equal consumption:

Emission of SF ₆ = Consumption of SF ₆ in magnesium and aluminium foundries



Completing the Worksheet

Use WORKSHEET 2-11 METAL PRODUCTION to enter data for this submodule.

STEP 1 ESTIMATING CO₂ EMITTED - TIER 1a

- 1 Estimate the Mass of Reducing Agent and enter this value in column A in tonnes.
Enter the corresponding Emission Factor (Table 2-11) in column B in tonnes CO₂/tonne reducing agent.
- 3 If the information is available, estimate the Carbon Content of Ore (in tonnes) (C_{ore}) and subtract the Carbon Content of Metal (in tonnes) (C_{metal}). Multiply the result by 3.67 and enter the result in column C.
If this information is not available, the product of column A and column B will probably be sufficient for making a first estimate of the emissions.
- 4 Multiply column A by column B and add column C (if available) to obtain CO₂ Emitted in tonnes CO₂, and enter this value in column D.
- 5 Divide column C by 10^3 to convert to units of gigagrams CO₂, and enter this value in column E.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Tier 1b - Based on Iron or Steel Production

STEP 2 ESTIMATING CO₂ EMITTED

- 1 Estimate the Amount of Iron or Steel Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding Emissions Factor (Table 2-12) in column B in tonne CO₂ per tonne of iron or steel produced.
- 3 Multiply column A by column B to obtain CO₂ Emitted in tonnes of CO₂ and enter this value in column C.
- 4 Divide column C by 10^3 to convert to units of gigagrams CO₂, and enter this value in column D.

STEP 3 ESTIMATING NO_x, NMVOC, CO AND SO₂ EMITTED

- 1 Estimate the Amount of Iron or Steel Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding Emission Factor (Tables 2-13 and 2-16) in column B in grams pollutant per tonne of iron or steel produced for NO_x, NMVOC, CO and SO₂.

- 3 Multiply column A by column B to obtain Pollutant Emitted in grams of pollutant and enter this value in column C.
- 4 Divide column C by 10^9 to convert to units of gigagrams of pollutant, and enter this value in column D.

Tier 1b - Based on Ferroalloy Production

STEP 4 ESTIMATING CO₂ EMITTED FROM FERROALLOYS

- 1 Estimate the Amount of Ferroalloy Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding Emission Factor (Table 2-17) in column B in tonnes CO₂ per tonne of ferroalloys produced.
- 3 Multiply column A by column B to obtain CO₂ emitted in tonnes of CO₂ and enter this value in column C.
- 4 Divide column C by 10^3 to convert to units of gigagrams CO₂, and enter this value in column D.

Tier 1b - Based On Aluminium Production

STEP 5 ESTIMATING CO₂ EMITTED FROM ALUMINIUM TIER 1b

- 1 Estimate the Amount of Aluminium Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding Emission Factor (Table 2-18) in column B in tonne CO₂ per tonne of aluminium produced.
- 3 Multiply column A by column B to obtain CO₂ emitted in tonnes, and enter this value in column C.
- 4 Divide column C by 10^3 to convert to units of gigagrams CO₂, and enter this value in column D.

Tier 1a - Based On Measurements

Every effort should be made to obtain measurement data due to the uncertainty of emission estimates.



Tier 1b - Based On The Number Of Anode Effects

Table 2-19 provides default data to be used with Tier 1b.

STEPS 6 AND 7 ESTIMATING PFC EMITTED

- 1 Enter the Type of Cell in column A.
- 2 Estimate the Amount of Aluminium Produced and enter this value in column B in tonnes.
- 3 Enter the corresponding Equation Constant (Table 2-19) in column C for CF_4 and C_2F_6 emissions from aluminium production.
- 4 Enter the corresponding Average Fraction of Pot Gas During Anode Effects of CF_4 or C_2F_6 (Table 2-19) in column D.
- 5 Enter the Current Efficiency as a fraction in column E.
- 6 Enter the Number of Anode Effects Per Day in column F.
- 7 Enter the Anode Effect Duration in minutes in column G.
- 8 Multiply columns B through G to obtain CF_4 or C_2F_6 Emitted in kg and enter this value in column H.
- 9 Divide column H by 10^6 to convert to units of gigagrams of CF_4 or C_2F_6 , and enter this value in column I.

Tier 1c - Based on Aluminium Production

The method in Step 8 should be used only when no measured data exists.

STEP 8 ESTIMATING CF_4 EMITTED

- 1 Estimate the Amount of Aluminium Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding emissions factor (Table 2-20) in column B in kg CF_4 per tonne of aluminium produced.
- 3 Multiply column A by column B to obtain emissions in kg and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams, and enter this value in column D.

The method in Step 9 should be used only when no measured data exists. It is assumed that C_2F_6 emissions are approximately 10 per cent of the CF_4 emissions.

STEP 9 ESTIMATING C₂F₆ EMITTED

- 1 Enter estimated mass of CF₄ Emitted in gigagrams from column D of sheet 8 to column A of Sheet 9.
- 2 Enter the C₂F₆ emissions factor based on CF₄ emissions (0.1) in column B.
- 3 Multiply column A by column B to obtain emissions in gigagrams and enter this value in column C.

STEP 10 ESTIMATING NO_x, CO AND SO₂ EMITTED

- 1 Estimate the Amount of Aluminium Produced and enter this value in column A in tonnes.
- 2 Enter the corresponding Emission Factor (Table 2-21) in column B in kg pollutant per tonne of aluminium produced.
- 3 Multiply column A by column B to obtain Pollutant Emitted in kg pollutant and enter this value in column C.
- 4 Divide column C by 10⁶ to convert to units of gigagrams of pollutant, and enter this value in column D.

STEP 11 ESTIMATING SF₆ EMITTED

- 1 Estimate the Consumption of SF₆ in magnesium and aluminium foundries and enter this value in column A in tonnes.
- 2 This value is set equal to SF₆ Emitted. Enter this value in column B in tonnes.
- 3 Divide column B by 10³ to convert to units of gigagrams, and enter this value in column C.

2.14 Pulp and Paper Industries

Introduction

The production of pulp and paper involves three major processing steps: pulping, bleaching and paper production. The type of pulping and the amount of bleaching used depends on the nature of the feedstock and the desired quality of the end product.

There are two main processes: Kraft (sulphate) pulping, the most widely used, and Sulphite pulping. Sulphite pulping may be divided into the acid Sulphite process and the neutral sulphite semi-chemical process.



Data Sources

If site-specific emission data are not available, the emission estimates can be based on the total annual production of dried pulp. The production would have to be broken down by kraft, acid sulphite and neutral sulphite processes.

2.14.1 Methodology for Estimating Emissions of NO_x, NMVOC, CO and SO₂

There is more information on the simpler methodologies in the EMEP/CORINAIR Guidebook.

Pollutant	Emission Factor (Default)	Emission Factor (Range)
NO _x	1.5	0.017-1.5
NMVOC	3.7	0.1-4.9
CO*	5.6	NAV
SO ₂	7	0.005-10

Ref: US EPA 1995.
NAV = Not Available

EMISSION FACTORS

Emission factors are based on the production of air dried pulp. The emissions of SO₂ may be lower in new mills than in the older ones (US EPA 1995).

There are at least four types of acid sulphite process: ammonium-based (NH₃), calcium-based (Ca), magnesium-based (MgO) and sodium-based (Na) (US EPA, 1995). Emissions factors from US EPA, 1995 are given in Table 2-24.

Pollutant	Type of Process	Emission Factor (Default)	Emission Factor (Range)
SO ₂	NH ₃ , Ca, MgO and Na	30	8-50

2.14.2 Detailed Methodology for Estimating Emissions for NO_x and SO_2

The preferred methodology is to use continuous measurements data which may be available for NO_x and SO_2 . This is only feasible in modern plants where the number of measurement points to be monitored is limited. Detailed emission factors related to the various processes are given in the EMEP/CORINAIR Guidebook.

Completing the Worksheet

Use WORKSHEET 2-12 PULP AND PAPER INDUSTRIES to enter data for this submodule.

STEP 1 ESTIMATING NO_x , NMVOC AND CO EMITTED

- 1 Estimate the annual Quantity of Air Dried Pulp Produced in tonnes for the kraft process and enter into column A.
- 2 Enter the corresponding Emission Factor (Table 2-23), in kilograms of pollutant (NO_x , NMVOC and CO) per tonnes of air dried pulp, in column B.
- 3 Multiply column A by column B to obtain Pollutant Emitted in kilograms and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams of pollutant (NO_x , NMVOC and CO) and enter this value in column D.

STEP 2 ESTIMATING SO_2 EMITTED

- 1 Estimate the annual Quantity of Air Dried Pulp Produced in tonnes broken down into the kraft and acid sulphite processes and enter into the appropriate column A.
- 2 Enter the corresponding Emission Factor (Table 2-23), in SO_2 kilograms per tonnes of air dried pulp, in column B.
- 3 Multiply column A by column B to obtain SO_2 Emitted in kilograms and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of SO_2 gigagrams and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of the column to obtain the total SO_2 emitted.



