2.15 Food and Drink

2.15.1 Alcoholic Beverages

NMVOCs are produced during the processing of cereals and fruits in preparation for the fermentation processes The activity rate is the total annual production. The emission factors given in the EMEP/CORINAIR Guidebook (SNAP 40606-40608) are shown in Table 2-24.

TABLE 2-24 EMISSION FACTORS FOR ALCOHOLIC BEVERAGE PRODUCTION (KG/HL 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

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

2.15.2 Bread Making and Other Food

The relevant precursor gas emitted during food production (SNAP 40605) is NMVOC. Emissions from processes not included are vegetable oil extraction (SNAP 60404), tobacco products and alcoholic beverages (see Section 2.15.1). Emissions are included from all processes in the food chain which occur after the slaughtering of animals or harvesting of crops.

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 2-25.

The activity rate is the total annual production of food. The emission factors and sources are derived for Europe; there may be different processes and emission factors in other parts of the world.

TABLE 2-25 EMISSION FACTORS FOR BREAD AND OTHER FOOD PRODUCTION (KG/TONNE)	
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

2.16 Emissions Related to Production of Halocarbons and Sulphur Hexafluoride (HFCs, PFCs and SF$_6$)

2.16.1 By-product Emissions

Chemical by-products of industrial processes, substances which are different from the desired end-product, may be released into the atmosphere. It is well known that HFC-23 is produced along with HCFC-22 and it is estimated that the HFC-23 released from this source is currently equivalent to 4 per cent of the production of HCFC-22 (U.S. EPA, 1994b) assuming no abatement measures.

In the Tier 1 methodology (Section 2.17.3), 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). Problems with collecting specific component data can be circumvented by providing a single number for total emissions of HFC-23.

> By-product Emissions (tonnes) = By-product Factor (tonnes/tonne)
> x Total HCFC-22 Production (tonnes)

For the Tier 2 methodology (Section 2.17.4), a potentially more accurate estimate is the sum of factory specific emissions determined using standard methods to estimate the composition and flowrate of gas streams vented to atmosphere. In this case:

$$\text{By-product Emissions} = \sum_i \sum_j \int_t f_{ij} C_{ij}$$

where:

> the sum over all i plants, over all j streams in each plant of the emitted flows f and concentrations c is integrated over time (t).

Other by-product emissions of HFCs, PFCs and other greenhouse gases from chemical production processes should be identified and treated in the same way.

2.16.2 Fugitive Emissions

Fugitive emissions of a chemical occur during the production and distribution of a chemical. In this chapter, fugitive emissions associated with use are not addressed specifically, being counted in the emissions 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).

In the Tier 1 methodology, 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. Problems with collecting specific component data can be circumvented by providing a single number for total emissions of each HFC and PFC.

> Fugitive Emissions (tonnes) = Fugitive Release Factor (tonnes/tonne)
>
> x Individual HFC or PFC Production (tonnes)

For a Tier 2 methodology, a potentially more accurate estimate is the sum of factory specific emissions determined using standard methods to estimate the composition and flowrate of gas streams vented to atmosphere. In this case:

$$\text{Fugitive Emissions} = \sum_i \sum_j \int_t f_{ij} C_{ij}$$

where:

> the sum over all i plants, over all j streams in each plant of the emitted flows f and concentrations c integrated over time (t).

2.17 Emissions Related to Consumption of Halocarbons and Sulphur Hexafluoride (HFCs, PFCs, and SF$_6$)

2.17.1 Overview

Partially fluorinated hydrocarbons (HFCs), perfluorinated hydrocarbons (PFCs), and sulphur hexafluoride (SF$_6$) are serving as alternatives to ozone depleting substances (ODS) being phased out under the Montreal Protocol. Current and expected application areas of HFCs and PFCs include (Kroeze, 1995; U.S. EPA, 1992b):

- refrigeration and air conditioning

- fire suppression and explosion protection

- aerosols

- solvent cleaning

- foam blowing

- other applications[5]

Primary uses of SF_6 include:

- gas insulated switch gear and circuit breakers

- fire suppression and explosion protection

- other applications[6]

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.

HFCs are chemicals containing only hydrogen, carbon, and fluorine. Prior to the Montreal Protocol and the phase-out of various ozone depleting substances (ODS), the only HFCs produced were HFC-152a, which is a component of the refrigerant blend R-500, and HFC-23, a low temperature refrigerant which is a by-product of HCFC-22[7] production. HFC-134a entered production in 1991 and a variety of other HFCs are now being produced (Enquete Commission, 1994).

