## 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 $CO_2$, $CH_4$, $N_2O$, 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.

**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.

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.

$CO_2$ 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 $N_2O$ emissions are recognised as important anthropogenic contributors to global $N_2O$ emissions. It is estimated that this source category represents 10 to 50 per cent of anthropogenic $N_2O$ emissions and 3 to 20 per cent of all global emissions of $N_2O$ (IPCC, 1992).

HFCs, PFCs and $SF_6$ 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 $SF_6$, 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.

## 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:

$$\boxed{TOTAL_{ij} = A_j \times EF_{ij}}$$

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.

$SO_2$ emissions will originate from sulphur in the fuel and in the clay raw material. The fuel emissions are counted as energy emissions while the $SO_2$ 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 $CO_2$

Because $CO_2$ 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 $CO_2$ emissions from clinker production is accomplished by applying an emission factor, in tonnes of $CO_2$ released per tonne of clinker produced, to the annual clinker output.

### 2.3.2 Methodology for Estimating Emissions of $SO_2$

Estimation of $SO_2$ emissions from cement production is accomplished by applying an emission factor, in terms of $SO_2$ released per tonne of cement produced, to the annual cement output. A non-combustion emission factor of 0.3 kg $SO_2$/tonne cement has been calculated (see the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual* for sources).

## Completing the Worksheet

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

**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 $CO_2$ 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 $CO_2$ 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:

   Emission Factor (t $CO_2$/t clinker) = 0.5701 x (f) / 0.646

   For cement production enter the Emission Factor of 0.4985 tonnes of $CO_2$ 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:

   Emission Factor (t $CO_2$/t cement) = 0.4985 x (f) / 0.635

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 2 ESTIMATING $SO_2$ EMITTED

1. Estimate Quantity of Cement Produced and enter this value in column A in tonnes.

2. Enter the Emission Factor in kg $SO_2$/tonne cement in column B. If no information on sulphur content and degree of absorption is available, enter a default of 0.3 kg $SO_2$/tonne cement.

3. Multiply column A by column B to obtain $SO_2$ Emitted in kg of $SO_2$, and enter this value in column C.

4. Divide column C by $10^6$ to convert to units of gigagrams $SO_2$, 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 ~ 1100° 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).

**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.

## 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.

**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.

**TABLE 2-1**
**SUMMARY OF EMISSION FACTORS FOR LIME PRODUCTION**

| 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.

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.

5 Sum the values in column D and enter the result in the bottom of the column to obtain the total $CO_2$ Emitted.

## 2.5 Limestone and Dolomite Use

### Introduction

**LIMESTONE USE**

$CO_2$ 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 $CO_2$ emissions.

In industrial applications involving the heating of limestone or dolomite at high temperatures, $CO_2$ 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 $CO_2$

Estimation of $CO_2$ emissions from limestone use is accomplished by applying an emission factor, in kilograms of $CO_2$ 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 $CO_2$ 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 $CO_2$ EMITTED

1 Estimate Quantity of Limestone or Dolomite Used and enter these values in column A in tonnes.

2 For the calculation of $CO_2$ emissions from limestone use, enter the Emission Factor of 440 kg of $CO_2$ per tonne of limestone used in column B. If the fractional purity (f) of limestone in $CaCO_3$ per tonne of total raw material is known, the emission factor can be converted as follows:

Emission Factor (kg $CO_2$/t limestone) = 440 x (f )

For the calculation of $CO_2$ emissions from dolomite use, enter the emission factor of 477 kg of $CO_2$ per tonne of dolomite used in column B. If the fractional purity (f) of dolomite in $CaCO_3 \cdot MgCO_3$ per tonne of total raw material is known, the emission factor can be converted as follows:

Emission Factor (kg $CO_2$/t dolomite) = 477 x (f )

3 Multiply column A by column B to obtain $CO_2$ Emitted in kilograms of $CO_2$, and enter this value in column C.

4 Divide column C by $10^6$ to convert to units of gigagrams $CO_2$, 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 $CO_2$ 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 $CO_2$ 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.

**DOUBLE COUNTING**

In order to avoid double counting, $CO_2$ 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.

### 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).

### 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 $CO_2$ emission from the Solvay Process.

#### STEP 1 ESTIMATING $CO_2$ 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 $CO_2$ per tonne of trona in column B.

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 2 ESTIMATING $CO_2$ 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 $CO_2$ per tonne of soda ash used in column B.

3 Multiply column A by column B to obtain $CO_2$ Emitted in kilograms of $CO_2$, and enter this value in column C.

4 Divide column C by $10^6$ to convert to units of gigagrams $CO_2$, 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.

**TABLE 2-2**
**EMISSION FACTORS FOR ASPHALT ROOFING PRODUCTION (KG/TONNE PRODUCT)[a]**

| | 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.

**TABLE 2-3**
**EMISSION FACTORS FOR ASPHALT BLOWING PROCESS (KG/TONNE PRODUCT)**

| | 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/$m^2$ 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 $SO_2$)

### Concrete Pumice Stone Production

The production of concrete pumice stone is similar to cement production in that $SO_2$ emissions will originate from the fuel use and the sulphur in clay. About 45 per cent of the $SO_2$ generated in the process will be sequestered in the product. An emission factor of approximately 0.5 kilograms $SO_2$ /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.

