

Environmental RTDI Programme 2000–2006

CLIMATE CHANGE
Emissions of Industrial Greenhouse Gases
(HFCs, PFCs and Sulphur Hexafluoride)
(LS-5.1.3a & LS-5.1.3b)

Final Report

Prepared for the Environmental Protection Agency

by

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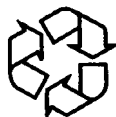
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Summary of Results of ERTDI Projects LS-5.1.3a and LS-5.1.3b

Reports from the University of Bristol (UB), UK and the Clean Technology Centre (CTC), Cork, Ireland have been provided on the emission inventories for HFCs, PFCs and SF₆ from Ireland.

LS-5.1.3a

Using a “top–down” approach, the University of Bristol based the project on statistics previously collected and results from a transport/dispersion model (“NAME”) created by the Meteorological Office in the UK. NAME is a Lagrangian particle model that uses three hourly three-dimensional meteorology fields from the Unified Model (a compilation of atmospheric and oceanic modelling software) in order to abstract particles around the model domain. The project, therefore, compares and contrasts emission values calculated conventionally against those derived from the statistical analysis of emissions calculated at Mace Head monitoring station and back trajectories using the NAME model.

LS-5.1.3b

CTC, using a “bottom–up” approach, based the project on the results of extensive data gathering through contact with relevant gas manufacturers, distributors, users, and retail outlets in Ireland and abroad. Through this approach, CTC determined that, although HFC and PFC production does not occur in Ireland, the consumption of halocarbons and SF₆ does. CTC used a number of production and consumption categories in order to

determine a speciated breakdown of gas emissions within Ireland.

The focus of these studies is on chemical species HFC-134a, HFC-125, HFC-152a, HFC-143a, HFC-227ea, PFC-14 & 116, and SF₆. As shown in [Table 1](#) overleaf, values for HFC-134a are comparable with that calculated by UB and the NAME model. However, the value estimated by CTC for the same species is significantly lower.

In the case of HFC-125, there is a greater degree of agreement between the value estimated by UB and that estimated by CTC.

HFC-152a was not estimated by CTC in connection with the present project. The values for HFC-143a estimated by UB and CTC are in the same general range and are, therefore, comparable for purposes of this study. This is also the case for the estimation of HFC-227ea.

A combined total UB value of 3.2 t is estimated for species PFC-14 and 116, which fits within the estimated CTC range for the same species of 1.0–7.4 t combined.

The value for SF₆ estimated by UB covers only emissions from gas-insulated switchgear. If additional uses (not covered by the UB study) are included in the total, estimates of SF₆ values estimated by UB and CTC are nearly exact.

Table 1. Industrial gas emissions data as determined by the LS-5.1.3 project research groups.

Species	University of Bristol		UK Meteorological Office	Clean Technology Centre
	Top-down method (1995) ^a	Top-down method (1998) ^a	Atmospheric model (1998) ^b	Bottom-up method (1998) ^c
	(t)	(t)	(t)	(t)
HFC-23				0.0
HFC-32	0.7	0.5		2.0
HFC-134a	27.9	135	127	30.4
HFC-125	1.1	6.6	53	8.9
HFC-152a	2.8	10.9	7.1	
HFC-143a	0.6	3.8		7.2
HFC-227ea	0.4	0.9		2.3
CF ₄ (PFC-14)	0.9	1.2		Lower-bound to upper-bound range
C ₂ F ₆ (PFC-116)	1.6	2		1.0 to 7.4 (combined)
SF ₆	1.1	1.1		3.8
CFC-11			84	
CFC-12			140	
CFC-113			111	
HCFC-141b	71.5	87.5	202	
HCFC-142b	42.6	56.9	36	
HCFC-22	276.8	377.6	310	
CH ₃ CCl ₃			247	
CH ₂ Cl ₂			1400	
CH ₄			683000	

^aGridded Irish emissions; ^bNAME Model calculation; ^cCalculations from responses.

CLIMATE CHANGE

Emissions of Industrial Greenhouse Gases
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LS-5.1.3a

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Executive Summary

National emissions estimates for HFCs 23, 32, 125, 134a, 152a, 143a and 227ea, PFCs 14 and 116, and sulphur hexafluoride (SF₆) during 1995 and 1998 have been developed for Ireland. The most significant of these have been verified against Irish source strengths calculated independently by inverse modelling from continuous observations of their atmospheric concentrations at Mace Head, Co. Galway. The method of estimating emissions involved firstly using macroeconomic parameters to calculate the quantities used in Ireland based on known European usages of the compounds. In the case of the HFCs which replace ozone-depleting substances (ODS), the Irish usages were verified at this stage against historical data for consumption of ODS. Emissions were then calculated using standard global functions that have been extensively tested in other work. Similar estimates were also made for emissions of HCFCs 22, 141b and 142b that are emitted from Ireland in much larger amounts than the Kyoto greenhouse gases. The higher emissions, however, afforded a more rigorous assessment of the methodologies for estimating emissions and verification by inverse modelling.

European Data

Details of the sales of HCFCs within the EU are supplied to the Commission, under the Montreal Protocol. Under a Decision that stemmed from the Rio Convention, similar data are required for HFC and PFC use. Emission Functions, which relate the timing and extent of emissions to sales into particular categories have been developed and refined as part of the work of the Advanced Global Atmospheric Gases Experiment. The test for these emission functions and global sales data is whether or not the atmospheric concentrations calculated from them match those measured. For most of the CFCs, HCFCs and HFCs, the fit between calculation and the atmospheric measurements is good – well within the uncertainty of the calculation, and the emission functions can be taken to be definitive.

The NAME dispersion model, developed by the UK Meteorological Office, can be used to calculate emissions

over a large part of Europe from the continuous record of atmospheric measurements at Mace Head, Co. Galway. For those compounds for which there are specific data for European use (from the industrial databases), i.e. HCFCs 141b, 142b, 22, HFC-134a, CFCs 11, 12, 113, 1,1,1-trichloroethane and dichloromethane, the emission functions described above were used to calculate European releases. The values for 1995 to 1999 were then compared with results derived from the NAME model. The results show that the two data sets are related systematically.

National Emissions of HFCs, PFCs and SF₆

A number of EU Parties to the Rio Convention have provided inventory data for their greenhouse gas emissions that includes values for HFCs, PFCs and SF₆. This enabled the values for Ireland to be interpolated with 95% confidence limits significantly better than a factor of two. Values were adjusted to eliminate the difference between the total reported by countries and the total verified European emissions. As a final step, emissions were geographically distributed within Ireland according to population density. The emissions inventory for PFCs was calculated similarly and Irish emissions were assumed to arise totally from semiconductor manufacture and were distributed among the grid boxes according to the number of point sources corresponding to semiconductor plants. In this case, emissions arise from the use and servicing of gas insulated switchgear and transmission losses during the distribution of electricity were taken to be a surrogate activity that would be equivalent to SF₆ use and, in the absence of other information, it was assumed that this was the sole source of Irish emissions of SF₆.

The contributions from Ireland to European emissions of HFCs, PFCs and SF₆ are very small. The HFC contribution in both 1995 and 1998 was 0.8% of the total emission of manufactured HFC (i.e. *excluding* HFC-23). Similarly the SF₆ contribution was 0.2% of the total. These results show a small growth in PFC emissions, from 0.25 to 0.33%, but the increase is not significant.

1 Introduction

1.1 Milestones

1. Emissions inventories, together with uncertainty estimates, for HFCs 32, 125, 134a, 152a, 143a and 227ea have been calculated for Ireland for 1995 and 1998.
2. Similar inventories have been calculated for PFCs (CF_4 and C_2F_6).
3. Similar inventories have been calculated for SF_6 .
4. Similar inventories have been calculated for HCFCs 141b, 142b and 22.
5. European emissions of HCFCs 141b, 142b, 22, HFC-134a, CFCs 11, 12, 113, 1,1,1-trichloroethane and dichloromethane have been calculated and compared to those calculated using the NAME dispersion model.
6. The NAME model has been revised using new methods to calculate the quantities and distribution of European emissions.
7. Direct comparison has been made between revised NAME and Irish emission inventories for several of the compounds of interest.

1.2 Project Overview

This project covers the verification of emissions calculated conventionally against those derived from

statistical analysis of atmospheric concentrations measured at Mace Head, Co. Galway, and back trajectories (the NAME dispersion model). The conventional emissions inventory is 'top-down' and uses definitive European data on activity – the sales of these substances within Europe – coupled with rigorously tested emission functions to calculate European emissions. The European emissions inventory can be verified against the emissions calculated for Europe using the NAME model.

Further subdivision into emissions from each EU member state is accomplished partly with the data that these countries submitted to the UNFCCC and partly using national econometrics to piece together a homogeneous data set that is consistent with the entire European data set. Finally, in order to assist with the back-trajectory dispersion modelling, the emissions are distributed geographically within a member state, based on population density.

It is intended that the process is iterative, with verification leading to improvements in both modelling processes so that uncertainties can be significantly reduced. The results described here correspond to the first iteration in this process, between a calculated Irish inventory and that derived from measurements using NAME.

2 Emission Functions

Emissions of the target compounds are rarely measured as they occur. Almost all of the target compounds are eventually emitted when the substances are used or when the equipment containing them is opened for servicing, and the extent of emission and the delays must be calculated.