PFCs are chemicals containing only carbon and fluorine. PFCs have been produced commercially for 30 years, primarily for use as cooling/heating agents in specialised market segments and in vapour phase reflow soldering and electronic safety testing (Kroeze, 1995). Like HFC emissions, PFC emissions result from two sources; emissions from commercial use of PFCs and emissions as by-products of industrial processes. PFCs are anthropogenic compounds; no natural sources have been found, though a small, but as yet unidentified, natural source of one PFC is suspected (Abrahamson, 1992).

SF_6 is a particularly potent GHG with a 100-year GWP of 23,900 and an estimated lifetime of about 3200 years (IPCC, 1996)(Table 2-26).

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

Table 2-26 gives an overview over the most important HFCs and PFCs (U.S. EPA, 1992b; UNEP, 1994; Kroeze, 1995), including application area and GWP relative to CO_2 (100 year integration time). The various HFCs and PFCs have very different strengths as GHGs. PFCs have particularly high GWPs. The consumption pattern with respect to the individual gases must be known, therefore, or estimated with reasonable accuracy, to achieve useful estimates for the contribution to global warming from emission of these groups of chemicals.

---

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

[6] SF_6 may be used as an insulating medium, tracer, in leak detectors, and in various electronic applications. Aluminium and magnesium foundries are also major users of SF_6, but the emissions associated with these industries are covered in Section 2.13.8

[7] HCFCs - hydrochlorofluorocarbons.

As CFCs, halons, carbon tetrachloride, methyl chloroform, and, ultimately, HCFCs are phased out, HFCs are likely be widely used as replacements. PFCs may be used to a limited extent. Even though up to 75 per cent of current application of CFC may be covered by different technologies in the future (McFarland and Kaye, 1992), HFC use is expected to grow substantially.

NF_3 is another gas which is likely to contribute to global warming. It may be used for chip etching (Cook, 1995) but is not included here.

TABLE 2-26							
POTENTIAL APPLICATION AREAS AND GLOBAL WARMING POTENTIALS (GWPs) FOR HFCs, PFCs, AND SF$_6$							
Chemical	GWP[a]	Refrigeration and Air Conditioning	Fire Suppression and Explosion Protection	Aerosols	Solvent Cleaning	Foam Blowing	Other Applications[b]
HFC-23	11700	x	x				
HFC-32	650	x					
HFC-125	2800	x	x	x		x	x
HFC-134a	1300	x	x	x		x	x
HFC-143a	3800	x				x	
HFC-152a	140	x		x		x	
HFC-227ea	2900	x	x	x			x
HFC-236fa	6300	x				x	
HFC-245ca	560	x				x	
HFC-356						x	
HFC-43-10					x		
PFC-116	9200	x					
PFC-218	7000	x					
PFC-410	7000		x				
PFC-614			x		x		
Other PFCs[c]					x		
SF$_6$ [d]	23900		x				x
[a] 100 year time horizon (IPCC, 1996).							
[b] Other applications include sterilisation equipment, tobacco expansion applications, and as solvents in the manufacture of adhesive coatings and inks (Kroeze, 1995; U.S. EPA, 1992b).							
[c] E.g., PFC-512, PFC-612, PFC-716, PFC-819.							
[d] Gas insulated switchgear and circuit breakers.							

2.17.2 General Methodology

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

<u>Potential emissions</u> 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 export in the year of consideration. All chemicals consumed will eventually be emitted to the atmosphere over time if not destroyed[8], and in the long term (e.g., 50 yrs), potential emissions will equal actual emissions.

However, the method does not take into account accumulation or possible release[9] of chemical in various products and equipment, which means over the short term (e.g., 10-15 yrs) estimates may become very inaccurate. Since accumulation is thought to be the dominant process at the present time, potential emission calculations will strongly over estimate emissions.

The error is minimised when enough time has passed for HFC/PFC-containing equipment and products to begin to be retired. However, as long as emissions lag behind consumption and consumption continues to grow, the overestimation will persist. The error is zero only if there is no delay in emissions or if the consumption growth rate is zero for a long period of time.

<u>Actual emission</u> 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 lag results from the fact that a chemical is placed in new products and then slowly leaks out over time. A household refrigerator, for example, emits only small amounts of refrigerant through leakage and emissions during servicing throughout its lifetime and most of its charge is not released until its disposal, many years after production.

The amount of a chemical escaping to the atmosphere in a given year will only be similar to the quantity consumed in a static situation with respect to chemical usage pattern, market development, system or product design and tightness, servicing and recovery practices, etc. This is very different from the current situation. Since countries are only beginning to use and produce the chemicals, only a small fraction of products with HFCs/PFCs are being stored in the market.