2.15 Food and Drink

Introduction

NMVOCs are emitted during the production of alcoholic beverages, breadmaking and other food products.

Data Sources

The emission estimates are based on the total annual production of the particular food manufacturing process. National production statistics for alcoholic beverages broken down into a minimum of wine, beer and spirits are required. The Standard Nomenclature for Air Pollution (SNAP) numbers for food and drink are: alcoholic beverages (40606 - 40608) and breadmaking and other food products (40605).

For the breadmaking and other food production, national production statistics broken down into the categories listed in Table 2-26 are required.

BIOLOGICAL CARBON

Carbon dioxide emitted during certain operations in the production of food and drink, including vegetable oil extraction and tobacco are not counted here. They are from the use of biological carbon which, for the purposes of this chapter, is considered not to lead to net CO₂ emissions.

2.15.1 Methodology for Estimating Emissions of NMVOC from Alcoholic Beverages

NMVOCs are produced during the processing of cereals and fruits in preparation for the fermentation processes. The emission factors shown below in Table 2-25 are taken from in the EMEP/CORINAIR Guidebook and are based on the total annual production of an individual beverage.

Beverage	Emission Factor
Wine	0.08
Red wine	0.08
White wine	0.035
Beer	0.035
Spirits (unspecified)	15
Malt whiskey	15
Grain whiskey	7.5
Brandy	3.5
Note: hl = 100 litres	

The emission factors and sources used here are derived for Europe. If more region specific data are available, these should be used. There may be different processes and emission factors in other parts of the world. Please note that if the breakdown of red and white wine and spirits is known, use the specific emission factor.

2.15.2 Methodology for Estimating Emissions of NMVOC from Bread Making and Other Food

NMVOC are released during the heating of fats and oils and foodstuffs containing them, the baking of cereals, flour and beans, fermentation in bread making, the cooking of vegetables and meats, and the drying of residues. Food production is divided into seven categories, each with its own emission factor. The emission factors given in the EMEP/CORINAIR Guidebook are shown in Table 2-26.

Food Production Process	Emission Factor
Meat, fish and poultry	0.3
Sugar	10
Margarine and solid cooking fats	10
Cakes, biscuits and breakfast cereals	1
Bread	8
Animal feed	1
Coffee roasting	0.55

The emission factors and sources used here are derived for Europe. There may be different processes and emission factors in other parts of the world.

Completing the Worksheet

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

Use WORKSHEET 2-13 ALCOHOLIC BEVERAGE PRODUCTION to enter data for this submodule.

STEP 1 ESTIMATING NMVOC EMITTED FROM ALCOHOLIC BEVERAGES

- 1 Estimate total annual Quantity of Alcoholic Beverage Produced in hectolitres (hl), broken down into categories of beverages listed in Table 2-25 and enter this value in column A.



- 2 Enter the corresponding Emission Factor, in kilograms NMVOC per hectolitre of beverage produced, in column B.
- 3 Multiply column A by column B to obtain NMVOC Emitted in kilograms and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams NMVOC and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NMVOC emitted.

STEP 2 ESTIMATING NMVOC EMITTED FROM BREAD MAKING AND OTHER FOOD

- 1 Estimate total annual Quantity of Food Produced, in tonnes, broken down into categories of food manufacturing processes listed in Table 2-26 and enter into column A.
- 2 Enter the corresponding Emission Factor, in kilograms NMVOC per tonne of food produced, in column B.
- 3 Multiply column A by column B to obtain NMVOC Emitted in kilograms and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams NMVOC and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of that column to obtain the total NMVOC Emitted.

2.16 Emissions Related to Production of Halocarbons (HFCs, PFCs) and Sulphur Hexafluoride (SF₆)

Introduction

Atmospheric release of materials may be the result of by-product emissions during manufacture or from fugitive releases. A fugitive emission is an emission that is not controlled or contained, such as a leak from a flange or coupling.

Data Sources

The type of data required depends on the level of effort that is to be expended and the accuracy required. For the simpler methodology that uses an emission factor, data on production should be available from chemical companies. For the more detailed approach, plant specific emission information is required.

2.16.1 Methodology for Estimating Emissions of By-Products

It is estimated that the HFC-23 released, as a by-product during manufacture of HCFC-22, is currently equivalent to 4 per cent of the production of HCFC-22 assuming no abatement measures, although lower figures have been suggested.

This factor, or a similar number derived for the particular country's circumstances, can be used to estimate national emissions of HFC-23 from the total national HCFC-22 production (for both potentially dispersive and feedstock end-uses).

The Reference Manual (Section 2.16.1) describes a Tier 2 methodology but no worksheets are provided here.

2.16.2 Methodology for Estimating Fugitive Emissions

Fugitive emissions of a chemical may occur both during the production and the distribution of a chemical. For this section, fugitive emissions associated with use are not addressed as they are covered in the section related to consumption (see Section 2.17). In the case of fluorocarbon processes, fugitive emissions have been estimated to be approximately 0.5 per cent of the total production of each compound (UNEP, 1994).

This factor, or a similar number derived for the particular country's circumstances, can be used to estimate national fugitive emissions of individual HFCs and PFCs associated with national production.

The Reference Manual (Section 2.16.2) describes a Tier 2 methodology but no worksheets are provided here.

Completing the Worksheet

Use WORKSHEET 2-14 PRODUCTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE - BY-PRODUCTS - HFCs AND PFCs to enter data for this submodule.

Note that only a Tier 1 method is presented. If data exist, the Tier 2 method described above is preferable.

STEP 1 ESTIMATING HFCs AND PFCs EMITTED

- 1 Estimate the total annual Quantity of Halocarbon Produced in tonnes of the specific halocarbon in question and enter into the appropriate column A.
- 2 Enter the corresponding Emission Factor, in kilograms of pollutant (HFCs or PFCs) per tonnes of halocarbon, in column B.
- 3 Multiply column A by column B to obtain Halocarbon Emitted in kilograms and enter this value in column C.



- 4 Divide column C by 10^6 to convert to units of gigagrams HFCs or PFCs and enter this value in column D.

STEP 2 ESTIMATING HFCs AND PFCs EMITTED

- 1 Estimate the total annual Quantity of Halocarbon Produced in tonnes of the specific pollutant in question and enter it into the appropriate column A.
- 2 Enter the corresponding Emission Factor, in kilograms of pollutant (HFCs or PFCs) per tonnes of halocarbon produced, in column B.
- 3 Multiply column A by column B to obtain Halocarbon Emitted in kilograms and enter this value in column C.
- 4 Divide column C by 10^6 to convert to units of gigagrams HFCs or PFCs and enter this value in column D.

2.17 Emissions Related to Consumption of Halocarbons (HFCs, PFCs) and Sulphur Hexafluoride (SF_6)

Introduction

The chemicals (HFCs, PFCs, SF_6) are of concern, because they have high global warming potentials and long atmospheric residence times.

Current and expected application areas of HFCs and PFCs include:

- refrigeration and air conditioning
- fire suppression and explosion protection
- aerosols
- solvent cleaning
- foam blowing
- other applications¹

Primary uses of SF_6 include:

- gas insulated switch gear and circuit breakers
- fire suppression and explosion protection
- other applications²

¹ HFCs and PFCs may be used in sterilisation equipment, for tobacco expansion applications, and as solvents in the manufacture of adhesives, coating, and inks.

² SF_6 may be used as an insulating medium, a tracer, in leak detectors, and in various electronic applications. For SF_6 consumption in magnesium and aluminium foundries, see Section 2.13.6.1.

THE MONTREAL PROTOCOL

Partially and fully fluorinated hydrocarbons, HFCs and PFCs, are not controlled by the Montreal Protocol because they do not contribute to depletion of the stratospheric ozone layer.

Table 2-26 (*Reference Manual*) gives an overview of the most important HFCs and PFCs including application area and GWP relative to CO₂ (100 year integration time).

Data Sources

HFCs, PFCs AND SF₆

HFCs are chemicals containing only hydrogen, carbon, and fluorine. PFCs are chemicals containing only carbon and fluorine. SF₆ is a particularly potent GHG with a 100-year GWP of 23,900 and an estimated lifetime of about 3,200 years.

The type of data required depends on the level of effort that is to be expended and the accuracy required. At a minimum, quantities of halocarbons and SF₆ imported and exported in bulk and national production are required. For the next level, the quantities of these materials contained in products imported and exported are required. Data on production and exports of chemicals in bulk should be available from chemical companies and/or national production statistics. Information on imports of chemicals in bulk and in products may be available from Customs and Duty records. National environmental protection authorities may keep records of HFCs/PFCs destroyed, if any.

POTENTIAL AND ACTUAL EMISSIONS

Emissions from industrial processes can be estimated in two ways; as potential emissions, Tier 1 (a and b), and as actual emissions, Tier 2. Tier 1b is preferred to the Tier 1a methodology.

General Methodology

In Tier 1 (a and b) methodology, potential emissions of a certain chemical are equal to the amount of virgin chemical consumed in the country minus the amount of chemical recovered for destruction or exported in the year under consideration. All chemicals consumed will eventually be emitted to the atmosphere over time if not destroyed, and in the long term (e.g., 50 yr), potential emissions will equal actual emissions.