Emission Functions, which relate the timing and extent of emissions to use in particular categories (such as those above), have been developed and refined as part of the work of the AFEAS (Alternative Fluorocarbons Environmental Acceptability Study) as a contribution to the Advanced Global Atmospheric Gases Experiment. In some cases, notably aerosol propellants and solvents, the materials are emitted promptly as a consequence of use. This, together with an allowance for stockholding, is factored into the emission function (McCulloch and Midgley, 2001). However, refrigerants are emitted only slowly, if at all. For hermetically sealed units, such as those in domestic refrigerators, the major emission

occurs at the end of the lifetime of the unit if it is scrapped. For the larger industrial units that contain most of the refrigerant in service, emissions occur with a normal distribution around a 4- or 5-year average. This is often described as a mean emission rate (of, say, 13% or 10% per year) but such a linear term does not actually describe the year-to-year emissions expected. Fluorocarbons used to blow plastic foam matrices show a more complex emission pattern, with an initial loss when the foam is formed, a subsequent annual loss due to release from the foam during service and a final loss on disposal. The emissions at each stage depend on the function and material of the plastic matrix but are relatively independent of the nature of the blowing agent (McCulloch *et al.*, 2001).

The test for these emission functions and the sales data is whether or not the atmospheric concentrations calculated from them match those measured. Figures 2.1 to 2.8 show comparisons between these calculations and

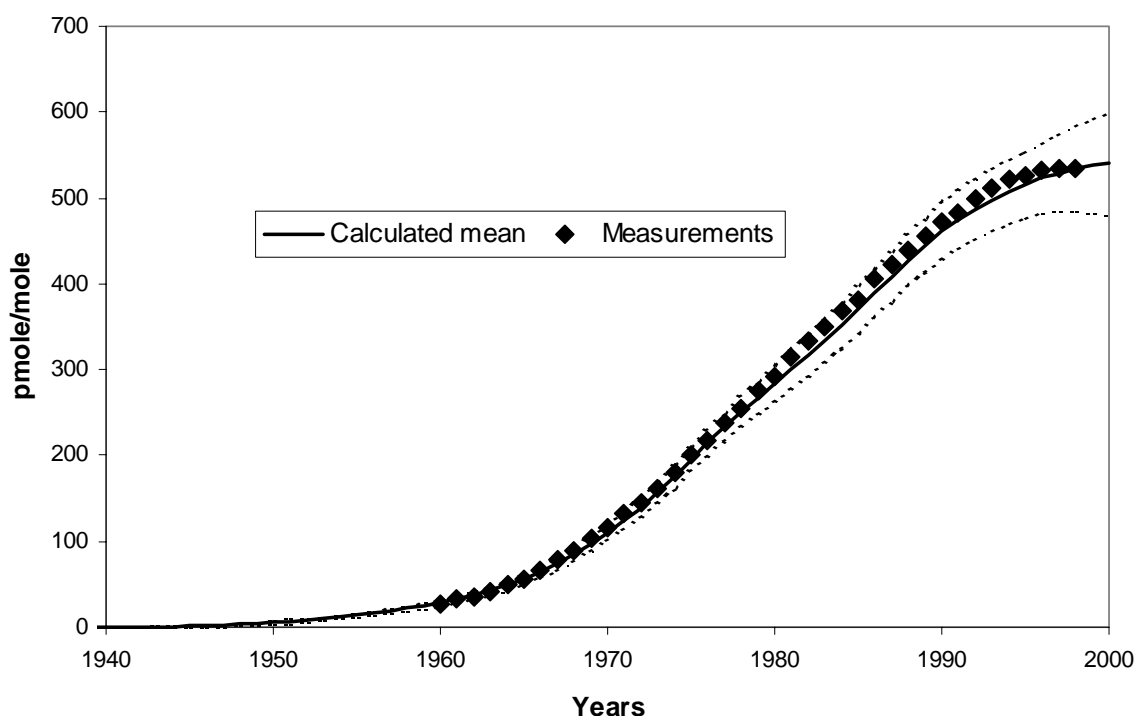


Figure 2.1. Comparison of measured and calculated atmospheric concentrations of CFC-12. Dotted lines show 2σ uncertainty of the calculated mean.

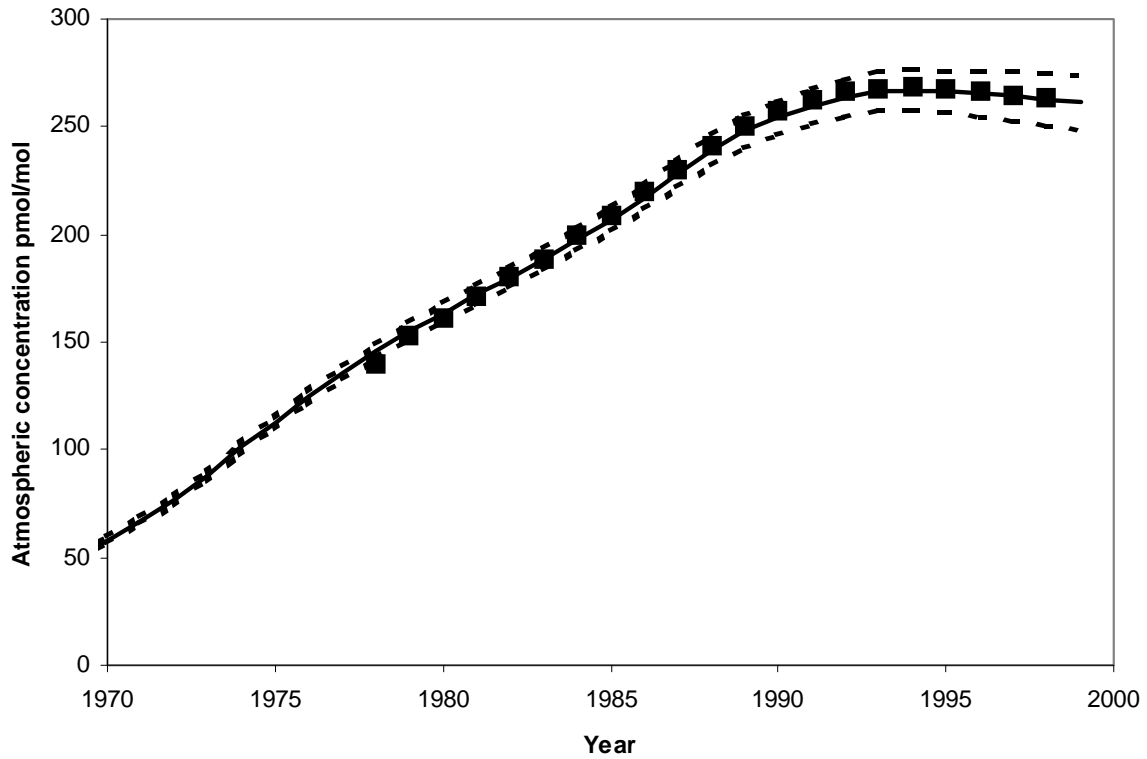


Figure 2.2. Comparison of measured and calculated atmospheric concentrations of CFC-11. Dotted lines show 2σ uncertainty of the calculated mean which is shown as a solid line.

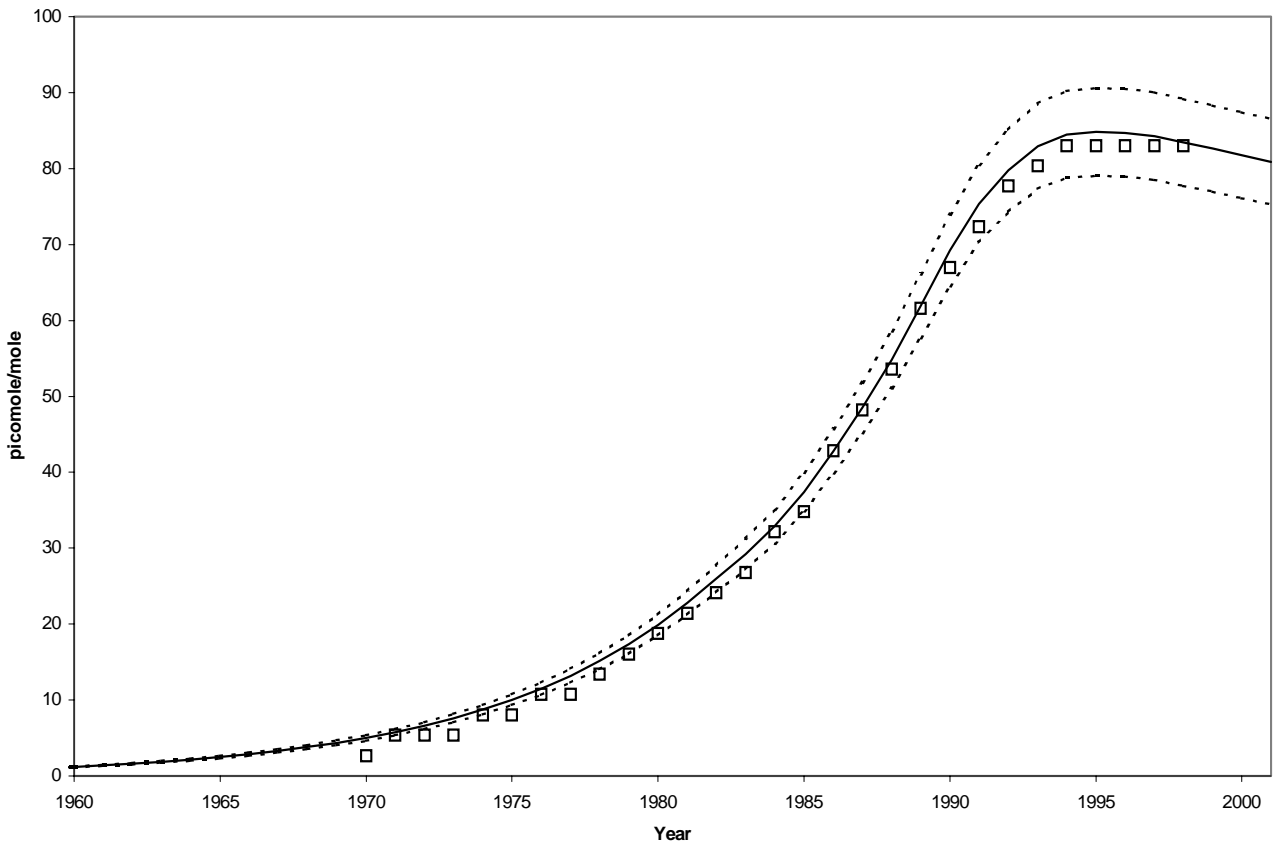


Figure 2.3. Calculated global concentrations of CFC-113, compared with measurements.