Until a more stationary situation is established, which may take 15-20 years for industrialised countries and an additional 10 years for developing countries, the time lag between consumption and emission has to be taken into account to achieve reasonably correct estimates for annual emissions.

Hence, 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 more simple approach for reasonable emission estimates.

The following procedures described for HFCs/PFCs are applicable for SF_6 as well.

_____

[8] The destruction of fluorocarbons could be costly but there are several destruction processes recommended by the Parties to the Montreal Protocol: liquid injection incineration; reactor cracking; gaseous/fume oxidation; rotary kiln incinerators; cement kilns; plasma destruction; municipal solid waste incinerators (foams only).

[9] If non-halocarbon technology takes over market shares.

2.17.3 Tier 1: Basic Method

2.17.3.1 Overview

Potential emission calculations are regarded as the basic methodology for HFC and PFC emission estimates, which any country should apply. However, if relevant information is available, it is recommended that emissions are reported according to the Tier 2 methodology in Section 2.17.4.

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

> Potential Emissions = Production + Imports - Exports - Destruction

Although destruction of HFCs and PFCs is currently not practised, and may be technically difficult (U.S. EPA, 1995), it should be included as a future option to reduce emissions. 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. Reprocessing of recovered fluid should not be included. Imports and exports include bulk chemicals and may or may not include the quantity of chemical contained in products, such as refrigerators, air-conditioners, packaging materials, insulating foams, fire extinguishers etc.

There are two versions of Tier 1 (a and b) depending upon whether HFCs/PFCs in products are taken into account. In Tier 1a, chemicals contained in products are _not_ considered. In Tier 1b, chemicals contained in products _are_ considered. The reason for two versions is that it is expected that there may be difficulties in many countries with the availability of data regarding imports and exports of HFCs/PFCs in products, at least in the short term. The Tier 1b methodology is preferred if relevant data are available.

Irrespective of the Tier 1 methodology chosen, emissions with respect to individual HFCs and PFCs have to be reported. Information on the practical use of the various commercial types of HFC/PFC refrigerants, blowing agents, solvents, etc. will be required. Many of these products are mixtures of two to four HFCs/PFCs, and the composition of fluids for similar purposes may vary according to individual formulas developed by the different chemical companies.

2.17.3.2 Tier 1a

Quantities of HFCs/PFCs contained in various products imported into or exported from a country may be difficult to estimate. In Tier 1a, only chemicals imported or exported in bulk are considered in the calculation of potential emissions, which is a similar approach presently used to report Ozone Depleting Substances (ODS) under the Montreal Protocol. The following definitions apply:

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

The application of Tier 1a may lead to underestimation or overestimation of potential emissions, depending on whether the majority of HFC/PFC containing products is being imported or exported.

Data on production and exports of chemicals in bulk should be available from chemical companies. Information on imports of chemicals in bulk may be available from customs services. National environmental protection authorities may keep records of HFCs/PFCs destroyed, if any.

Potential emission data for each individual chemical should be calculated according to the scheme in Table 2-27:

TABLE 2-27 CALCULATION SCHEME FOR POTENTIAL EMISSIONS ACCORDING TO TIER 1a	
Reporting year:	
Type of chemical (e.g., HFC-134a):	
Production of chemical	tonnes
+ Import of chemical in bulk	tonnes
- Export of chemical in bulk	tonnes
- Destruction of chemical	tonnes
= Sum (potential emission of chemical)	tonnes

Emissions related to production and distribution of HFCs/PFCs have to be taken into account as described in Section 2.16.2.

2.17.3.3 Tier 1b

Tier 1b is an extension of Tier 1a and includes HFCs/PFCs contained in various products which are imported and exported. The following definitions then 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

Data on production and exports of HFCs/PFCs in bulk should be available from the chemical companies to their national governments. Information on imports of bulk chemicals should be available from customs services, as well as imports and exports of products and equipment containing HFCs or PFCs. National environmental protection authorities may keep records of HFCs/PFCs destroyed.

To calculate the potential emissions according to Tier 1b, the calculation scheme in Table 2-27 has to be extended to include the import and export of chemicals in products. Table 2-28 demonstrates a possible set-up for calculation of emissions from exports/imports and the results should be added to the emissions calculated using Table 2-27. In Table 2-28, HFC-xxx is used as an example to demonstrate the procedure, which in practice will have to be performed for individual HFCs and PFCs, and with SF_6.