**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 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.

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 $SO_2$ 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 $SO_2$ per tonne of product) in column B in kilograms of $SO_2$ per tonne of product produced.

3 Multiply column A by column B to obtain $SO_2$ Emitted in kilograms of $SO_2$ and enter this value in column C.

4 Divide column C by $10^6$ to convert to units of gigagrams $SO_2$ 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 $CH_4$) 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 ($NH_3$). The remaining carbon is eventually emitted as $CO_2$.

Emissions of $NO_x$, NMVOC, CO and $SO_2$ 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 $CO_2$

Emissions of $CO_2$ 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 $m^3$ gas/tonne $NH_3$ and 0.525 kg carbon/$m^3$ gas.

**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.

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 $CO_2$ per tonne $NH_3$ 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 $CO_2$ 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 $CO_2$ in downstream manufacturing processes and products.

## 2.8.2 Methodology for Estimating Emissions of NMVOC, CO and $SO_2$

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

**TABLE 2-4**
**EMISSION FACTORS FOR AMMONIA PRODUCTION (KG/TONNE PRODUCT)**

| 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 t $CO_2$/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 $SO_2$ 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 $SO_2$.

2 Enter the corresponding Emission Factor for each pollutant NMVOC, CO and $SO_2$ 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 $SO_2$ in column C.

4 Divide column C by $10^6$ to convert to units of gigagrams for each pollutant NMVOC, CO and $SO_2$, and enter this value in column D.

## 2.9 Nitric Acid Production

### Introduction

The production of nitric acid ($HNO_3$) generates nitrous oxide ($N_2O$) as a by-product of the high temperature catalytic oxidation of ammonia ($NH_3$).

### 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 $N_2O$

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.

**TABLE 2-5**
**EMISSION FACTORS FOR $N_2O$ FROM NITRIC ACID PRODUCTION**

| | Emission Factor kg $N_2O$/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 $N_2O$/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 $N_2O$ 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.

**TABLE 2-6**
**EMISSION FACTORS FOR $NO_X$ FROM NITRIC ACID PRODUCTION**

| 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 $N_2O$ 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 $N_2O$ 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).

**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.

## 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).

**TABLE 2-7**
**EMISSION FACTORS FOR ADIPIC ACID PRODUCTION (KG/TONNE PRODUCT)**

| $NO_X$ | 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 $N_2O$, $NO_X$, 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 $N_2O$, a default value of 300 kg $N_2O$/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 $10^6$ 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 $CO_2$, $CH_4$, CO and $SO_2$.

### 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 $CO_2$ and $CH_4$ from Silicon Carbide Production

#### $CO_2$ Emissions

In the production of silicon carbide, $CO_2$ 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 $CO_2$/tonne coke.

### $CH_4$ Emissions

The petrol coke used in this process may contain volatile compounds which will form $CH_4$. Some of this $CH_4$ will escape to the atmosphere, particularly during start up. Measurements at Norwegian plants suggest emission factors of 10.2 kg $CH_4$/tonne petrol coke or 11.6 kg $CH_4$/tonne carbide product.

## 2.11.2 Methodology for Estimating Emissions of $CO_2$ from Calcium Carbide Production

Calcium carbide is made by heating calcium carbonate ($CaCO_3$) and subsequently reducing lime (CaO) with carbon (e.g., petrol coke). Both steps lead to emissions of $CO_2$.

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 $CaCO_3$. 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.

**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 reported as emissions from calcium carbide manufacture.

**TABLE 2-8**
**EMISSION FACTORS FOR $CO_2$ FROM CALCIUM 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 |

### Completing the Worksheet

Use WORKSHEET 2-9 CARBIDE PRODUCTION - to enter data for this submodule. If the quantity of coke consumed is not known, $CO_2$ emissions can be estimated from carbide production data. See method presented for calcium carbide production.

For $CH_4$ 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.

**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.

### Silicon Carbide

### STEP 1 ESTIMATING $CO_2$ 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.

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 x $10^{-4}$ to obtain $CO_2$ Emitted in tonnes, and enter this value in column D.

5 Divide column D by $10^3$ to convert to units of gigagrams $CO_2$, and enter this value in column E.

*Tier 1a - Based On Petrol Coke Consumption*

### STEP 2 ESTIMATING $CH_4$ EMITTED FROM SILICON CARBIDE PRODUCTION - TIER 1a

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 $CH_4$ per tonne of petrol coke consumed, in column B. The suggested emission factor is 10.2 kg $CH_4$/tonne petrol coke if no other information is available.

3 Multiply column A by column B to obtain $CH_4$ Emitted in kg and enter this value in column C.

4 Divide column C by $10^6$ to convert to units of gigagrams $CH_4$, and enter this value in column D.

*Tier 1b - Based On Silicon Carbide Production*

### STEP 3 ESTIMATING $CH_4$ EMITTED FROM SILICON CARBIDE PRODUCTION- TIER 1b

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 $CH_4$ per tonne of carbide produced, in column B. An emission factor of 11.6 kg $CH_4$/tonne carbide product can be used if no other information is available.

3 Multiply column A by column B to obtain $CH_4$ Emitted in kg, and enter this value in column C.

4 Divide column C by $10^6$ to convert to units of gigagrams $CH_4$, and enter this value in column D.