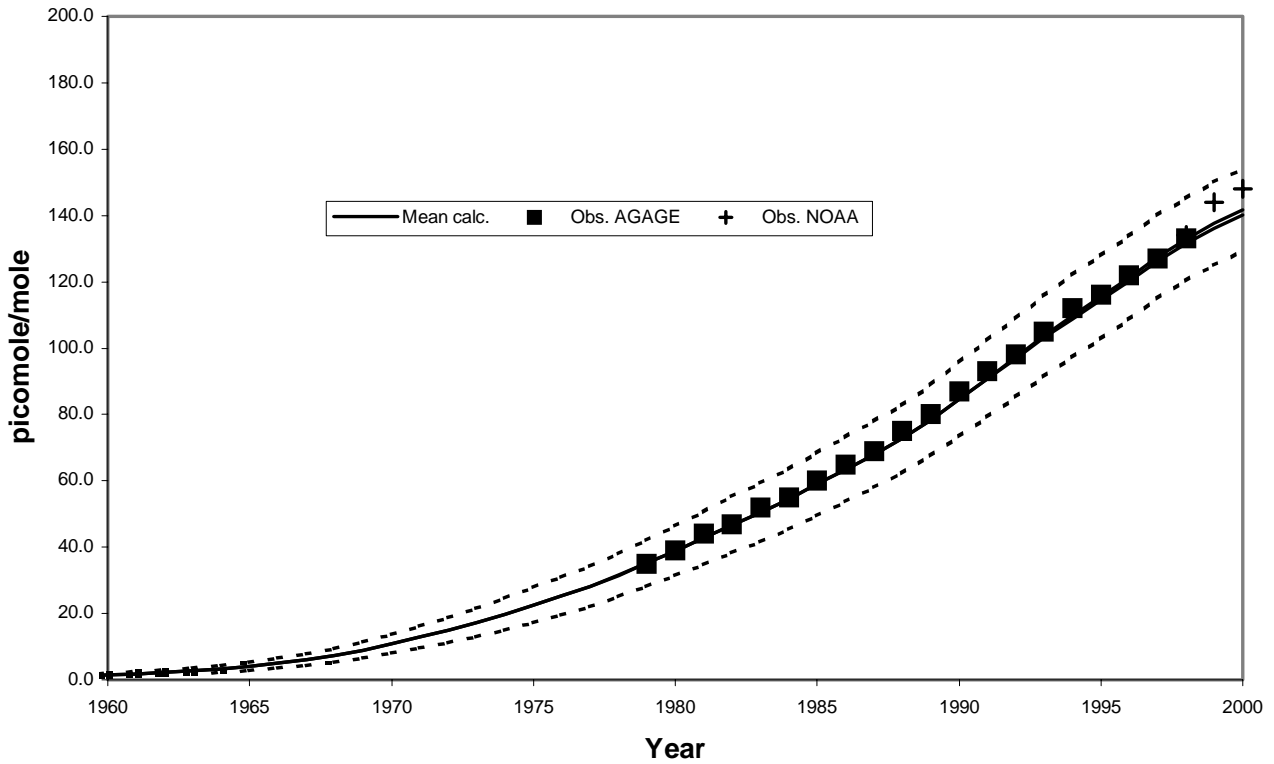


Figure 2.4. Calculated and measured atmospheric concentrations of HCFC-22. Dotted lines show 2σ uncertainty in the calculation.

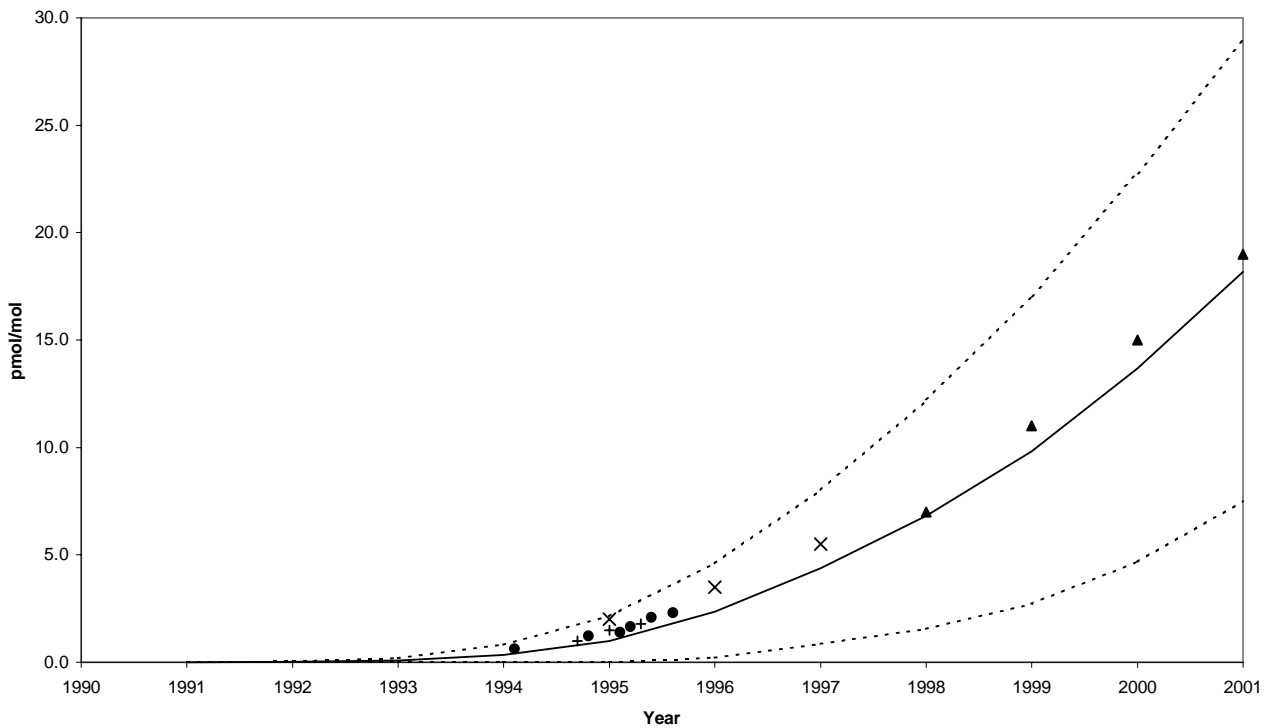


Figure 2.5. Northern hemispherical concentration of HFC-134a, calculated and measured (data from Montzka *et al.*, 1996 [●], Oram *et al.*, 1996 [+], and S. O'Doherty, personal data, 2001 [▲ and ×]).

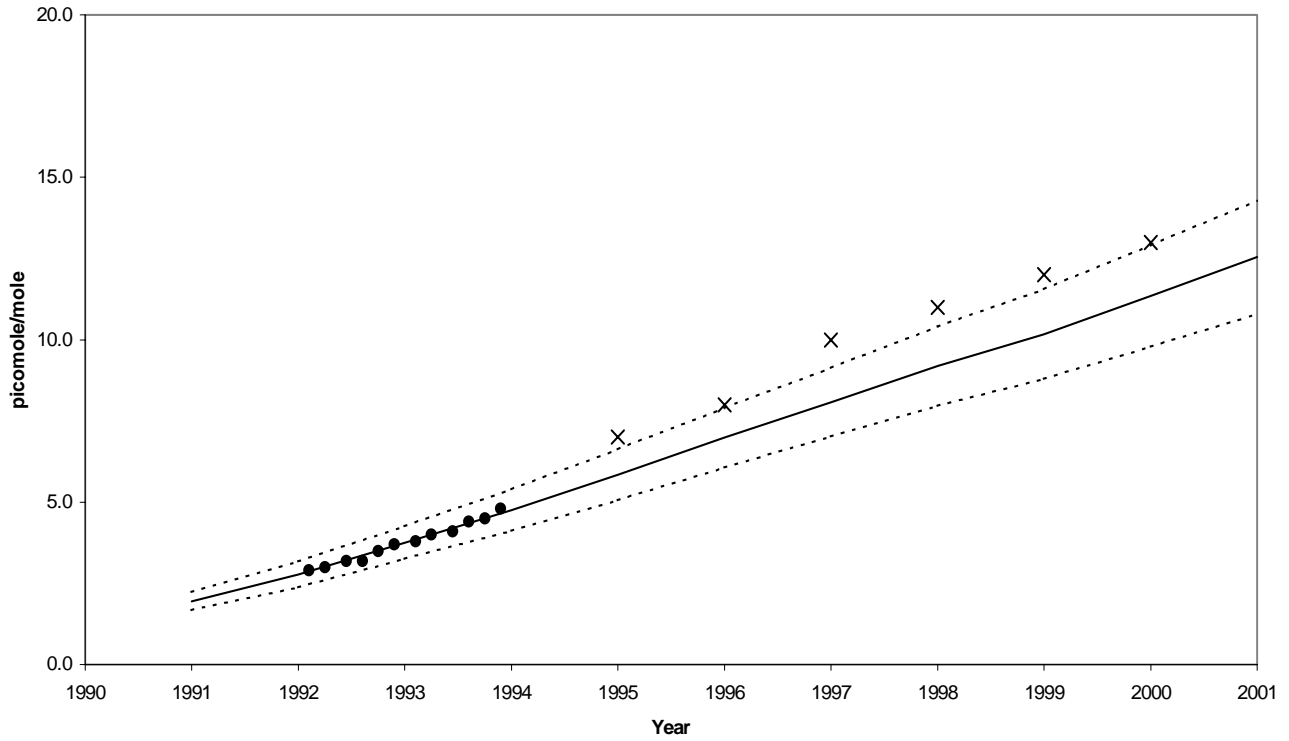


Figure 2.6. Northern hemispherical concentration of HCFC-142b, calculated and measured (data from Montzka *et al.*, 1994 [•] and S. O’ Doherty, personal data, 2001 [×]).