In the Tier 2 methodology, actual emission estimates take into account the time lag between consumption and emission, which may be considerable in some application areas, e.g., closed cell foams, refrigeration and fire extinguishing equipment. Time lags result from the fact that a chemical is placed in new products and then slowly leaks out over time.

Actual emissions estimates are the most accurate with respect to emissions in individual years, provided that the necessary information is available for their calculation. If essential data are not available, the potential emission calculations provide a simpler approach for reasonable emission estimates.

The following procedures described for HFCs/PFCs are applicable for SF₆ as well.

2.17.1 Methodology for Estimating Emissions for Tier 1a and Tier 1b

Since net consumption of a chemical equals production plus imports minus exports, the calculation formula for the basic method (Tier 1) is as follows:

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



By-product emissions during HFC/PFC production and fugitive emissions related to production and distribution have to be calculated separately, as described in Section 2.16.

Production refers to production of new chemical only and not the reprocessing of recovered fluid.

There are two versions of Tier I (a and b) depending upon whether HFCs/PFCs in products are taken into account. Two versions are presented because it is expected that there may be difficulties in many countries with the availability of data regarding imports and exports of HFCs/PFCs in products, at least in the short term. The Tier Ib methodology is preferred if the relevant data are available.

Tier Ia

In Tier Ia, only chemicals imported or exported in bulk are considered in the calculation of potential emissions. The following definitions apply:

Imports = Imported HFC/PFC in bulk
Exports = Exported HFC/PFC in bulk

The application of Tier Ia may lead to an under-estimation or an over-estimation of potential emissions, depending on whether the majority of HFC/PFC-containing products is being imported or exported.

Tier Ib

Tier Ib is an extension of Tier Ia and includes HFCs/PFCs contained in various products which are imported and exported. The following definitions apply:

Imports = Imported chemical in bulk + quantity of chemical imported in HFC/PFC containing products
Exports = Exported chemical in bulk + quantity of chemical exported in HFC/PFC containing products

The product types that should be considered are

- refrigeration and air conditioning units
- foam products
- fire extinguishers
- solvents
- aerosol cans

Most of these items will use mixtures of halocarbons that must be assessed separately due to their vastly different global warming potentials.

REFRIGERATION, FIRE EXTINGUISHERS AND SOLVENTS

Refrigeration units, fire extinguishers and solvents will normally contain HFC/PFC mixtures. The fraction of each chemical must be considered separately. Refrigeration units may be refrigerators, ice machines, AC window units, split-units, chillers, etc.

FOAM PRODUCTS

Foam products include insulating and non-insulating foams in a variety of products, like refrigerators, insulation panels, pour-in-place sprays, car seats, furniture, bedding, packaging material, etc.

2.17.2 Tier 2: Advanced Methodology for Estimating Emissions

The advanced method, Tier 2, contains *actual emission calculations for each individual chemical*. This is the preferred method if input data are available. It is recommended that routines are established to report HFC/PFC emissions according to Tier 2.

To use this methodology one must employ a “bottom-up” approach or a “top-down” approach. In a “bottom-up” approach, one calculates or estimates the consumption of each individual HFC and PFC chemical based on the number of pieces of equipment or uses at a detailed level, e.g., refrigerators, other stationary refrigeration/AC equipment, soft foam, hard foam etc., to establish the volume basis for emission calculations. A “top-down” approach estimates emissions on the basis of the consumption distribution and emission characteristics related to various processes and equipment, also taking current service and recovery practices into account.

Table 2-27 gives examples of current distribution of HFC/PFC use among various application areas in certain countries. Since HFCs and PFCs have only recently entered the market, the relative size of each area will change over time and will have to be updated.

Country	Refrigeration Air Conditioning	Foam Blowing	Solvent	Fire Extinguishing	Aerosol Propellant	Other Applications
Norway	99%	<1%	0%	<1%	0%	0%
Sweden	90%	5%	0%	0%	5%	0%
United Kingdom	76%	12%	0%	7%	5%	0%

See the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual for sources.

Any given application area may employ several types of HFC/PFC fluid. Consumption figures should be collected or estimated and the type of HFC/PFC used should be identified.

A) Refrigeration and Air Conditioning Equipment

For the purposes of emission estimation, refrigeration and air-conditioning systems are classified into three categories, according to their emission characteristics:

- i) Household refrigerators and freezers;
- ii) Other stationary refrigeration and air conditioning equipment, including:
 - cold storage warehouses;



- retail food refrigeration;
 - industrial process refrigeration;
 - commercial and industrial appliances such as refrigerated vending machines, ice machines, dehumidifiers, and water coolers;
 - refrigerated transport including trucks, trains, and ships with refrigerated compartments; and
 - commercial and residential air conditioning including chillers, heat pumps, window air conditioners, central air conditioners.
- iii) Mobile air conditioners used to cool the passenger compartment of automobiles, trucks, buses, and trains.

Methods for estimating average emission rates for the above-uses sectors are outlined below.

The *quantity of refrigerant emitted during system assembly* is related to the amount charged by the following empirical formula:

EQUATION 1

$$E_{\text{assembly, } t} = E_{\text{charged, } t} \cdot (k/100)$$

where:

- $E_{\text{assembly, } t}$ = emissions during system manufacture/assembly in year t
- $E_{\text{charged, } t}$ = amount of refrigerant charged into new systems in year t
- k = assembly losses in per cent of the amount charged

The amount charged ($E_{\text{charged, } t}$) should include all systems which are charged in the country, including those which are made for export. Systems that are imported precharged should not be considered.

Annual leakage from the stock, including venting during service, is given by :

EQUATION 2

$$E_{\text{operation, } t} = E_{\text{stock, } t} \cdot (x/100)$$

where:

- $E_{\text{operation, } t}$ = amount of HFC/PFC emitted during system operation in year t
- $E_{\text{stock, } t}$ = amount of HFC/PFC stocked in existing systems in year t
- x = annual leakage rate in per cent of total HFC/PFC charge in the stock, per cent.

HFC USE IN REFRIGERANTS

HFC-134a is the primary fluorocarbon substitute for CFC-12 in many refrigeration and air-conditioning applications including refrigerators, chillers, and mobile air conditioners. Other HFCs may also be used in refrigeration applications, particularly as components of blends. These include HFC-23, HFC-32, HFC-125, HFC-143a, and HFC-152a.

PFC USE IN REFRIGERANTS

PFC-218 is used as a component in refrigerant blends. PFC-116 may be used in a blend as a substitute for R-503.

In calculating the refrigerant “bank” ($E_{\text{stock},t}$) all systems in operation in the country (home-made and imported) have to be considered.

The amount of refrigerant released from scrapped systems depends upon the amount of refrigerant left at the time of disposal, and the portion recovered.

To estimate emissions at system disposal, the following calculation formula is applicable:

EQUATION 3

$$E_{\text{disposal}, t} = E_{i \text{ charge}, (t-n)} \cdot (y/100) \cdot (100 - z)/100$$

or

$$E_{\text{disposal}, t} = E_{i \text{ charge}, (t-n)} \cdot Q$$

where:

$E_{\text{disposal},t}$	=	amount of HFC/PFC emitted at system disposal in year t
$E_{i \text{ charge}, (t-n)}$	=	amount of HFC/PFC initially charged into new systems installed in year (t-n)
n	=	average equipment lifetime, years
y	=	amount of HFC/PFC in systems at time of disposal in per cent of initial charge, per cent
z	=	amount of HFC/PFC recovered in per cent of actual charge (“recovery efficiency”), per cent
Q	=	amount of HFC/PFC emitted at system disposal in per cent of the quantity of chemical originally charged into the system, per cent ($Q = y(100-z)/100$)

In estimating the amount of refrigerant initially charged into the systems ($E_{i \text{ charged } (t-n)}$), both systems charged in the country (for home market) and systems imported precharged should be taken into account. The first charge into systems made for export should not be considered. For example, if calculating emissions for 1995 with equipment that has a 15-year lifetime, then information on quantity of HFC/PFC charged in 1980 (1995-15) is required. Total emissions in year t will then be found as the sum of emissions at assembly, during operational life and at disposal:

EQUATION 4

$$E_{\text{total}, t} = E_{\text{assembly}, t} + E_{\text{operation}, t} + E_{\text{disposal}, t}$$

See Section 2.17.4.2 in the *Reference Manual* for more information on the “top-down” and “bottom-up” approaches and on the derivation of the factors used in Equations 1 to 4.

i) Household Refrigerators and Freezers

TABLE 2-28 HOUSEHOLD REFRIGERATORS AND FREEZERS INPUT PARAMETERS			
Input	Definition	Default Value	Comment
k	assembly losses in % of amount charged	2%	range 2-5%
x	annual leakage rate in % of the total HFC/PFC charge in the stock	1%	
n	average equipment lifetime	15 yr	
y	amount of HFC/PFC in systems at time of disposal in % of initial charge	90%	
z	amount of HFC/PFC recovered in % of actual charge ("recovery efficiency")	50%	0% if no recovery practices

REFRIGERANT ACTIVITY DATA

Reasonable estimates for the number of refrigerators and freezers manufactured are generally available, as well as the number of imported and exported units and the total stock. The amount of refrigerant banked in the stock can be estimated by multiplying the number of units by the average charge size.