TABLE 2-28
ADDITIONAL CALCULATIONS FOR ESTIMATING
POTENTIAL EMISSIONS ACCORDING TO TIER 1B

Refrigeration

$$G_{HFC-xxx} \quad = \quad G(\text{Unit } i) \times n(\text{Unit } i) \times F_{HFC-xxx}(\text{Unit } i) + \ \text{-----} + \\ G(\text{Unit } m) \times n(\text{Unit } m) \times F_{HFC-xxx}(\text{Unit } m)$$

where:

$G_{HFC-xxx}$ = total import (export) of HFC-xxx in precharged refrigeration units[10]

$G(\text{Unit } i)$ = refrigerant charge in a refrigeration unit of type "i" ($i = i \rightarrow m$)

$n(\text{Unit } i)$ = number of refrigeration units of type "i" imported (exported)

$F_{HFC-xxx}$ = fraction of component HFC-xxx[11] in the refrigerant (mixture) of a unit of type "i"

Foam products[12]

$$G_{HFC-xxx} \quad = \quad V(\text{Foam } i) \times J_{HFC-xxx}(\text{Foam } i) + \ \text{-------} + \\ V(\text{Foam } m) \times J_{HFC-xxx}(\text{Foam } m)$$

where:

$G_{HFC-xxx}$ = total import (export) of HFC-xxx in foams (flexible and rigid)

$V(\text{Foam } i)$ = volume of foam of type "i" imported (exported) ($i = i \rightarrow m$)

$J_{HFC-xxx}$ = remaining amount of blowing agent HFC-xxx per volume unit of foam of type "i"

----

[10] "Refrigeration units" may be refrigerators, ice machines, AC window units, split-units, chillers etc. Typical charge ranges for various types of equipment are given in Section 2.17.4.2.

[11] Many refrigeration units will contain HFC/PFC-mixtures. The fraction of each chemical (HFC-xxx) has to be considered.

[12] 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.

Fire extinguishers

$$G_{HFC-xxx} = G(Unit\ i) \times n(Unit\ i) \times F_{HFC-xxx}(Unit\ i) + \cdots + G(Unit\ m) \times n(Unit\ m) \times F_{HFC-xxx}(Unit\ m)$$

where:

$G_{HFC-xxx}$ = total import (export) of HFC-xxx in precharged fire extinguishers

$G(Unit\ i)$ = charge of fire extinguishing agent in a fire extinguishing unit of type "i" (i = l → m)

$n(Unit\ i)$ = number of fire extinguishing units of type "i" imported (exported)

$F_{HFC-xxx}$ = fraction of component HFC-xxx[13] in the fire extinguishing agent of a unit of type "i"

Solvents

$$G_{HFC-xxx} = G(Solvent\ i) \times F_{HFC-xxx}(Solvent\ i) + \cdots + G(Solvent\ m) \times F_{HFC-xxx}(Solvent\ m)$$

where:

$G_{HFC-xxx}$ = total import (export) of HFC-xxx in solvents

$G(Solvent\ i)$ = quantity of solvent of type "i" imported (exported) (i = i → m)

$F_{HFC-xxx}$ = fraction of component HFC-xxx[14] in solvent of type "i"

Aerosols

$$G_{HFC-xxx} = G(Can\ i) \times n(Can\ i) + \cdots + G(Can\ m) \times n(Can\ m)$$

where:

$G_{HFC-xxx}$ = total import (export) of HFC-xxx in aerosol cans

$G(Can\ i)$ = charge of HFC-xxx propellant in an aerosol can of type "i" (i = i → m)

$n(Can\ i)$ = number of aerosol cans of type "i" imported (exported)

---

[13] Most fire extinguishing units will contain HFC/PFC-mixtures. The fraction of each chemical (HFC-xxx) has to be considered.

[14] Solvents will normally not be pure HFCs or PFCs. The fraction of the HFC/PFC in consideration (HFC-xxx) has to be considered.

2.17.4 Tier 2: Advanced Method

2.17.4.1 Overview

The advanced method, Tier 2, contains *actual emission calculations for each individual chemical,* comparable with methods currently applied by AFEAS for CFCs and HCFCs (Gamlen et al., 1986; Fisher and Midgley, 1993; AFEAS, 1995). This is the preferred method if input data are available. Some countries may have the relevant information available already to apply the Tier 2 methodology. However, countries that do not are recommended to establish routines to report HFC/PFC emissions according to Tier 2.