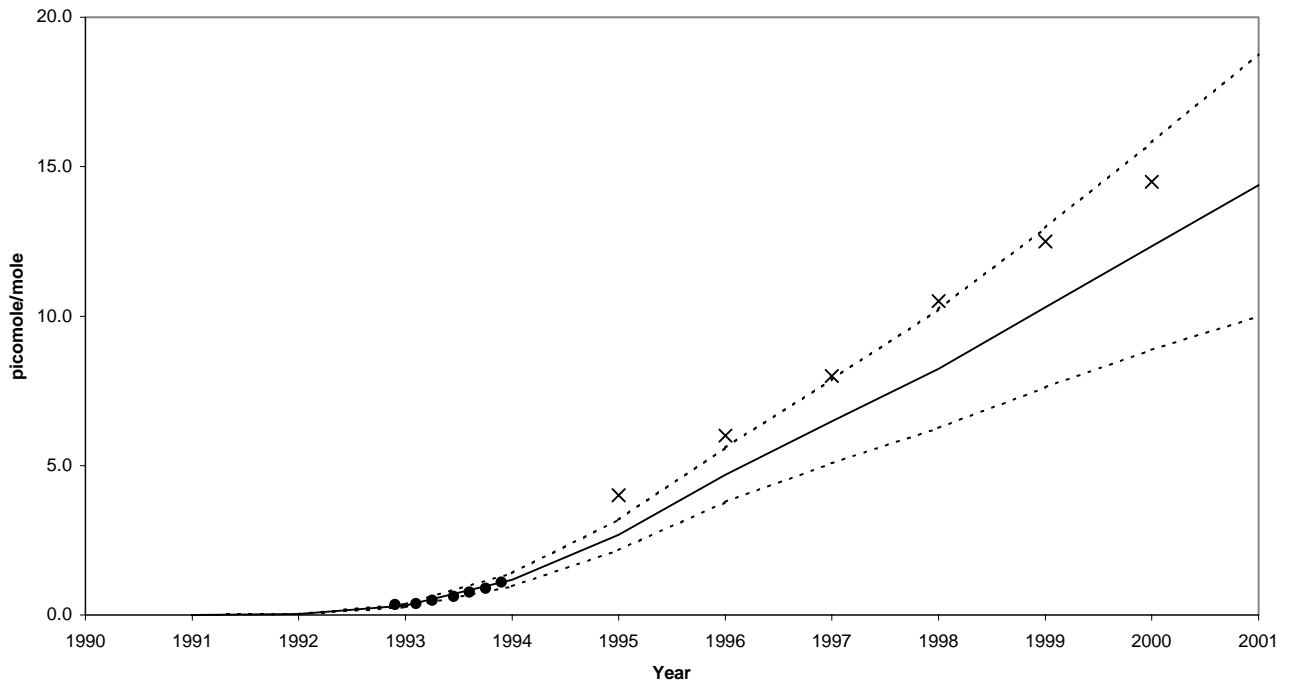


Figure 2.7. Northern hemispherical concentrations of HCFC-141b (data from Montzka *et al.*, 1994 [•] and S. O’ Doherty, personal data, 2001 [×]).

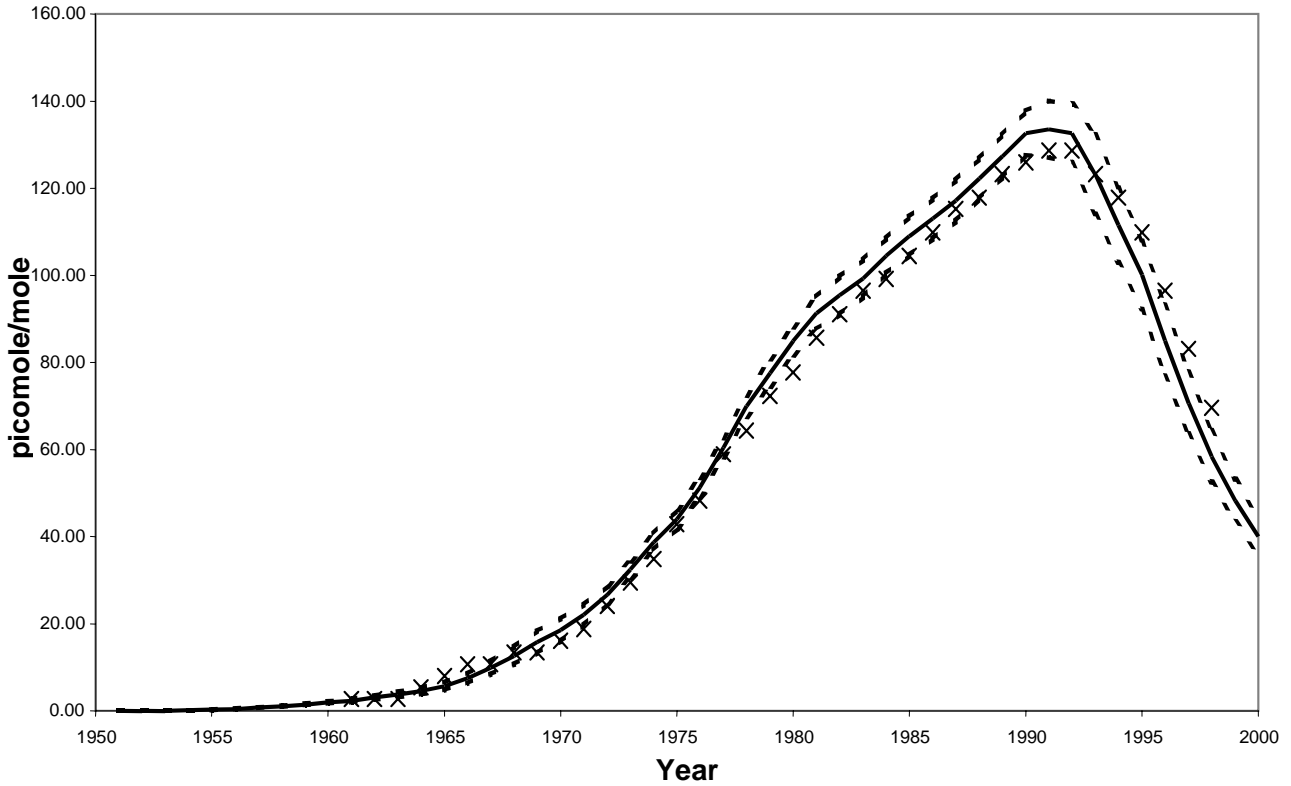


Figure 2.8. Global concentrations of 1,1,1-trichloroethene, calculated and measured.

measurements. Unless stated otherwise, the latter were taken from Prinn *et al.* (2000). For most of the substances shown, the fit between observation and calculation is good – well within the uncertainty of the calculation. The functions themselves are described in outline in the AFEAS database (AFEAS, 2001).

In view of the generally good fit between the calculated concentrations and the observations, the emission functions can be taken to be definitive. There is no practical reason to suppose that there are any regional differences that could affect their application within Europe.

3 European Usage

Because HCFC use (defined as “placing on the market”) is capped for the EU as a whole, under the Montreal Protocol (EU, 2000), manufacturers and importers are required to supply details of their sales within the EU to the Commission. Although these data are confidential and cannot themselves be reported, they were made available through CEFIC (Conseil Européen des Federations de l'Industrie Chimique) to provide the bases for emissions calculations. The sales data are compounded, as ODPtonnes, for all HCFCs split into categories of sales to aerosol propellants, refrigeration, foam blowing and solvent uses. Sales of HCFC-22 are also reported separately and the data have been collected since 1989.

Under a Decision that stemmed from the Rio Convention (EU, 1993), similar data are required for HFC and PFC use within the EU, and the same group of manufacturers and importers has provided information on these substances from 1995 onwards. Both sets of data are accurate (in an accountancy sense) and definitive.

The quantities of SF₆ placed on the market in Europe are not reported in the same way and all calculations have been based only on national submissions to UNFCCC (SBI, 2000).

In addition limited information on the movement of fluorocarbons, particularly CFCs, is contained in the Eurostat databases.