These values are typical of industrialised countries and may be different for developing countries.

ii) Other Stationary Refrigeration and Air Conditioning Equipment

TABLE 2-29 OTHER STATIONARY REFRIGERATION AND AIR CONDITIONING EQUIPMENT INPUT PARAMETERS			
Input	Definition	Default Value	Comment
k	assembly losses in % of amount charged	2-5%	2-3% for factory built 4-5% for site built
x	annual leakage rate in % of the total HFC/PFC charge in the stock	17%	3% if improved valves and fittings are used
n	average equipment lifetime	15 yr	
y	amount of HFC/PFC in systems at time of disposal in % of initial charge	90%	
z	amount of HFC/PFC recovered in % of actual charge ("recovery efficiency")	0%	80% if use recovery practices

Refrigerant charge may vary over a wide range, depending upon system size and design. The following range may indicate orders of magnitude.

- Residential air conditioning: 2 to 3 kg
- Transport Refrigeration: 8 kg
- Retail Food Refrigeration: 10 to 230 kg
- Chillers: 75 to 900 kg
- Industrial Process Refrigeration: 340 to 9100 kg
- Commercial and industrial appliances: 0.10 to 0.50 kg

To apply the bottom-up approach, reliable average values for system charge sizes valid for each country will be required to develop useful estimates.

iii) Mobile Air Conditioning (MAC) Equipment

Input	Definition	Default Value	Comment
k	assembly losses in % of amount charged	4-5%	
x	annual leakage rate in % of the total HFC/PFC charge in the stock	30%	10% with improved seals fittings and hosing
n	average equipment lifetime	12 yr	11 yr (small cars) to 15 yr (trucks)
y	amount of HFC/PFC in systems at time of disposal in % of initial charge	75%	
z	amount of HFC/PFC recovered in % of actual charge ("recovery efficiency")	0%	80% if use recovery practices

Typical refrigerant charges in mobile air conditioners are 1.2 kg/unit for cars and 1.5 kg/unit for trucks. MACs in newer cars may have a lower charge, e.g., 800 g which is typical for Japanese passenger cars.

B) Foam Blowing

i) Open Cell Foam

For open cell foams, HFC and PFC emissions occur at the time of manufacture and are equal to 100 per cent of the total quantity of chemical used as the blowing agent. As a result total HFC or PFC emissions in year t for open cell foam can be calculated as follows:

Emissions of HFCs or PFCs in year t = 100% of the quantity of HFCs or PFCs sold for blowing open cell foam in year t
--

ii) Closed Cell Foam

For closed cell foams, only about 10 per cent of the blowing agent is released during the blowing of the foam, while the remaining chemical is contained in the insulation. This quantity remaining in the foam is slowly released over the 20 to 25 year lifetime of the foam. HFC or PFC emissions from insulating foam in year t are therefore calculated as follows:



$$\begin{aligned}
 & \text{Emissions of HFCs or PFCs in year } t \\
 & = \\
 & 10 \text{ per cent of the total quantity of HFC or PFC used in manufacturing} \\
 & \quad \text{new insulating foam in year } t \\
 & + \\
 & 4.5 \text{ per cent of the quantity of original HFC or PFC charge blown into} \\
 & \quad \text{the insulated foam manufactured between year } t \text{ and year } t-20
 \end{aligned}$$

The total quantity of HFC or PFC contained in the existing stock of insulating foam can be calculated as the product of the total quantity of insulating foam in use in year t and the average charge of chemical contained in each tonne of such installed insulating foam.

If action is taken to control emissions from foam blowing by recycling or leakage control then an alternative formula may be applicable. See *Reference Manual*, Section 2.17.4.3.

C) Fire Extinguishers

Total halon emissions can be estimated as 60 per cent of total halon 1211 contained in new portable halon fire extinguishers installed each year, and as 35 per cent of total Halon 1301 contained in new total flooding equipment installed each year. The remaining amounts of chemical, 40 per cent for portable fire extinguishers and 65 per cent for total flooding equipment respectively, adds to the bank of fire extinguishing chemicals. As halons are replaced, emissions of HFCs and PFCs may be calculated:

$$\begin{aligned}
 & \text{Emissions of HFCs or PFCs in year } t \\
 & = \\
 & 60 \text{ per cent of the total quantity of HFC or PFC used in new portable} \\
 & \quad \text{halocarbon fire extinguishing equipment installed in year } t
 \end{aligned}$$

Similarly, emissions estimates in year t for total flooding equipment can be calculated as:

$$\begin{aligned}
 & \text{Emissions of HFCs or PFCs in year } t \\
 & = \\
 & 35 \text{ per cent of the total quantity of HFC or PFC used new fixed} \\
 & \quad \text{halocarbon fire extinguishing equipment installed in year } t
 \end{aligned}$$

D) Aerosols

Emissions from aerosols are modelled by the following equation :

$$\begin{aligned}
 & \text{Emissions of HFCs in year } t \\
 & = \\
 & 50\% \text{ of the quantity of HFCs contained in aerosols sold in year } t \\
 & + \\
 & 50\% \text{ of the quantity of HFC contained in aerosols sold in year } t-1
 \end{aligned}$$

HFC AND PFC USE IN FIRE EXTINGUISHERS

HFCs and PFCs are potential replacements for Halon 1211 in portable fire extinguishers and Halon 1301 in total flooding fixed fire extinguishing systems. Potential substitutes include HFC-23, HFC-125, HFC-227ea, PFC-410, and PFC-614.

SF₆ USE IN FIRE EXTINGUISHERS

Some of the new substitutes for halon in fire extinguishing equipment contain sulphur hexafluoride, SF₆, probably in blends with HFC. If the products contain SF₆, it is emitted to the atmosphere in the same manner as HFC or PFC. The equations for the estimation of HFC and PFC emissions from fire extinguishing equipment are therefore also valid for SF₆, since they have to be adjusted for the proportion of the SF₆ in the original blend. Emissions of SF₆ are to be calculated according to the proportion of this chemical in the blend.

This calculation accounts for the six-month lag from purchase to use.

E) Solvents

HFC AND PFC USE AS SOLVENTS

HFCs and PFCs may be used as replacements for CFC-113 in metal cleaning, electronics, and precision cleaning applications and as replacements for aerosol cleaning. The compounds that may be used include HFC-43-10, PFC-614, PFC-512, PFC-612, PFC-716, and PFC-819.

Chemicals used as cleaning agents are emitted during, or shortly after, use and are typically 100 per cent of total use. This methodology assumes that solvents, on average, are used six months after they are sold.

$$\begin{aligned} &\text{Emissions of HFCs or PFCs in year } t \\ &= \\ &50\% \text{ of the quantity of HFCs or PFC} \\ &\text{sold for use in solvent applications in year } t \\ &+ \\ &50\% \text{ of the quantity of HFCs} \\ &\text{sold for use in solvent applications in year } t-1 \end{aligned}$$

F) Other Applications

OTHER HFC AND PFC USE

Other applications in which HFCs and PFCs may replace CFC and HCFC include sterilisation equipment, tobacco expansion applications, and as solvents in the manufacture of adhesives, coatings and inks. The specific compounds include HFC-125, HFC-134a, and HFC-227 ea.

For other applications, it is assumed that all HFCs and PFC are released within 6 months after production. Emissions in the year t can be calculated as follows:

$$\begin{aligned} &\text{Emissions of HFCs or PFCs in year } t \\ &= \\ &50\% \text{ of the quantity of HFCs/PFCs sold for other applications in year } t \\ &+ \\ &50\% \text{ of the quantity of HFCs/PFCs sold in year } t-1 \end{aligned}$$

Sulphur Hexafluoride (SF_6) Emissions

SF_6 is used as an insulation medium in high tension electrical equipment including gas insulated switchgear (GIS) and circuit breakers.

The use of SF_6 in production of aluminium and magnesium is covered under *Reference Manual*, Section 2.13.8.

Total annual emissions of SF_6 used in GIS applications and circuit breakers can be assumed to be approximately 1 per cent of the total quantity of SF_6 contained in equipment. In addition, if it is assumed that GIS has a lifetime of 30 years, then approximately 70 per cent of the SF_6 will remain in the equipment upon retirement and will then be released upon disposal of the equipment. Total emissions from GIS applications can therefore be estimated as:



$$\begin{aligned}
 &\text{Emissions of SF}_6 \text{ in year } t \\
 &= \\
 &1\% \text{ of the total charge of SF}_6 \text{ contained in the existing stock of equipment in} \\
 &\quad \text{year } t \\
 &+ \\
 &70\% \text{ of the quantity in equipment manufactured in year } t-30.
 \end{aligned}$$

Completing the Worksheet

Use WORKSHEETS 2-15 CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE - TIER 1a AND TIER 1b to enter data for this submodule. Each individual compound must be assessed separately.