The Tier 2 methodology:

a)   calculates or estimates the consumption of each individual HFC and PFC chemical at a rather detailed level, e.g., refrigerators, other stationary refrigeration/AC equipment, soft foam, hard foam etc., to establish the volume basis for emission calculations.

b)   estimates emissions on the basis of the consumption distribution from (a), and emission characteristics related to various processes and equipment, also taking current service and recovery practices into account.

Table 2-29 gives examples of current HFC/PFC use distribution 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. This information may allow countries with similar practices to those in Table 2-29 to make first order estimates for their own HFC/PFC consumption and distribution.

TABLE 2-29 EXAMPLE DISTRIBUTION OF **HFC/PFC** USE BY APPLICATION AREA (1994)						
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[a]	76%	12%	0%	7%	5%	0%

[a] March Consulting Group (1996), *UK Use and Emissions of Selected Halocarbons*, A Study for the UK Department of Environment.

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.

Nevertheless, real emission data for a given year will never be exactly known, irrespective of the refinement of the estimation methods. Cross checking of integrated emission figures against real net consumption of HFC/PFC, together with judgement of banking over the same period of time must be performed at regular intervals, and the input factors have to be adjusted to achieve agreement over time.

Examples of how the Tier 2 methodology may be applied are given in the remainder of this chapter.

2.17.4.2 Estimation Of Emissions Of HFCs And PFCs From Use In Refrigeration And Air Conditioning Equipment

Overview

HFCs and PFCs are potential replacements to the use of CFCs and HCFCs in refrigeration and air conditioning equipment. A wide array of such equipment is used globally. For the purposes of emission estimation, refrigeration and air-conditioning systems are classified into three categories, according to emission characteristics:

- Household refrigerators and freezers;

- 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;

  - commercial and residential air conditioning including chillers, heat pumps, window air conditioners, centralised air conditioners.

- Mobile air conditioners used to cool the passenger compartment of automobiles, trucks, buses, and trains.

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 (Du Pont, 1994; Fay, 1995). PFC-218 is used as a component in refrigerant blends from (at least) one manufacturer. PFC-116 may be used in a blend as a substitute for R-503. In addition, a significant portion of the refrigerant market may be taken over by non-halocarbon technologies (McFarland & Kay, 1992).

Calculation methods

Gas emissions from refrigeration and air conditioning systems result from:

- losses during system erection/assembly[15] ;

- emissions from the stock of existing systems (small leakages, breakdowns, venting at service);

- venting of refrigerant at system disposal.

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

---

[15] e.g., losses from using HFC/PFC as tracer gas for checking leak tightness, losses in relation to system development and testing etc.

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

> **EQUATION 1**
>
> $E_{assembly, t} = E_{charged, t} \cdot (k/100)$

where:

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

The amount charged ($E_{charged,t}$) 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.

Typical range for the emission factor k is 2-5 per cent (Radian Corp., 1986). For some types of unit production, alternative leak detection methods may be used. Assembly losses may then be less than indicated here, and in some cases may be negligible.

Annual leakage from the stock, including venting during service, is commonly expressed in per cent of total amount of "banked" refrigerant in the existing stock of systems. Emission rates related to current system design and service practices are available from half a century of CFC and HCFC refrigeration. The following calculation formula applies:

> **EQUATION 2**
>
> $E_{operation, t} = E_{stock, t} \cdot (x/100)$

where:

$E_{operation,t}$	=	amount of HFC/PFC emitted during system operation in year t
$E_{stock,t}$	=	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.

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

Examples of typical leakage rates (x) for various types of equipment describing the respective refrigeration sectors are given later in this section.

The amount of refrigerant released from scrapped systems depends on the amount of refrigerant left at the time of disposal, and the portion recovered. Normally, less refrigerant is left than was originally charged. From a technical point of view, the major part of the remaining fluid can be recovered.

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

> ### EQUATION 3
>
> $E_{disposal, t} = Ei_{charge\ (t-n)} \bullet (y/100) \bullet (100 - z)/100$
>
> or
>
> $E_{disposal, t} = Ei_{charge\ (t-n)} \bullet Q$

where:

$E_{disposal,t}$	=	amount of HFC/PFC emitted at system disposal in year t
$Ei_{charge\ (t-n)}$	=	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 ($Ei_{charged,\ (t-n)}$), both systems charged in the country (for home market) and systems imported precharged should be taken into account. First charge of systems made for export should not be considered.

Values applicable to n, y and z are discussed later in this section when dealing with the respective sectors.