4 Estimating Emissions Using NAME

4.1 NAME Modelling

NAME is a Lagrangian particle model (Ryall and Maryon, 1998). It uses 3 hourly 3D meteorology fields from the Unified Model (Cullen, 1993) to move the abstract particles around the model domain. The model grid covers from 19° W to 25° E and from 35° N to 65° N, with each grid equal to 0.555° latitude by 0.833° longitude. Thirty particles each hour are randomly released in time and space (between the ground and 80 m) from each grid. Each grid square is simulated to emit 1 g/m²/s of passive material spread evenly between the released particles. The particles are moved in 15-min time steps around the model domain. At each time step, information about all of the particles within the boundary layer in the target square, a grid square 0.555° latitude by 0.833° longitude centred on the Mace Head measurement site on the west coast of Ireland, is recorded in an output file. The location and time of the particle's creation, the current time and the particle's contribution to the boundary layer air concentration are stored. The model simulated the movement of particles between 1995 and 2000 inclusive. No effects of dry or wet deposition or atmospheric chemistry were modelled. Using the stored information, it is possible to determine the total contribution to the modelled concentration at the Mace Head grid box from each grid in the model domain at each time step. These data were averaged into 6-hourly attribution maps (see Fig. 4.1 for a typical example) and so provided 4 (maps a day) × 365 (days a year) × 6 (years) maps.

During some of the 6-h periods studied, the modelled meteorology or the dispersion transporting material to Mace Head can be poorly represented. If the number of grids contributing to the modelled concentration at Mace Head is small, it implies that material has been rapidly transported and therefore the probability of compounded meteorological or dispersion errors is reduced. In converse situations, however, large numbers of 'active' grid squares indicate slack winds and long transit times, both potentially leading to significant errors in modelled

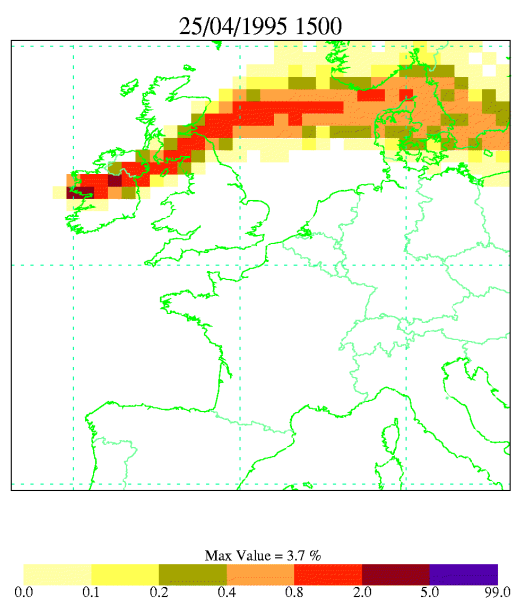


Figure 4.1. Example of an attribution map for one time period.

transportation. In order to reduce the impact of such situations, all 6-h periods where at least 20% of the total modelled contribution at Mace Head is made up of 'active' grids adding less than 0.1% to the total have been removed. Other problem periods are when the actual trajectories that material took to reach Mace Head are very extended and may have left the model domain. In these situations the model will fail to correctly attribute the source of the concentrations measured at Mace Head. To minimise the problems of large re-circulations, any 6-h period that has widely spaced non-contiguous active grids on the edge of the domain has been removed. For CFC-11, removing those time periods that were identified as potentially affected by either situation reduced the number of time periods from 8293 (the number of time periods when measurements are available) to 7561. A similar reduction, from 8153 to 7426, occurs when CH₄ is considered.

4.2 Baseline Concentrations

Using a much bigger model domain (−30° to 25° West–East and 30° to 70° South–North) and larger grids (1.11° latitude by 1.67° longitude) but fewer particles emitted

per grid (4/h), the NAME model again simulated the period from 1995 to 2000 inclusive. Using a similar technique, as described in Ryall *et al.* (2001), a time-series of baseline information (i.e. the general background air concentration unaffected by local and regional sources) for each species was estimated. The method ignores times when the air was modelled to have come from the east (i.e. Ireland, UK and the rest of Europe) or the equator, or when the air was not well mixed (i.e. in stable atmospheric conditions – modelled as boundary layers less than 300 m).

By removing the time-varying baseline concentration from the measurement data, a time-series of excursions from the general background value was determined. The observed deviations from baseline are averaged over 6 h, in line with the modelled values, with all negative values considered to be zero. This resultant series will be referred to as the observation time series, $\mathbf{o}(t)$, with each species having a unique trace.

4.3 Attributing the Observations to Areas of Emission

The modelled attribution data are an array of data \mathbf{A} ($n \times m$), where m is the number of grid points in the model domain (36×37) and n is the number of 6-h time intervals accepted in the 6-year period. The object of the study is to determine the n -element vector of scaling factors, \mathbf{s} , to transform the modelled $1 \text{ g/m}^2/\text{s}$ grid emissions to the actual observed values for each species. Therefore,

$$\mathbf{A} \mathbf{s} = \mathbf{o} + \mathbf{e} \quad (4.1)$$

where \mathbf{e} is the n -dimensional error vector. The causes and effects of errors are discussed later. The problem is further constrained by:

$$\mathbf{s} \geq 0, (\mathbf{A} \geq 0 \text{ and } \mathbf{o} \geq 0 \text{ by definition}) \quad (4.2)$$

Since n is much greater than m , the equation is over-determined, i.e. it has either zero or an infinite solution set. Since \mathbf{e} is potentially significant and unknown, equation 4.1 cannot be solved exactly. Exact matrix inversion techniques, such as *simplex* (Press *et al.*, 1992), are thus inappropriate. In order to derive a vector \mathbf{s} per species that best fits (minimises \mathbf{e}) equations 4.1 and 4.2,

a version of the method of *simulated annealing* is used (Press *et al.*, 1992).

4.4 Simulated Annealing Technique

From $m+1$ randomly generated possible solutions (the solution set), and a measure of the best fit (the skill score), the solution set is iterated towards the best solution. At each step, the solution set spans a section of the whole solution space (Fig. 4.2). Each node is one solution and each has an associated skill score. The nearer the solution possibility is to the *best* solution, the higher the skill score and vice versa. At each step, the worst solution (\mathbf{s}_w in this case) is discarded and a new solution possibility (\mathbf{s}_n), which is nearer to the current *best* solution (\mathbf{s}_b), is added to the solution set. This new solution may now become the *best* solution. These steps are repeated many times, the solution set gradually contracting around the *best* score within the spanned solution space. The distance from the worst solution (\mathbf{s}_w) to the new possibility (\mathbf{s}_n) is slowly reduced in steps between iterations. Initially the change can be large, enabling the new possible solutions to investigate a wide area of the solution space, and thus hopefully capture the true *best* solution within the entire solution space.

After a set number of iterations (120,000) this process is halted and only the current best solution (\mathbf{s}_b) is taken forward to the next stage. This best solution is iterated to a potentially even better skill score by randomly choosing one grid box, perturbing its value (randomly between $\pm 60\%$ of the grid's current value) and assessing the skill score of the new solution. If the new solution has an improved skill score, it is kept; if not, it is discarded and the original is retained. This process is continued until the total change in skill score after each 2000 iterations is less than 1×10^{-4} . The solution that emerges from this process is considered to be one possible (local minima) solution to the equation. The value for each grid box is the scaling factor needed to scale the modelled $1 \text{ g/m}^2/\text{s}$ release rate to the actual emission rate of that area.

The whole process of simulated annealing is repeated 26 times per species, each time starting with a different set of randomly generated solutions. The result is 26 possible solutions (maps of scaling factors) to the equation set, i.e.

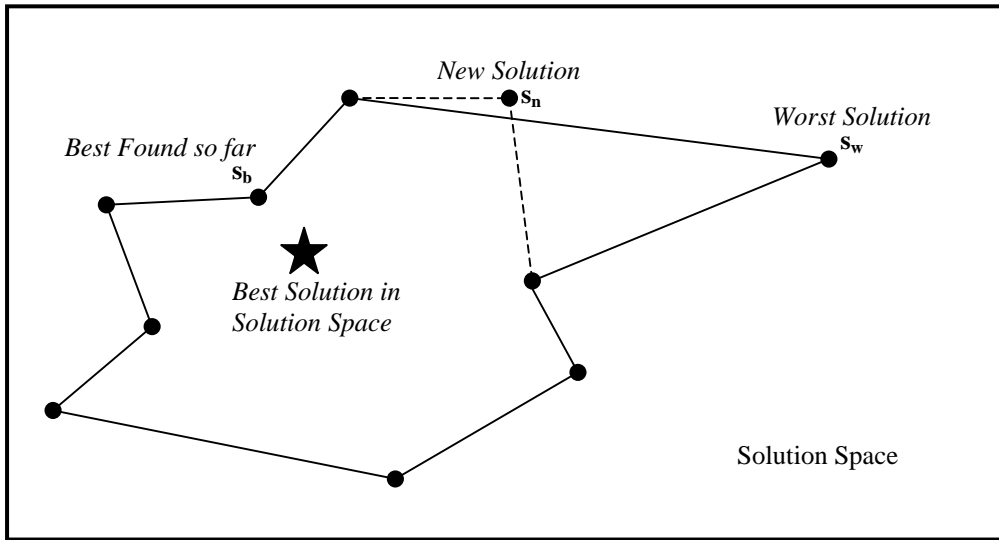


Figure 4.2. Schematic of the solution set within the solution space derived as part of the simulated annealing technique. The technique progressively iterates towards the ‘best’ solution.

an ensemble of different possible solutions. The mean scaling values for each grid box are derived.

4.5 Skill Score Attributed to Each Solution Possibility

The choice of the measure of a solution’s skill is critical to the success of the technique. In this study the following was used:

$$\text{Skill Score} = 10(1 - r) + nmse + 4(1 - fac2) \quad (4.3)$$

where r is the Pearson correlation coefficient, $nmse$ is the normalised mean square error

$$nmse = \left(\frac{(C_{\text{model}} - C_{\text{obs}})^2}{C_{\text{model}} C_{\text{obs}}} = \frac{(rmse)^2}{C_{\text{model}} C_{\text{obs}}} \right)$$

$fac2$ is the fraction of model values within a factor of 2 of the observations. If the observed value is less than the STD of the baseline observations, then the model is considered within a factor of two if it lies between zero and twice this STD value.