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.

STEP 1 ESTIMATING HFCs AND PFCs EMITTED - TIER 1a AND TIER 1b

- 1 Estimate the total annual Quantity of Halocarbon Produced in tonnes of the specific halocarbon in question and enter it into column A.
- 2 Estimate the total annual Quantity of Halocarbon Imported and Exported in Bulk, into and out of the country, in tonnes of the specific halocarbon in question, and enter these values into columns B and C, respectively.
- 3 Estimate the total annual Quantity of Halocarbon Destroyed in tonnes of the specific halocarbon in question that was destroyed and enter it into column D.
- 4 Add column A to column B, subtract column C, subtract column D and enter the result in column E to obtain the Potential Bulk Halocarbon Emissions.

STEP 2 ESTIMATING HFCs AND PFCs EMITTED - TIER 1b

- 1 Estimate the total annual Number of Units of Imported (as positive numbers) or Exported (as negative numbers) of individual product types, containing the specific halocarbon in question, and enter these into column F.
- 2 Estimate the total Quantity of Material per Unit for each individual product type in kg and the fraction of halocarbon in material (%100) of the specific halocarbon in question and enter these into columns G and H, respectively.

- 3 Multiply column F, G and H to calculate kg of each halocarbon, convert to tonnes by dividing by 10^3 and enter this value in column I to obtain Potential Product Halocarbon Emissions.
- 4 Sum the values in column I and enter the result in the bottom of that column to obtain the total Potential Product Halocarbon Emissions.

STEP 3 SUMMARY OF HFCs AND PFCs EMITTED - TIER 1a AND TIER 1b

- 1 Enter the totals from columns E and I respectively in the appropriate columns J and K and sum these two columns and enter result in column L.
- 2 Divide column L by 10^3 to convert to units of gigagrams HFCs or PFCs and enter this value in column M to obtain the Total Potential Halocarbon Emissions.

WORKSHEET

The same worksheet can be used for home refrigeration and freezers, other stationary refrigeration and air conditioning equipment and mobile air conditioning. Each worksheet must be duplicated for every HFC and PFC under assessment.

STEP 4 ESTIMATING HFCs AND PFCs EMITTED - REFRIGERATION ASSEMBLY TIER 2

- 1 Estimate the Amount of HFC/PFC Charged into New Systems in Year t (inventory year) in tonnes and enter in column A.
- 2 Enter appropriate value of k Assembly Losses in amount charged in per cent into column B.
- 3 Multiply column A by column B (see Equation 1), and enter result in column C.
- 4 Divide the result in column C by 10^3 and enter the result in column D.

STEP 5 ESTIMATING HFCs AND PFCs EMITTED - REFRIGERATION OPERATION - TIER 2

- 1 Estimate the total Amount of HFC/PFC Stocked in Existing Systems in Year t (inventory year) in tonnes, and enter in column E.
- 2 Enter appropriate value of x, Annual Leakage Rate, in per cent, into column F.
- 3 Estimate the Halocarbon Emitted in tonnes using Equation 2 as shown in Column G. Enter result in column G.
- 4 Divide the result in column G by 10^3 and enter the result in column H.



STEP 6 ESTIMATING HFCs AND PFCs EMITTED - REFRIGERATION DISPOSAL - TIER 2

- 1 Estimate the total Amount of HFC/PFC Charged into New Systems in Year t-n in tonnes and enter in column I.
- 2 Enter appropriate values of n, Average Equipment Lifetime in years into column J.
- 3 Enter appropriate values of y, Amount of HFC/PFC in Systems at Time of Disposal in Per Cent of Original Charge into column K.
- 4 Enter appropriate values of z, Amount of HFC/PFC Recovered in Per Cent of Actual Charge into column L.
- 5 Calculate Halocarbon Emitted during disposal by using Equation 3 as shown in Column M. Enter the result in column M.
- 6 Divide the value in column M by 10^3 and enter the result in column N.

STEP 7 ESTIMATING HFCs AND PFCs EMITTED-SUMMARY - TIER 2

- 1 Transfer sums of columns D, H and N for emissions during Assembly, Operation and Disposal respectively into appropriate columns O, P and Q.
- 2 Sum the values in columns O, P and Q and enter the result in column R to obtain the Total Halocarbon Emissions.

STEP 8 ESTIMATING HFCs AND PFCs EMITTED FROM FOAM PRODUCTS- TIER 2

This worksheet contains both open cell and closed cell foams. Each worksheet must be duplicated for every HFC and PFC under assessment.

Open Cell

- 1 Estimate the Quantity of HFCs/PFCs Used in open cell foam for the year under study, in tonnes, and enter it in column A.
- 2 Enter the appropriate Fraction Loss during Production for open cell foam in per cent (100% if no recovery) in column C.
- 3 Calculate HFC/PFC Emitted during production by multiplying column A by column C and enter result in tonnes into column E.
- 4 Divide column E by 10^3 to convert to units of gigagrams HFCs or PFCs and enter this value in column F

HFC AND HCFC USE IN FOAM

HFCs are potential replacements for CFCs and HCFCs in the manufacture of insulating, cushioning, and packaging foams. The specific compounds that may be used include HFC-125, HFC-134a, HFC-143a, and HFC-152a.

Closed Cell Foam

RECYCLING

Approximately 55 per cent of the HFC or PFC used as a blowing agent in the manufacture of open cell foams could potentially be recycled. If such recycling occurs, total emissions from open cell foam manufacture would still be 100 per cent of the chemical sold for foam blowing purposes. The quantity required, however, would be reduced since the gas used for the blowing process will be a mixture of 45 per cent virgin chemical and 55 per cent recycled chemical.

- 1 Estimate the Quantity of HFC/PFC Used in closed cell foam for the year under study, in tonnes, and enter it in column A.
- 2 Estimate the Quantity of HFC/PFC in Use contained in existing stock of insulating foam for the year under study in tonnes and enter this value in column B.
- 3 Enter the appropriate Fraction Loss during Production (closed cell) in per cent (100% if no recovery) in column C.
- 4 Enter the Fraction Loss during Use in per cent in column D.
- 5 Multiply column A by column C and add this value to the result of column B times column D. Enter the result in tonnes in column E.
- 6 Divide column E by 10^3 to convert to units of gigagrams HFCs or PFCs and enter this value in column F.

STEP 9 ESTIMATING HFCs, PFCs AND SF₆ EMITTED FROM FIRE EXTINGUISHERS - TIER 2

USING THE WORKSHEET

- Copy the Worksheet at the end of this section to complete the inventory.
- Keep the original of the Worksheet blank so you can make further copies if necessary.
- Each worksheet must be duplicated for every HFC, PFC and SF₆ under assessment.

Portable and Fixed Fire Extinguishers

- 1 Estimate the Total Quantity of HFC/PFC/SF₆ Used in New Extinguishers in tonnes, broken down into portable and fixed, systems for the year under study and enter this value into column A.
- 2 Enter appropriate Fractional Loss Factor for portable and fixed fire extinguishers in per cent into column B.
- 3 Calculate HFC/PFC/SF₆ Emitted by multiplying column A by column B and enter result, in tonnes, in column C.
- 4 Divide column C by 10^3 to convert to units of gigagrams HFCs, PFCs or SF₆ and enter this value in column D.
- 5 Sum the values in column D and enter the result in the bottom of column to obtain the Total HFC/PFC/SF₆ Emitted.

HFC USE IN AEROSOLS

HFCs may be used as replacements for CFCs in aerosol propellants in industrial and technical applications, and household, medical and personal care products. The HFCs that may be used include HFC-125, HFC-134a, 152a, and HFC-227ea.

STEP 10 ESTIMATING HFCs, PFCs AND SF₆ EMITTED FROM AEROSOLS - TIER 2

- 1 Estimate the Use of HFCs or PFCs for Aerosols in Inventory Year in tonnes, and enter this number in column A.
- 2 Estimate the Use of HFCs/PFCs for Aerosols in Prior Year in tonnes and enter this number in column B.



- 3 Enter the appropriate factor of Loss of Current Year's Use for the year under inventory in column C in per cent divided by 100. A default of 0.5 can be used.
- 4 Calculate the Emission of HFCs/PFCs from Aerosols by multiplying column A by column C and adding the result to the multiplication of column B times (1-column C). Enter the result into column D.
- 5 Divide column D by 103 to convert to units of gigagrams HFC or PFCs and enter this value in column E.

STEP 11 ESTIMATING HFCs, PFCs AND SF₆ EMITTED FROM SOLVENTS - TIER 2

- 1 Estimate the Use of HFCs or PFCs for Solvents in Inventory Year in tonnes, and enter this number in column A.
- 2 Estimate the Use of HFCs/PFCs for Solvents in Prior Year in tonnes and enter this number in column B.
- 3 Enter the appropriate factor of Loss of Current Year's Use for the year under study in column C in per cent divided by 100. A default value of 0.5 can be used.
- 4 Calculate the Emission of HFCs/PFCs from Solvents by multiplying column A by column C and adding the result to the multiplication of column B times (1-column C). Enter the result into column D.
- 5 Divide column D by 103 to convert to units of gigagrams HFC or PFCs and enter this value in column E.