Total emissions in year t will then be found as the sum of emissions at assembly, during operational life and at disposal:

> ### EQUATION 4
>
> $E_{total, t} = E_{assembly, t} + E_{operation, t} + E_{disposal, t}$

Estimating input data for actual emission calculations

To provide a good basis for emission calculations according to Tier 2, it appears that much detailed information (Equations 1-3) about HFC/PFC use is required. The most important information is reliable estimates for the overall consumption and consumption distribution.

In principle, there are two different approaches to determine consumption figures. One is to estimate the amounts and types of each chemical from the number of refrigerating and air conditioning systems in question ("bottom-up approach").

Alternatively, one may start with more general registrations or estimates of HFC/PFC use for refrigeration purposes, and distribute these figures among the various sectors according to the relative magnitude of each sector ("top-down approach"). A reasonably good distribution key has to be developed also with respect to the individual types of

HFCs/PFCs. Refrigeration and air conditioning organisations in the country may possess useful data with respect to the information required.

A bottom-up approach may work well when estimating emissions from refrigerating units of similar type and design, the number of which may be large but known (such as refrigerators, AC units, mobile air conditioners etc.).

The top-down approach is more general, and probably more practical for systems which are erected and charged at site, and for production of systems with large variations in purpose, design and charge. This approach is less likely to under-estimate emissions, since it is based on total HFC/PFC consumption figures.

It may be practicable to apply elements from both approaches. However, one has to be cautious about double counting.

Examples demonstrating the top-down approach are provided in Table 2-30, which shows distribution of individual HFCs/PFCs within the same sectors.

TABLE 2-30 DISTRIBUTION OF INDIVIDUAL HFCS/PFCS IN REFRIGERATION, IN NORWAY AND SWEDEN, IN 1994								
		HFC-23	HFC-32	HFC-125	HFC-134A	HFC-143A	HFC-152A	PFC-218
Household refrigeration	Norway	0	0	0	100%	0	0	0
	Sweden	0	0	0	100%	0	0	0
Other stationary equipment	Norway	<1%	<1%	19%	71%	7%	2%	<1%
	Sweden	<1%	<1%	<5%	95%	<5%	<1%	<1%
Mobile air conditioning	Norway	0	0	0	100%	0	0	0
	Sweden	0	0	0	100%	0	0	0

Estimated amounts of the various "base chemicals" going into each specified sector may follow from total quantities HFCs/PFCs consumed and the distribution keys laid down in Table 2-29. Since HFCs and PFCs have only recently entered the market, consumption figures for the various chemicals relative to each other may change somewhat over time.

These figures may be useful for countries with similar practices as those shown in the table, to make first estimates for their own HFC/PFC consumption distribution in refrigeration.

Estimating emissions from household refrigeration

Information for household refrigerators and freezers is very reliable, and emission rates in the form of leakages and service losses are very low. Average lifetime is expected to be 15 years (n in Equation 3 is equal to 15). Even though a refrigerator is sensitive with respect to low charge, it is estimated that only 1 per cent of the units in operation fail each year due to loss of charge (U.S. EPA, 1992a), resulting in an average refrigerant loss per year of 1 per cent of the total quantity banked in the stock.

A certain, but small amount of the charge of those refrigerators reaching the average lifetime will have escaped during operation. The remaining charge is emitted upon disposal of the refrigerator (Kroeze 1995; U.S. EPA 1992a). This was common practice until recently. Over the past 2-4 years, recovery and recycling practices have been

established in many countries to minimise CFC emission. Similar practices may be applied to reduce HFC/PFC emission as well.

In the industrialised world, the overwhelming majority of household refrigerators are not serviced during their lifetime (U.S. EPA, 1992a). However, recharging is very common in many developing countries, and 2 to 3 charges during the lifetime of a fridge may be typical. From this it may be deduced that the average failure rate is higher in these countries, and the physical lifetime of a refrigerator may be longer.

Emission of HFCs/PFCs during assembly, operation and disposal of household refrigerators and freezers in the year t are to be calculated according to Equations 1-4. Emission factors related to system assembly, operation and disposal (k, x and Q respectively) should be chosen according to each country's experience.

Example of common range of variation for k in the past is given under Calculation Methods earlier in this section. It is believed that k for household refrigerators and freezers belongs to the lower part of the range (2 per cent). In those cases where trace gases other than the refrigerant itself are used for leak detection, e.g., helium, k becomes practically zero.

American experience with respect to annual leakage rate, as referenced above, indicates that a typical value for x in developed countries may be 1 per cent.