The skill score is always positive and a perfect map, assuming no errors, would have a skill score of zero. The multiplying factors used for each statistic were chosen to help weight each quantity equally.

4.6 NAME Emission Estimates (1995–2000 inclusive)

The Irish and European emission totals generated for each species using NAME and this back-attribution technique are given in Table 4.1. The range and mean of the totals over the 26 ensemble solutions are given.

4.7 Dispersion Modelling

In using this back-attribution technique, there are three main assumptions made, the validity of each of which varies from species to species.

1. The baseline levels calculated are accurate and correctly reflect the pollutant concentrations of air entering the model domain from any direction.
2. The emissions from each grid box are uniform in both time and space.
3. The pollutants are well mixed within the boundary layer by the time they arrive at the Mace Head receptor.

Assumption 1 implies that the air entering the domain from any direction is clean and well mixed. Obviously this is incorrect, especially for air entering the eastern domain where Russian emissions will be influential. The effect of this import of pollution from outside will lead to edge effects, where the emissions from cells at the edge

Table 4.1. Emissions calculated using NAME model.

Species	Irish			European		
	Min (kt/year)	Max (kt/year)	Mean (kt/year)	Min (kt/year)	Max (kt/year)	Mean (kt/year)
CFC-11	0.066	0.110	0.084	8.527	9.624	8.866
CFC-12	0.11	0.16	0.14	13.5	15.24	14.34
HFC-125	0.048	0.058	0.053	1.625	1.796	1.712
HFC-134a	0.109	0.150	0.127	11.063	12.411	11.826
HCFC-141b	0.167	0.228	0.202	11.743	12.688	12.256
HCFC-142b	0.028	0.044	0.036	10.305	11.146	10.699
HFC-152a	0.0059	0.0094	0.0071	1.2950	1.4160	1.3475
HCFC-22	0.218	0.352	0.310	31.024	35.418	33.210
CH ₃ CCl ₃	0.194	0.313	0.247	31.711	34.254	32.542
CFC-113	0.083	0.127	0.111	5.495	5.845	5.679
CH ₂ Cl ₂	1.1	1.6	1.4	90.0	106.5	100.0
Methane	565	757	683	25243	28312	26635

of the domain are artificially increased. Therefore, the emissions from cells near to or adjacent to the edge of the domain not only reflect the releases from those cells but also the average import of pollution to them. As the number of distinct trajectory paths through a cell to Mace Head increases (this increases as the distance to Mace Head decreases), the errors due to imported pollution decrease.

The calculation of baselines also assumes that each pollutant has a sufficiently long (more than 2 weeks) atmospheric lifetime. Rapid loss processes through chemical conversion or deposition will lead to unquantifiable results as both of these processes depend on other non-linear factors such as terrain (dry deposition), other species (chemistry) and meteorology (wet deposition).

The validity of assumption 2 will vary strongly from species to species. The main factors influencing this assumption are as follows:

- A pollutant has a natural (biogenic) component, e.g. methane release from peat bogs. Usually natural emissions are strongly dependent on a range of meteorological factors such as temperature and diurnal/annual and growth/decay cycles.
- The anthropogenic activities leading to the release of a pollutant have a definite cycle. An example of a strong dependence to a diurnal cycle is the release of

carbon monoxide where emissions are dominated by traffic sources.

- The anthropogenic practices leading to the release of a pollutant may change over the time span covered by the back-attribution technique. For example, the opening or closing of an industrial complex may add or remove a significant source at some point during the time period under review.

For all three of these problems, the back-attribution method will smooth out the changes. If, for example, a factory operated at full capacity from 1995 to 1998 and then closed, the calculated solutions will oscillate between the source being active and inactive, with the mean solution falling somewhere in between. The balance point of the mean solution will depend on the frequency and number of trajectories reaching Mace Head when the emissions are active and the frequency and number when they are inactive.

Species released near to the receptor site (within approximately 50 km) may not be well mixed and so the measurements will be strongly influenced by local features such as terrain and shore breezes, resulting in a high degree of intermittency in the concentrations. Since the measurements have been averaged out over 6 h, these difficulties have been largely removed. The remoteness of the site means that few anthropogenic sources will fall into this category.

5 European Emissions – Verification of Calculations Using NAME

For those compounds for which there are specific data for European use (from the industrial databases), i.e. HCFCs 141b, 142b, 22, HFC-134a, CFCs 11, 12, 113, 1,1,1-trichloroethane and dichloromethane, the emission functions described in Chapter 2 were used to calculate European releases. In general, these provided annual values for the years from 1995 to 1999. The average of these for each compound was compared directly with the equivalent 1995–2000 means shown in Table 4.1, and the results are shown in Figs. 5.1 and 5.2. The only difference between the figures is that the values for dichloromethane were omitted from Fig. 5.2; the emissions of this compound are so much larger than those of the other substances that its values unduly influence the comparison.

The estimates of EU emissions from the revised NAME model, described in Chapter 4, are largely consistent with those developed by the conventional application of emission functions to usage data; emissions calculated to be small by one method are also small in the other

method. However, on the geographical scale of the EU, the relationship between the two methods is not as good as when the previous version of NAME was used, as recorded in the interim report of July 2001. The previous version, described in Ryall *et al.* (2001), shows emissions estimates that are consistently lower, by a factor of approximately 1.7–1.8, than those calculated from the usage data (see Fig. 5.3), but with much better coefficients of variance than those derived using the current version. Thus, in the previous version of NAME, when dichloromethane is not included, the mean ratio of the estimated emission to that calculated using NAME was 1.7, with a coefficient of variance (R^2) of 0.86. In the current version described here, the ratio is much closer to unity at 0.9, but R^2 is now only 0.49. However, such a direct comparison between the two versions of the model may be misleading. The previous version of NAME was able to provide robust annual estimates of emissions but the current version makes more intensive use of the measurement data and so provides only average values for the 6 years of data.

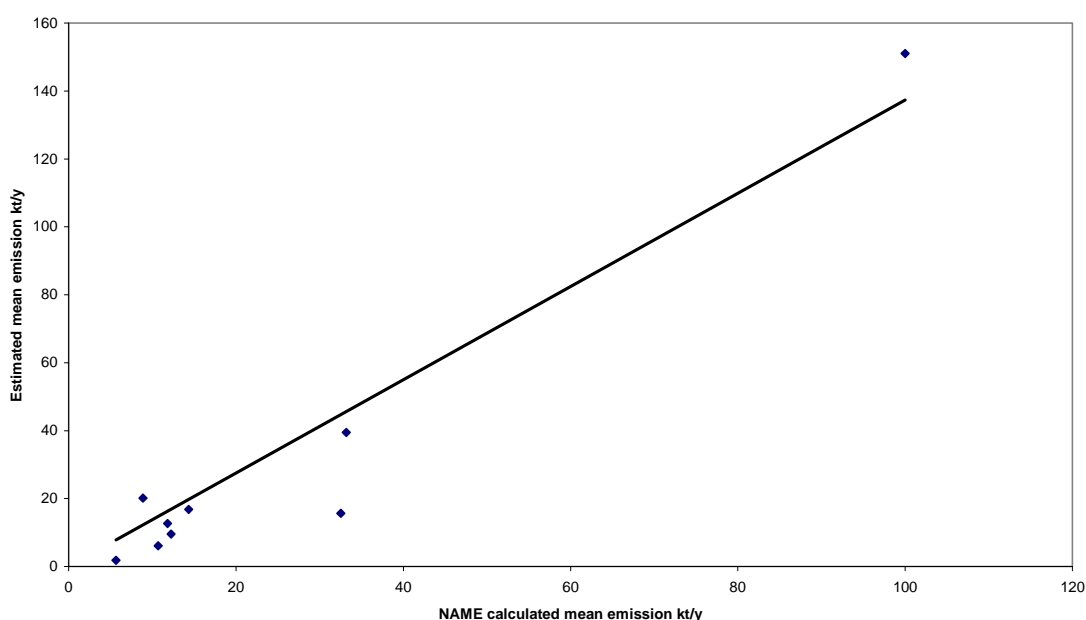


Figure 5.1. Comparison of 1995–2000 average estimated European Emissions of Halocarbons (Gg) by (a) conventional Use-plus-Emission-Function methodology, and (b) modelling by current version of NAME (dichloromethane results included).

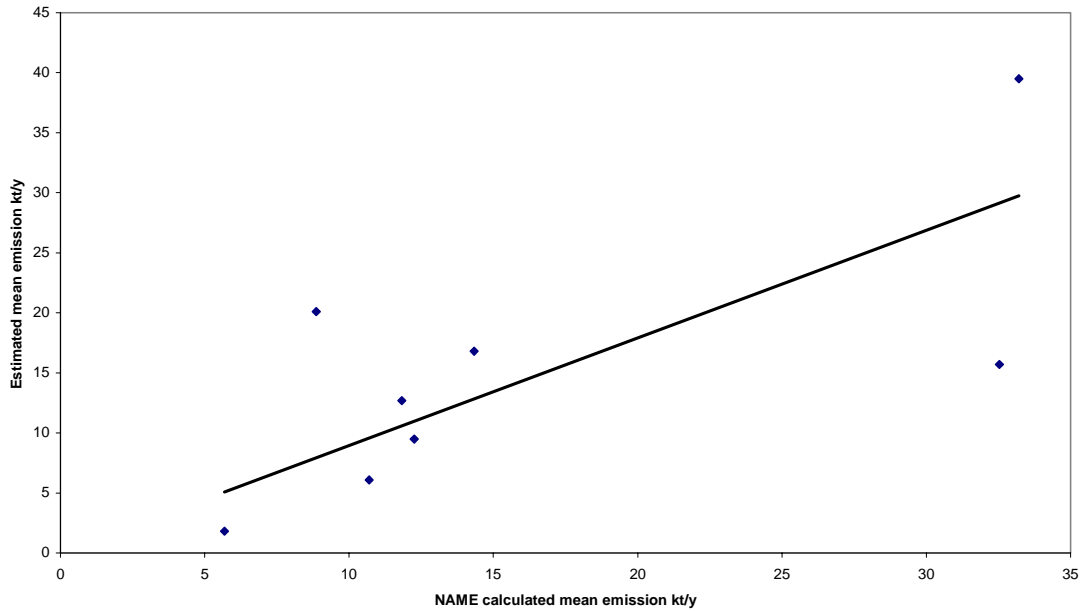


Figure 5.2. Comparison of 1995–2000 average estimated European Emissions of Halocarbons (Gg) by (a) conventional Use-plus-Emission-Function methodology, and (b) modelling by current version of NAME (dichloromethane results omitted).