STEP 12 ESTIMATING HFCs, PFCs AND SF₆ EMITTED FROM OTHER APPLICATIONS - TIER 2

- 1 Estimate the Use of HFCs or PFCs for Other Applications in Inventory Year in tonnes, and enter this number in column A.
- 2 Estimate the Use of HFCs/PFCs for Other Applications in Prior Year in tonnes and enter this number in column B.
- 3 Enter the appropriate factor of Loss of Current Year's Use for the year under study in column C in per cent divided by 100. A default value of 0.5 can be used.
- 4 Calculate the Emission of HFCs/PFCs from Other Applications by multiplying column A by column C and adding the result to the multiplication of column B times (1-column C). Enter the result into column D.
- 5 Divide column D by 103 to convert to units of gigagrams HFC or PFCs and enter this value in column E.

STEP 13 ESTIMATING SF₆ EMITTED

SF₆ ACTIVITY DATA

The total charge of SF₆ contained in equipment can be estimated as the product of the total quantity of equipment in operation and the typical charge size. Charge sizes for GIS equipment rated to 50 kV or more can range from hundreds to thousands of kilograms per installation, and for low-voltage switches contain 1-2 kg per installation. If data on the total stock of GIS are unavailable, it should be assumed that emissions equal consumption.

This worksheet is for SF₆ used in GIS and circuit breakers.

- 1 Estimate the Quantity of SF₆ in Use in Inventory Year, in tonnes, in GIS and circuit breakers and enter this value in column A.
- 2 Enter the appropriate Loss Factor for SF₆ in Use for the year under study, in column B, in per cent divided by 100.
- 3 Estimate the Quantity of SF₆ in Use 30 years Prior to the Inventory Year in tonnes, in GIS and circuit breakers and enter this in column C.
- 4 Enter the appropriate Fraction Remaining in SF₆ Equipment at Time of Disposal, in column D, in per cent divided by 100.
- 5 Calculate SF₆ Emitted by multiplying column A by column B, and adding it to the result of multiplying column C by column D. Enter the result into column E.
- 6 Divide column E by 10³ to convert to units of gigagrams SF₆ Emitted and enter this value in column F.



MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CEMENT PRODUCTION		
WORKSHEET	2-1		
SHEET	1 OF 2 CO₂ EMISSIONS		
STEP 1			
A Quantity of Clinker or Cement Produced (t)	B Emission Factor (t CO ₂ /t clinker or cement produced)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^3$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CEMENT PRODUCTION		
WORKSHEET	2-1		
SHEET	2 OF 2 SO₂ EMISSIONS		
STEP 2			
A Quantity of Cement Produced (t)	B Emission Factor (kg SO ₂ /t cement produced)	C SO ₂ Emitted (kg)	D SO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF LIME			
WORKSHEET	2-2			
SHEET	1 OF 1 CO₂ EMISSIONS			
Lime Type	A Quantity of Lime Produced (t)	B Emission Factor (t CO ₂ /t quicklime or dolomitic lime produced)	C CO ₂ Emitted (t) C = (A x B)	D CO ₂ Emitted (Gg) D = C/10 ³
Quicklime				
Dolomitic Lime				
			Total (Gg):	



MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	LIMESTONE AND DOLOMITE USE			
WORKSHEET	2-3			
SHEET	1 OF 1 CO₂ EMISSIONS			
Material Type	A Quantity of Limestone or Dolomite Used (t)	B Emission Factor (kg CO ₂ /t limestone or dolomite used)	C CO ₂ Emitted (kg)	D CO ₂ Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Limestone				
Dolomite				
Total (Gg):				

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	SODA ASH PRODUCTION AND USE		
WORKSHEET	2-4		
SHEET	1 OF 2 SODA ASH PRODUCTION- CO₂ - EMISSIONS		
STEP 1			
A Quantity of Trona Utilised (t)	B Emission Factor (t CO ₂ /t trona utilised)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^3$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	SODA ASH PRODUCTION AND USE		
WORKSHEET	2-4		
SHEET	2 OF 2 SODA ASH USE - CO₂ EMISSIONS		
STEP 2			
A Quantity of Soda Ash Used (t)	B Emission Factor (kg CO ₂ /t soda ash used)	C CO ₂ Emitted (kg)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$



MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION AND USE OF MISCELLANEOUS MINERAL PRODUCTS			
WORKSHEET	2-5			
SHEET	1 OF 5 ASPHALT ROOFING PRODUCTION - NMVOC EMISSIONS			
STEP 1				
Process Type	A Quantity of Asphalt Roofing Produced (t)	B Emission Factor (kg NMVOC /t asphalt roofing produced)	C NMVOC Emitted (kg)	D NMVOC Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Saturation Process				
Blowing Process				
			Total (Gg):	

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION AND USE OF MISCELLANEOUS MINERAL PRODUCTS			
WORKSHEET	2-5			
SHEET	2 OF 5 ASPHALT ROOFING PRODUCTION - CO EMISSIONS			
STEP 2				
A Quantity of Asphalt Roofing Produced (t)	B Emission Factor (kg CO /t asphalt roofing produced)	C CO Emitted (kg)	D CO Emitted (Gg)	
			$C = (A \times B)$	$D = C/10^6$

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION AND USE OF MISCELLANEOUS MINERAL PRODUCTS			
WORKSHEET	2-5			
SHEET	3 OF 5 ROAD PAVING WITH ASPHALT- NMVOC EMISSIONS			
STEP 3				
Emission Source	A Quantity of Road Paving Material Used (t)	B Emission Factor (kg NMVOC/t road paving material used)	C NMVOC Emitted (kg)	D NMVOC Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Asphalt Plant				
Road Surface				
			Total (Gg):	

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION AND USE OF MISCELLANEOUS MINERAL PRODUCTS			
WORKSHEET	2-5			
SHEET	4 OF 5 PRODUCTION OF OTHER MINERAL PRODUCTS - GLASS PRODUCTION - NMVOC EMISSIONS			
STEP 4				
Glass Type	A Quantity of Glass Produced (t)	B Emission Factor (kg NMVOC/t glass produced)	C NMVOC Emitted (kg)	D NMVOC Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Container Glass				
Flat Glass				
Total (Gg):				

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION AND USE OF MISCELLANEOUS MINERAL PRODUCTS			
WORKSHEET	2-5			
SHEET	5 OF 5 PRODUCTION OF OTHER MINERAL PRODUCTS - CONCRETE PUMICE STONE - SO₂ EMISSIONS			
STEP 5				
A Quantity of Concrete Pumice Stone Produced (t)	B Emission Factor (kg SO ₂ /t concrete pumice stone produced)	C SO ₂ Emitted (kg)	D SO ₂ Emitted (Gg)	
			$C = (A \times B)$	$D = C/10^6$



MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	AMMONIA PRODUCTION			
WORKSHEET	2-6			
SHEET	1 OF 3 TIER 1a - CO₂ EMISSIONS			
STEP 1				
A Amount of Gas Consumed (m ³)	B Carbon Content of Gas (kg/m ³)	C Conversion Ratio	D CO ₂ Emitted (kg)	E CO ₂ Emitted (Gg)
		44/12	$D = (A \times B \times C)$	$E = D/10^6$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	AMMONIA PRODUCTION		
WORKSHEET	2-6		
SHEET	2 OF 3 TIER 1b - CO₂ EMISSIONS		
STEP 2			
A Amount of Ammonia Produced (t)	B Emission Factor (t CO ₂ /t ammonia produced)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^3$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	AMMONIA PRODUCTION		
WORKSHEET	2-6		
SHEET	3 OF 3 NMVOC, CO AND SO₂ EMISSIONS		
STEP 3			
A Amount of Ammonia Produced (t)	B Emission Factor (kg pollutant/ t ammonia produced)	C Pollutant Emitted (kg)	D Pollutant Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$
	NMVOC		NMVOC
	CO		CO
	SO ₂		SO ₂

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	NITRIC ACID PRODUCTION		
WORKSHEET	2-7		
SHEET	I OF I N₂O AND NO_x EMISSIONS		
A	B	C	D
Amount of Nitric Acid Produced (t)	Emission Factor (kg pollutant/t nitric acid produced)	Pollutant Emitted (kg)	Pollutant Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$
	<i>N₂O</i>		<i>N₂O</i>
	<i>NO_x</i>		<i>NO_x</i>



MODULE		INDUSTRIAL PROCESSES	
SUBMODULE		ADIPIC ACID PRODUCTION	
WORKSHEET		2-8	
SHEET		1 OF 1 N ₂ O, NO _x , NMVOC AND CO EMISSIONS	
A	B	C	D
Amount of Adipic Acid Produced	Emission Factor (kg pollutant / t adipic acid produced)	Pollutant Emitted	Pollutant Emitted
(t)		(kg)	(Gg)
		$C = (A \times B)$	$D = C/10^6$
	N ₂ O		N ₂ O
	NO _x		NO _x
	NMVOC		NMVOC
	CO		CO