The remaining charge after 15 years (y in Equation 2) is not well known, but is believed to be in the order of 90 per cent. If recovery and recycling are not practised (z in Equation 3 is equal to zero), Q becomes equal to 90 per cent. However, if one allowed for the recovery and recycling which is possible now, Q could decrease to 40 per cent. The practical recovery rate (z) for refrigerant in refrigerators is just below 50 per cent (McCulloch, 1994). Kroeze indicates a range of recovery of 30-60 per cent (Kroeze, 1995), which is consistent with the figure given by McCulloch (1994).

Reasonable estimates for the number of refrigerators and freezers manufactured in a country 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 calculated by multiplying the number of units with average charge sizes. American refrigerators have an average charge of 170 grams, while the corresponding figures for Europe and Japan are 140 grams and 137 grams respectively (Fischer et al., 1991; Fujimoto, 1991).

Refrigerators made in developing countries may have different (probably larger) average charges than those values indicated above.

Emissions from Other Stationary Refrigeration and Air Conditioning Equipment

Other stationary refrigeration and air conditioning equipment is not usually hermetically sealed and therefore has higher leak rates and requires servicing on a regular basis to replace refrigerant leaked over time. In addition, these units typically have much larger charge sizes than household refrigeration equipment.

Emissions of HFCs/PFCs during assembly, operation and disposal of other stationary refrigeration and air conditioning equipment in the year t are to be calculated according to Equations 1 to 4. Emission factors related to system assembly, operation and disposal (k, x and Q respectively) should be chosen according to each country's experience. Average system lifetime is expected to be 15 years (n in Equation 3 is equal to 15).

An example of a common range of historical variation for k is given under Calculation Methods earlier in this section. It is believed that k for factory built systems (unit

systems) belongs to the lower part of the range (2-3 per cent), while k for systems erected and charged at site are higher (4-5 per cent).

Various references (Enquete Commission, 1994; U.S. EPA, 1993; McCulloch, 1994) seem to agree that leakage emissions from other stationary equipment are approximately 17 per cent on average (x = 17%).

Since all systems leak, the average charge at the point of disposal will be less than the amount initially charged into the systems (and after topping up at service). However, exact figures are not known. If country specific data are not available, 90 per cent of that initially charged may be assumed for calculation purposes (y in Equation 2 represents 90 per cent). The charge remaining in the equipment upon retirement is normally vented (z in Equation 3 is equal to zero), which means that Q equals 90 per cent.

Emissions at assembly, during operation, and at disposal may be reduced through the implementation of future actions designed to reduce leakage and disposal emissions. Specifically, leakage rates in other stationary refrigeration and air conditioning equipment can be reduced through the use of improved valves and fittings that minimise such emissions, and emissions that occur upon service and disposal of equipment can be reduced through the use of recovery or recycling technologies.

Assuming the implementation of these technologies, leakage emissions can be reduced to as low as 3 per cent (x = 3%) per year and emissions upon retirement of equipment can be reduced by as much as 80 per cent (z = 80%, Q = 18%).

Refrigerant charge may vary over a wide range, dependent upon system size and design. The following range may indicate orders of magnitude (U.S. EPA, 1993):

- 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.

Emissions from Mobile Air Conditioning (MAC)

Car air conditioners are relatively leaky systems that require frequent servicing. Estimates for current applications are that approximately one-third of the charge is leaked each year (McCulloch, 1994), and that the remaining charge in equipment is emitted upon its retirement. Car air conditioners have typical lifetimes of 11 years (small cars) to 15 years (trucks) (UNEP, 1989). On average, a lifetime of 12 years may be assumed (n in Equation 3 is equal to 12).

Emission of HFCs/PFCs during assembly, operation and disposal of mobile air conditioners in the year t are to be calculated according to Equations 1-4. Emission factors related to system assembly, operation and disposal (k, x and Q respectively) should be chosen according to each country's experience.

New HFC systems may have less leakage, e.g., 10-20 per cent (x = 10-20%) (Arai, personal communication, 1996).

Example of common range of variation for k in the past is given under Calculation Methods earlier in this section. It is believed that k for MACs belongs to the upper part of the range (4-5 per cent).

With respect to x, a typical value according to past CFC/HCFC experience, as referenced above, is, about one third (x = 30%).

Since MACs are generally more leaky than stationary systems, average charge at the point of disposal will most probably be less than typical values for stationary systems. However, exact figures are not known. If country specific data are not available, 75 per cent of that initially charged may be assumed for calculation purposes (y in Equation 2 is equal to 75 per cent). In most cases, the refrigerant is vented at disposal (z in Equation 3 is zero), which means that Q equals 75 per cent.