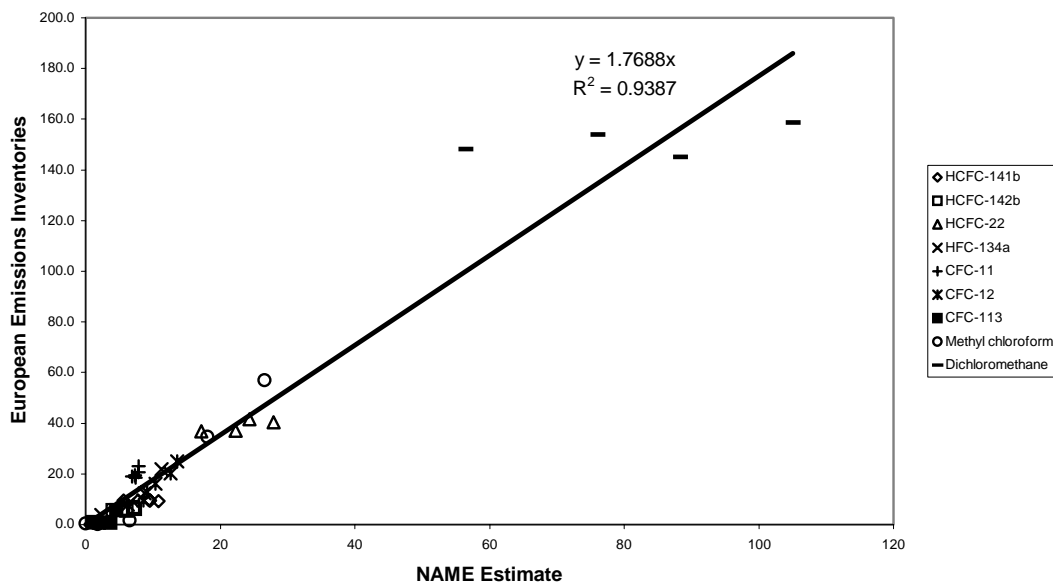


Figure 5.3. Comparison of annual pairs of estimated European Emissions of Halocarbons (Gg) by (a) conventional Use-plus-Emission-Function methodology, and (b) modelling by the previous version of NAME (dichloromethane results included).

The benefit of the fit between the NAME model and the conventionally calculated emissions lies not just in the independent verification of the calculations but in the ability to use both methods to derive a more

comprehensive set of emission estimates for a broader range of compounds than could be possible with only one method.

6 National Emissions of HFCs, PFCs and SF₆

6.1 HFCs

6.1.1 Emission estimates

A number of Parties to the Rio Convention have provided inventory data for their greenhouse gas emissions that include values for HFCs, PFCs and SF₆. In some cases these are aggregated as GWPTonnes¹ (or otherwise total actual tonnes) for each class of material (SBI, 2000). In Europe, full data were reported by Austria, Belgium, Denmark, Finland, France, Greece, Italy, the Netherlands, Spain and Sweden for individual HFCs and PFCs for the years 1990, 1995 and 1998.

Germany and the United Kingdom reported aggregate HFCs (as both GWPTonnes and actual tonnes) and individual PFCs. Ireland and Portugal did not submit estimates. All of the estimates appear to have been made using 'bottom-up' methods, assembling emissions from estimates of activity, in areas such as refrigeration, and estimates of the emissivity of those activities (see March CG, 1999 and Olivier *et al.*, 2001). This is allowed within the methodology specified by the IPCC/OECD for emissions inventory calculations by "country-specific surveys" (IPCC, 2000). However, it does not mean that the results are directly comparable between countries or that the total would be an accurate estimate of real European emissions.

After making corrections for minor data errors and omissions by ensuring that the totals of national submissions for individual HFCs and PFCs matched the calculated aggregates quoted, the more serious omissions were addressed.

To derive an internally consistent data set, the missing information concerning emissions of individual HFCs from Germany and the United Kingdom was interpolated from the data supplied in SBI (2000) (comprising aggregate HFC emissions, as both tonnes and GWPTonnes, and the GWPs). After allowing for

emissions of HFC-23 from the manufacture of HCFC-22 (which happens in both countries), emissions of the remaining individual HFCs were calculated assuming that, in Germany, they were mainly HFCs 152a and 134a and, in the United Kingdom, they were mainly HFCs 125 and 134a. To enable the missing data for Ireland and Portugal to be interpolated, the national releases were compared to Gross Domestic Product (GDP) statistics. Previous studies have shown that GDP is a useful tool for distributing a known total activity between similar countries in a group (McCulloch *et al.*, 1994; McCulloch and Midgley, 1996). It is used in that way here, and Fig. 6.1 shows this comparison. It enables the values for Ireland and Portugal to be interpolated with 95% confidence limits significantly better than a factor of two. These aggregate values for the HFC emissions from the two countries were distributed among individual substances at the European average.

Finally, the whole set of values, for all countries and for both 1995 and 1998, was multiplied by the ratio between the total reported by countries and the total verified European emissions. The result for 1998 is shown in Table 6.1.

6.1.2 Uncertainty

Uncertainty in these values arises from a number of sources: the activity data, the distribution of these to individual compounds (or the assignment of sales to end uses that have differing emissions), and the timing and extent of emissions from each category. Uncertainties have been calculated by *Monte Carlo* simulation methods for the global emissions of fluorocarbons (e.g. McCulloch *et al.*, 2001, 2003) and these should be applicable to the member states' emissions shown in Table 6.1. For materials that are currently used for applications that have prompt emissions (such as HFC-227ea in metered dose inhalers), the effect of variability in the timing and extent of emissions is relatively small and, by comparison with similar applications of CFCs, the uncertainty in the emissions of HFC-227ea and HFC-152a (expressed as coefficient of variance) is 9% in 1998.

1. GWPTonnes are the mathematical product of metric tonnes and the Global Warming Potential of the substance as defined in IPCC (1995). They approximate to CO₂ equivalent tonnes.

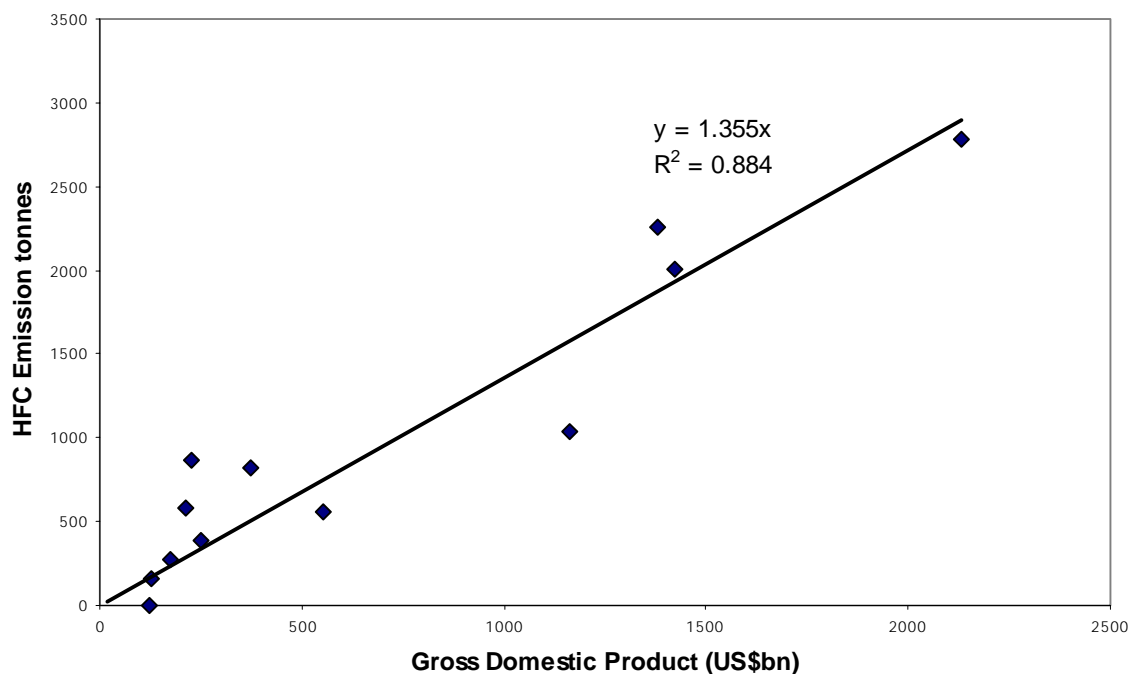


Figure 6.1. HFC emissions (total tonnes) from EU member states during 1998, source of GDP data: European Marketing (2000).

Table 6.1. EU member states' emissions of HFCs during 1998 Mg (tonnes).