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	CARBIDE PRODUCTION			
WORKSHEET	2-9			
SHEET	1 OF 4 SILICON CARBIDE PRODUCTION - CO₂ EMISSIONS			
STEP 1				
A Consumption Of Coke (t)	B Carbon Content in Coke (%)	C Carbon Input Sequestered In Product (%)	D CO ₂ Emitted (t)	E CO ₂ Emitted (Gg)
			$D = A \times B (100-C) \times 3.67 \times 10^{-4}$	$E = D/10^3$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CARBIDE PRODUCTION		
WORKSHEET	2-9		
SHEET	2 OF 4 SILICON CARBIDE PRODUCTION - TIER 1a - CH₄ EMISSIONS		
STEP 2			
A Amount of Petrol Coke Consumed (t)	B Emission Factor (kg CH ₄ / t petrol coke consumed)	C CH ₄ Emitted (kg)	D CH ₄ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$



MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CARBIDE PRODUCTION		
WORKSHEET	2-9		
SHEET	3 OF 4 SILICON CARBIDE PRODUCTION - TIER 1b - CH₄ EMISSIONS		
STEP 3			
A Amount of Silicon Carbide Produced (t)	B Emission Factor (kg CH ₄ / t silicon carbide produced)	C CH ₄ Emitted (kg)	D CH ₄ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CARBIDE PRODUCTION		
WORKSHEET	2-9		
SHEET	4 OF 4 CALCIUM CARBIDE PRODUCTION - CO₂ EMISSIONS		
STEP 4			
A Amount of Carbide Produced (t)	B Emission Factor (t CO ₂ / t carbide produced)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^3$
Total (Gg):			

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF OTHER CHEMICALS			
WORKSHEET	2-10			
SHEET	1 OF 5 CH ₄ EMISSIONS			
STEP 1				
Chemical	A Amount of Chemical Produced (t)	B Emission Factor (kg CH ₄ / t chemical produced)	C CH ₄ Emitted (kg) C = (A × B)	D CH ₄ Emitted (Gg) D = C/10 ⁶
Total (Gg):				

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF OTHER CHEMICALS			
WORKSHEET	2-10			
SHEET	2 OF 5 NO _x EMISSIONS			
STEP 2				
Chemical	A Amount of Chemical Produced (t)	B Emission Factor (kg NO _x / t chemical produced)	C NO _x Emitted (kg) C = (A × B)	D NO _x Emitted (Gg) D = C/10 ⁶
Total (Gg):				



MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF OTHER CHEMICALS			
WORKSHEET	2-10			
SHEET	3 OF 5 NMVOC EMISSIONS			
STEP 3				
Chemical	A Amount of Chemical Produced (t)	B Emission Factor (kg NMVOC / t chemical produced)	C NMVOC Emitted (kg)	D NMVOC Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Total (Gg):				

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF OTHER CHEMICALS			
WORKSHEET	2-10			
SHEET	4 OF 5 CO EMISSIONS			
STEP 4				
Chemical	A Amount of Chemical Produced (t)	B Emission Factor (kg CO / t chemical produced)	C CO Emitted (kg)	D CO Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Total (Gg):				



MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	METAL PRODUCTION			
WORKSHEET	2-11			
SHEET	1 OF 11 TIER 1a - CO ₂ EMISSIONS			
STEP 1				
A Mass of Reducing Agent (t)	B Emission Factor (t CO ₂ /t reducing agent)	C (Carbon content of ore minus carbon content of metal) x 3.67 (t CO ₂ /t carbon)	D CO ₂ Emitted (t)	E CO ₂ Emitted (Gg)
			$D = (A \times B) + C$	$E = D/10^3$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	METAL PRODUCTION		
WORKSHEET	2-11		
SHEET	2 OF 11 IRON AND STEEL - TIER 1b - CO ₂ EMISSIONS		
STEP 2			
A Amount of Iron or Steel Produced (t)	B Emission Factor (t CO ₂ /t of iron or steel produced)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^3$

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	METAL PRODUCTION		
WORKSHEET	2-11		
SHEET	3 OF 11 IRON AND STEEL - NO _x , NMVOC, CO AND SO ₂ EMISSIONS		
STEP 3			
A Amount of Iron or Steel Produced (t)	B Emission Factor (g gas/t of iron or steel produced)	C Gas Emitted (g)	D Gas Emitted (Gg)
		$C = (A \times B)$	$D = C/10^9$
	NO _x		NO _x
	NMVOC		NMVOC
	CO		CO
	SO ₂		SO ₂

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	METAL PRODUCTION		
WORKSHEET	2-11		
SHEET	4 OF 11 FERROALLOYS - TIER 1b - CO₂ EMISSIONS		
STEP 4			
A Amount of Ferroalloy Produced (t)	B Emission Factor (t CO ₂ /t ferroalloy produced)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		C = (A x B)	D = C/10 ³



MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	METAL PRODUCTION		
WORKSHEET	2-11		
SHEET	5 OF 11 ALUMINIUM - TIER 1b - CO₂ EMISSIONS		
STEP 5			
A Amount of Aluminium Produced (t)	B Emission Factor (t CO ₂ /t aluminium produced)	C CO ₂ Emitted (t)	D CO ₂ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^3$

MODULE	INDUSTRIAL PROCESS							
SUBMODULE	METAL PRODUCTION							
WORKSHEET	2-11							
SHEET	6 OF 11 ALUMINIUM - TIER 1b - CF₄ EMISSIONS							
STEP 6								
A Type of cell	B Amount of Aluminium Produced (tonnes)	C Equation Constant CF ₄	D Average Fraction of Pot Gas During Anode Effects	E Current Efficiency (fraction)	F Number of Anode Effects Per Day	G Anode Effect Duration (minutes)	H CF ₄ Emitted (kg)	I CF ₄ Emitted (Gg)
		1.698					$H = (B \times C \times D \times E \times F \times G)$	$I = H/10^6$

MODULE	INDUSTRIAL PROCESS							
SUBMODULE	METAL PRODUCTION							
WORKSHEET	2-11							
SHEET	7 OF 11 ALUMINIUM - TIER 1b - C₂F₆ EMISSIONS							
STEP 7								
A Type of cell	B Amount of Aluminium Produced (tonnes)	C Equation Constant C ₂ F ₆	D Average Fraction of Pot Gas During Anode Effects	E Current Efficiency (fraction)	F Number of Anode Effects per Day	G Anode Effect Duration (minutes)	H C ₂ F ₆ Emitted (kg)	I C ₂ F ₆ Emitted (Gg)
		0.1698					$H = (B \times C \times D \times E \times F \times G)$	$I = H/10^6$

INDUSTRIAL PROCESSES

MODULE		INDUSTRIAL PROCESSES	
SUBMODULE		METAL PRODUCTION	
WORKSHEET		2-11	
SHEET		8 OF 11 ALUMINIUM - TIER 1c - CF₄ EMISSIONS	
STEP 8			
A	B	C	D
Amount of Aluminium Produced (t)	Emission Factor (kg CF ₄ /t aluminium produced)	CF ₄ Emitted (kg)	CF ₄ Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$

MODULE		INDUSTRIAL PROCESSES	
SUBMODULE		METAL PRODUCTION	
WORKSHEET		2-11	
SHEET		9 OF 11 ALUMINIUM - TIER 1c - C₂F₆ EMISSIONS	
STEP 9			
A	B	C	
Total CF ₄ Emissions (Gg)	C ₂ F ₆ Emission Factor (C ₂ F ₆ /CF ₄)	C ₂ F ₆ Emitted (Gg)	
	0.1	$C = (A \times B)$	

MODULE		INDUSTRIAL PROCESSES	
SUBMODULE		METAL PRODUCTION -	
WORKSHEET		2-11	
SHEET		10 OF 11 ALUMINIUM - NO_x, CO, SO₂ EMISSIONS	
STEP 10			
A	B	C	D
Amount of Aluminium Produced (t)	Emission Factor (kg gas/t aluminium produced)	Pollutant Emitted (kg)	Pollutant Emitted (Gg)
		$C = (A \times B)$	$D = C/10^6$
	NO _x		NO _x
	CO		CO
	SO ₂		SO ₂



MODULE	INDUSTRIAL PROCESSES	
SUBMODULE	METAL PRODUCTION	
WORKSHEET	2-11	
SHEET	11 of 11 SF ₆ USED IN ALUMINIUM AND MAGNESIUM FOUNDRIES - SF ₆ EMISSIONS	
STEP 11		
A Consumption of SF ₆ (t)	B SF ₆ Emitted (t)	C SF ₆ Emitted (Gg)
	B = A	C = B/10 ³

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PULP AND PAPER INDUSTRIES			
WORKSHEET	2-12			
SHEET	1 OF 2 NO_x, NMVOC AND CO EMISSIONS			
STEP 1				
Pulp Process Type	A Quantity of Air Dried Pulp Produced (t)	B Emission Factor (kg gas /t air dried pulp produced)	C Pollutant Emitted (kg)	D Pollutant Emitted (Gg)
			C = (A x B)	D = C/10 ⁶
Kraft		NO _x		NO _x
Kraft		NMVOC		NMVOC
Kraft		CO		CO