With improved system components, such as improved seals, fittings, and hosing, and the use of recycling at service, emissions from MACs during normal use (x) should eventually be reduced to 10 per cent of the charge per year

In addition, recycling at disposal provides the opportunity to reduce emissions upon retirement by more than 80 per cent. If recycling is fully utilised, emission at disposal may decrease to 15 per cent of the amount originally charged (Q =15%).

According to UNEP Technical Options Report (UNEP, 1989), 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 (Nagayama, 1996).

2.17.4.3 Estimation of Emissions of HFCs and PFCs from Foam Blowing

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 (Kroeze, 1995; U.S. EPA, 1992b).

HFCs and PFCs may potentially be used as alternative blowing agents in the manufacture of open cell foam products such as cushioning and packaging foams. 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 (U.S. EPA, 1992a; Fisher and Midgley, 1993). 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

The total quantity of HFCs or PFCs used in blowing open cell foam can be calculated as the quantity (in kg or tonnes) of foam manufactured in a given year times the quantity of HCF or PFC used per kilogram or tonne of open cell foam produced.

Kroeze (1995) estimates that approximately 55 per cent of the HFC or PFC used as 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 but this would be less because the

amount in use would be reduced by a quantity equal to that recycled. Provided that 55 per cent of the blowing agent is recycled, the gas used for the blowing process will be a mixture of 45 per cent virgin chemical and 55 per cent recycled chemical.

For insulating (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 (Gamlen et al., 1986). HFC or PFC emissions from insulating foam in year t are therefore calculated as follows:

> Emissions of HFCs or PFCs in year t
>
> =
>
> 10 per cent of the total quantity of HFC or PFC used in manufacturing new insulating foam in year t
>
> +
>
> 4.5 per cent of the quantity of original HFC or PFC charge blown into the insulated foam manufactured between year t and year t-20

The total quantity of HFCs or PFCs used in blowing insulating foam can be calculated as the quantity (in kg or tonnes) of new foam manufactured in a given year times the quantity of HFC or PFC used per kilogram or tonne of new insulating foam produced and with 10 per cent production lost added. Typically, the blowing agent accounts for 6-15 per cent of the total foam weight (Fischer et al., 1991).

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.

Finally, Kroeze (1995) estimates that approximately half of the quantity of chemical emitted during the blowing of insulating foam could be reduced through recycling and/or leakage control and that approximately 80 per cent of the HFCs or PFCs contained in insulating foam at retirement could be recycled or destroyed (approximately 30 to 40 per cent of the charge remains in the foam upon retirement). If such potential future actions are implemented, then emissions in year t from insulating foam can be calculated as follows:

> Emissions of HFCs or PFCs in year t
>
> =
>
> 5% of the total quantity of HFC or PFC sold for use in manufacturing new insulating foam in year t
>
> +
>
> 3.6% of the total HFC or PFC contained in the existing stock of insulating foam in year t.

The production losses of 5 per cent represents net losses, that is the amount of blowing agent escaped from the process minus the amount of blowing agent recovered.

2.17.4.4 Estimation of Emissions of HFCs, PFCs, and SF$_6$ from Fire Extinguishing

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 (U.S. EPA, 1992b; Kroeze, 1995).

McCulloch (1992) estimates that 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, add to the bank of fire extinguishing chemicals.

Replacement HFCs and PFCs for fire extinguishing equipment are likely to be emitted at lower rates than the halons they replace, due to improved testing and practising procedures. Until these new procedures are adopted, however, emission rates for replacement chemicals may be similar to those for existing systems.

The method used to estimate emissions here is appropriate for the mature market for fire extinguishing agents. Transition to HFCs and PFCs in this market would result in a relatively rapid increase in the banks of these materials held in equipment while the bank of halons would decline. Unless there is a requirement to replace the halons bank, the equations developed for halon emissions should be appropriate for HFCs and PFCs in this application and so the estimate for HFC or PFC emissions from portable equipment in year t would be:

> Emissions of HFCs or PFCs in year t
>
> =
>
> 60 per cent of the total quantity of HFC or PFC used in new portable halocarbon fire extinguishing equipment installed in year t

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

> Emissions of HFCs or PFCs in year t
>
> =
>
> 35 per cent of the total quantity of HFC or PFC used new fixed halocarbon fire extinguishing equipment installed in year t

Finally, McCulloch estimates that HFC and PFC emissions from the fire extinguishing equipment sector could eventually be reduced to 30 per cent of total sales for portable systems and 15 per cent of sales for fixed systems based on improved housekeeping, servicing, and bank management practices.