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PULP AND PAPER INDUSTRIES			
WORKSHEET	2-12			
SHEET	2 OF 2 SO₂ EMISSIONS			
STEP 2				
Pulp Process Type	A Quantity of Air Dried Pulp Produced (t)	B Emission Factor (kg SO ₂ /t air dried pulp produced)	C SO ₂ Emitted (kg)	D SO ₂ Emitted (Gg)
			C = (A x B)	D = C/10 ⁶
Kraft				
Acid Sulphite				
Total (Gg):				



MODULE		INDUSTRIAL PROCESSES		
SUBMODULE		FOOD AND DRINK		
WORKSHEET		2-13		
SHEET		1 OF 2 ALCOHOLIC BEVERAGE PRODUCTION - NMVOC EMISSIONS		
STEP 1				
Alcoholic Beverage Type	A Quantity of Alcoholic Beverage Produced (hl)	B Emission Factor (kg NMVOC/hL beverage produced)	C NMVOC Emitted (kg)	D NMVOC Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Total (Gg):				

MODULE		INDUSTRIAL PROCESSES		
SUBMODULE		FOOD AND DRINK		
WORKSHEET		2-13		
SHEET		2 OF 2 BREAD AND OTHER FOOD PRODUCTION - NMVOC EMISSIONS		
STEP 2				
Food Production Type	A Quantity of Food Produced (t)	B Emission Factor (kg NMVOC/t food processed)	C NMVOC Emitted (kg)	D NMVOC Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$
Total (Gg):				

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE			
WORKSHEET	2-14			
SHEET	1 OF 2 BY-PRODUCTS - HFCs AND PFCs EMISSIONS			
STEP 1				
Type of Halocarbon	A Quantity of Halocarbon Produced (t)	B Emission Factor (kg halocarbon by-product per tonne halocarbon produced)	C Halocarbon Emitted (kg)	D Halocarbon Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	PRODUCTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE			
WORKSHEET	2-14			
SHEET	2 OF 2 FUGITIVE EMISSIONS - HFCs AND PFCs EMISSIONS			
STEP 2				
Type of Halocarbon	A Quantity of Halocarbon Produced (t)	B Emission Factor (kg halocarbon lost per tonne halocarbon produced)	C Halocarbon Emitted (kg)	D Halocarbon Emitted (Gg)
			$C = (A \times B)$	$D = C/10^6$

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE - TIER 1a AND TIER 1b - SUMMARY OF HALOCARBONS EMISSIONS		
WORKSHEET	2-15		
SHEET	3 OF 13		
HALOCARBON NAME			
STEP 3			
J Potential Bulk Halocarbon Emissions (t)	K Potential Product Halocarbon Emissions (t)	L Total Potential Halocarbon Emission (t)	M Total Potential Halocarbon Emissions (Gg)
J= E from Step 1	K= I from Step 2	L = J + K	M = M/10 ³

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE		
REFRIGERATION TYPE			
HALOCARBON NAME			
WORKSHEET	2-15		
SHEET	4 OF 13 REFRIGERATION ASSEMBLY - TIER 2 - HFCs AND PFCs EMISSIONS		
STEP 4			
A Amount of HFC/PFC Charged into New Systems in Year t (E _{charged} (t)) (t)	B Assembly Losses (k) (%)	C Halocarbon Emitted (t)	D Halocarbon Emitted (Gg)
		C= (A x B)	D = C/10 ³



MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE		
REFRIGERATION TYPE			
HALOCARBON NAME			
WORKSHEET	2-15		
SHEET	5 OF 13 REFRIGERATION OPERATION - TIER 2 - HFCs AND PFCs EMISSIONS		
STEP 5			
E Amount of HFC/PFC Stocked in Existing Systems in Year t ($E_{\text{stock}(t)}$) (t)	F Annual Leakage Rate (x) (%)	G Halocarbon Emitted (t)	H Halocarbon Emitted (Gg)
		$G = E \times F/100$	$H = G/10^3$

MODULE	INDUSTRIAL PROCESSES				
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE				
REFRIGERATION TYPE					
HALOCARBON NAME					
WORKSHEET	2-15				
SHEET	6 OF 13 REFRIGERATION DISPOSAL - TIER 2 - HFCs AND PFCs EMISSIONS				
STEP 6					
I Amount of HFC/PFC Charged into New Systems in Year t-n ($E_{\text{charge}(t-n)}$) (t)	J Average Equipment Lifetime (n) (years)	K Amount of HFC/PFC in Systems at Time of Disposal in Per Cent of Original Charge (y) (%)	L Amount of HFC/PFC Recovered in Per Cent of Actual Charge (z) (%)	M Halocarbon Emitted (t)	N Halocarbon Emitted (Gg)
				$M = I \times [K/100] \times [(100 - L)/100]$	$N = M/10^3$

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES		
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE		
REFRIGERATION TYPE			
HALOCARBON NAME			
WORKSHEET	2-15		
SHEET	7 OF 13 REFRIGERATION SUMMARY - TIER 2 - HFCs AND PFCs EMISSIONS		
STEP 7			
O Assembly (Gg)	P Operation (Gg)	Q Disposal (Gg)	R Total Halocarbon Emissions (Gg)
O = D (from Step 4)	P = H (from Step 5)	Q = N (from Step 6)	R =(O+P+Q)

MODULE	INDUSTRIAL PROCESSES					
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE					
WORKSHEET	2-15					
SHEET	8 OF 13 FOAM PRODUCTS - TIER 2 - HFCs AND PFCs EMISSIONS					
STEP 8						
Foam Type	A Quantity of HFC/PFC Used (t)	B Quantity of HFC/PFC in Use (t)	C Fraction Loss during Production (%/100)	D Fraction Loss during Use (%/100)	E HFC/PFC Emitted (t)	F HFC/PFC Emitted (Gg)
					$E = (A \times C) + (B \times D)$	$F = E/10^3$
Open		NA		NA		
Closed						
NA= Not Applicable					Total (Gg):	

MODULE	INDUSTRIAL PROCESSES				
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE				
WORKSHEET	2-15				
SHEET	9 OF 13 FIRE EXTINGUISHERS - TIER 2 - HFCs, PFCs AND SF ₆ EMISSIONS				
STEP 9					
Extinguisher Type	A Total Quantity of HFC/PFC/SF ₆ Used in New Extinguishers (t)	B Fractional Loss Factor (%/100)	C HFC/PFC/SF ₆ Emitted (t)	D HFC/PFC/SF ₆ Emitted (Gg)	
			$C = (A \times B)$	$D = C/10^3$	
Portable					
Fixed					
				Total (Gg):	



MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE			
WORKSHEET	2-15			
SHEET	10 OF 13 - TIER 2 - AEROSOLS - HFCs AND PFCs EMISSIONS			
STEP 10				
A Use of HFCs/PFCs for Aerosols in Inventory Year (t)	B Use of HFCs/ PFCs for Aerosols in Prior Year (t)	C Loss of Current Year's Use	D Emission of HFCs/PFCs from Aerosols (t)	E Emission of HFCs/PFCs from Aerosols (Gg)
			$D = (A \times C) + B (1 - C)$	$E = D/10^3$

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE			
WORKSHEET	2-15			
SHEET	11 OF 13 SOLVENTS - TIER 2 - HFCs AND PFCs EMISSIONS			
STEP 11				
A Use of HFCs/PFCs for Solvents in Inventory Year (t)	B Use of HFCs/ PFCs for Solvents in Prior Year (t)	C Loss of Current Year's Use	D Emission of HFCs/PFCs from Solvents (t)	E Emission of HFCs/PFCs from Solvents (Gg)
			$D = (A \times C) + B (1 - C)$	$E = D/10^3$

MODULE	INDUSTRIAL PROCESSES			
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE			
WORKSHEET	2-15			
SHEET	12 OF 13 OTHER APPLICATIONS - TIER 2 - HFCs AND PFCs EMISSIONS			
STEP 12				
A Use of HFCs/PFCs for Other Applications in Inventory Year (t)	B Use of HFCs/ PFCs for Other Applications in Prior Year (t)	C Loss of Current Year's Use	D Emission of HFCs/PFCs from Other Applications (t)	E Emission of HFCs/PFCs from Other Applications (Gg)
			$D = (A \times C) + B (1 - C)$	$E = D/10^3$

INDUSTRIAL PROCESSES

MODULE	INDUSTRIAL PROCESSES				
SUBMODULE	CONSUMPTION OF HALOCARBONS AND SULPHUR HEXAFLUORIDE				
WORKSHEET	2-15				
SHEET	13 OF 13 SF₆ EMISSIONS				
STEP 13					
A Quantity of SF ₆ in Use in Inventory Year (t)	B Loss Factor for SF ₆ in Use (%/100)	C Quantity of SF ₆ in Use 30 Years Prior to the Inventory Year (t)	D Fraction Remaining in SF ₆ Equipment at Time of Disposal (%/100)	E SF ₆ Emitted (t)	F SF ₆ Emitted (Gg)
				$E = (A \times B) + (C \times D)$	$F = E/10^3$