	HFC-23	HFC-32	HFC-134a	HFC-125	HFC-152a	HFC-143a	HFC-227ea
Austria	0	0	1057	0	4	0	0
Belgium	0	7	643	16	9	0	0
Denmark	0	0	346	7	0	59	0
Finland	0	14	168	24	15	0	0
France	0	127	3177	1	80	1	0
Germany	15	129	1766	1150	107	0	15
Greece	0	0	0	0	0	0	0
Ireland	1	7	135	11	4	1	1
Italy	18	75	1594	0	39	0	18
Luxembourg	0	1	30	2	1	0	0
Netherlands	0	0	1393	16	27	0	0
Portugal	1	9	188	15	5	1	1
Spain	0	9	853	0	19	44	0
Sweden	15	66	1286	2	44	0	15
UK	12	325	3066	23	87	0	12
Total	63	768	15700	1266	440	107	63

The emission function for refrigerants encompasses total release that is normally distributed about a mean service lifetime of 4.5 years, with a standard deviation of 2 years. This broad range in the timing and extent of emissions

has a profound effect on their uncertainty. For HFC-134a, the coefficient of variance was 33% in 1998, most of which is due to the uncertainty in the timing of refrigerant releases. Similar uncertainty attaches to the other

hydrofluorocarbons that are used predominantly as refrigerants (HFCs 32, 125 and 143a).

Uncertainty in the European activity values (sales and distribution of these among emission categories) is included in the coefficients of variance.

6.1.3 Irish emissions

As a final step, emissions were geographically distributed within Ireland according to population density. Much of the industrial HFC use is in refrigeration and air-conditioning (RAC), and a relatively cursory examination of the trade (Kompass, 1998) showed the Irish RAC sector to be well dispersed geographically and that in each 1° latitude by 1° longitude grid box, the number of service engineering contractors was roughly proportional to the 1990 population reported in Li (1996). Emissions other than industrial are from consumer products (mainly commercial deep freeze, mobile air-conditioning and building products), the geographical distributions of which have strong affinities with population density. One significant potential point source for HFC emissions was identified: a large plant manufacturing refrigerated vehicles located in the outskirts of the city of Galway. From the Mace Head data record, there is no evidence to suggest that this makes a significant contribution, and so the emission distribution has not been altered.

Tables 6.2 and 6.3 show the Irish emissions calculated for 1995 and 1998 gridded into 1° latitude by 1° longitude boxes, together with the totals for each substance and the uncertainties.

6.2 PFCs

The principles of calculating the emissions inventory for PFCs were similar to those used for the HFCs inventory. The SBI data for PFCs were fitted to the GDP in both 1995 and 1998. Although the uncertainties were higher than for the fit of HFC emissions and GDP (R^2 values of 0.60–0.84, depending on year and compound), the relationship for CF_4 was the same in 1995 as in 1998 and the C_2F_6 data behaved similarly. Accordingly, missing national data (such as for Ireland, Luxembourg and Portugal) were calculated by interpolation using GDP. The results were then adjusted to match the industrial data for sales and emissions of individual PFCs. This

treats all PFCs as coming from similar sources and does not discriminate between those associated with the production of aluminium and those emitted during semiconductor etching but, without a comprehensive description of sources within each member state, there is no alternative but to treat all emissions as being equivalently related to GDP.

For the purposes of geographical distribution, the calculated Irish emissions were assumed to arise exclusively from semiconductor manufacture and so were distributed among the grid boxes according to the number of point sources corresponding to semiconductor plants. With so little connection to consumer products, their emissions are not likely to follow population distributions. The results are shown in Tables 6.2 and 6.3. In this case, uncertainties are simply subjective estimates based mainly on the fit to GDP. This is an area that could be improved in future work.

6.3 SF₆

This is the least certain of the estimates. As with HFCs and PFCs, it relies heavily on the SBI data (SBI, 2000). In this case, emissions arise from the use and servicing of gas-insulated switchgear, from use as a blanket gas in the casting of reactive metals (magnesium, aluminium and their alloys) and from specialist applications (notably the after-market refilling of car tyres and filling double glazing, particularly in Germany). Transmission losses during the distribution of electricity were taken to be a surrogate activity that would be equivalent to SF₆ use in gas-insulated switchgear (IEA, 1998) and, in the absence of other information, it was assumed that this was the sole source of Irish emissions of SF₆.

An examination of trade information showed that in Austria, Denmark, France, Germany, the Netherlands, Sweden and the UK, there is a significant magnesium or aluminium casting industry or other known emissive use of SF₆ (Kompass, 2001). After rejecting the submissions from these countries, there is a simple relationship between the declared emission and reported transmission losses. Multiplying the losses (expressed as TWh/year) by 0.673 gives an estimate of the annual tonnage emission of SF₆. The results are shown in Tables 6.2 and 6.3. Like the PFC estimates, the uncertainties of SF₆

Table 6.2. Gridded Irish emissions of fluorinated greenhouse gases (1995).

Grid-box		Percent of 1990 population	Point sources		1995 Emissions kg per grid-box								
Latitude	Longitude		HFCs	PFCs	HFC-32	HFC-125	HFC-134a	HFC-152a	HFC-143a	HFC-227ea	CF ₄	C2F ₆	SF ₆
51	8 and 9	12.3		2	9	140	3400	340	69	44	300	540	140
52	6	8.5			6	100	2400	240	47	31			100
52	7	18.1			13	200	5000	500	100	65			210
52	8	10.1		2	7	110	2800	280	56	36	300	540	120
52	9	4.2			3	50	1200	120	24	15			50
53	6	24.4		1	17	280	6800	680	140	88	300	540	280
53	7	4.2			3	50	1200	120	24	15			50
53	8 and 9	9.8	1		7	110	2700	270	55	35			110
54	8 and 9	8.5			6	100	2400	240	47	31			100
Total		100.0			71	1130	27900	2790	560	360	900	1630	1140

Table 6.3. Gridded Irish emissions of fluorinated greenhouse gases (1998).

Grid-box		Percent of 1990 population	Point sources		1998 Emissions kg per grid-box										
Latitude	Longitude		HFCs	PFCs	HFC-32	HFC-125	HFC-134a	HFC-152a	HFC-143a	HFC-227ea	CF ₄	C2F ₆	SF ₆		
51	8 and 9	12.3		2	66	810	17000	1300	460	110	410	680	140		
52	6	8.5			46	560	11000	900	320	78			100		
52	7	18.1			97	1190	24000	2000	680	170			210		
52	8	10.1		2	54	660	14000	1100	380	92	410	680	120		
52	9	4.2			23	280	6000	500	160	39			50		
53	6	24.4		1	130	1610	33000	2600	920	220	410	680	280		
53	7	4.2			23	280	6000	500	160	39			50		
53	8 and 9	9.8	1		53	650	13000	1100	370	90			110		
54	8 and 9	8.5			46	560	11000	900	320	78			100		
Total		100.0			540	6580	135000	10900	3770	920	1240	2040	1140		
						Uncertainty (±1 SD) kg	18	2200	45000	980	1200	80	600	1000	600
						Uncertainty (±1 SD) kg	31	490	12000	250	240	32	450	800	600

emissions shown in these tables are largely subjective and are based on the fit to the transmission loss statistics.

6.4 HCFCs

Although not included in the project remit, emissions estimates for HCFCs are of value in helping to verify the emissions calculated by back-trajectory analyses. These ozone-depleting substances are released in very much larger amounts than HFCs or PFCs, their detection and analysis is easier and the results are more robust. Consequently, they are better indicators of the performance of the models. The European usages of HCFC-22 (individually) and HCFCs 141b and 142b (in aggregate) form part of the CEFIC database and were used here, together with the emission functions described in AFEAS (2001), to provide estimates of European

emissions. These were then geographically distributed across Ireland in the same way as HFCs. The results are shown in [Tables 6.4](#) and [6.5](#), for 1995 and 1998, respectively. Partly as a consequence of the relative maturity of HCFC markets (compared to the HFC market) and partly because of their end uses, the uncertainties in HCFC emissions are markedly lower than in those for HFCs.

6.5 Comparison with NAME

The average emissions from Ireland over the period from 1995 to 2000 estimated for HFCs 125, 134a and 152a and for HCFCs 22, 141b and 142b using NAME (see [Table 4.1](#)) were compared directly with emissions of the same compounds for 1998 recorded in [Tables 6.3](#) and [6.5](#) herein ([Fig. 6.2](#)). In the absence of the full 6 years of data

Table 6.4. Gridded Irish emissions of hydrochlorofluorocarbons (1995).

Grid-box		Percent of 1990 population	Point sources		1995 Emissions kg per grid-box		
Latitude	Longitude		141&2b	22	HCFC-141b	HCFC-142b	HCFC-22
51	8 and 9	12.3	1		8800	5200	34000
52	6	8.5			6100	3600	23400
52	7	18.1			12900	7700	50000
52	8	10.1			7200	4300	27900
52	9	4.2			3000	1800	11700
53	6	24.4	3		17400	10400	67500
53	7	4.2	1		3000	1800	11700
53	8 and 9	9.8		1	7000	4200	27200
54	8 and 9	8.5			6100	3600	23400
Total		100.0			71500	42600	276800
Uncertainty (± 1 SD) kg					7100	2600	9700

Table 6.5. Gridded Irish emissions of hydrochlorofluorocarbons (1998).

Grid-box		Percent of 1990 population	Point sources		1998 Emissions kg per grid-box		
Latitude	Longitude		141&2b	22	HCFC-141b	HCFC-142b	HCFC-22
51	8 and 9	12.3	1		10700	7000	46300
52	6	8.5			7400	4800	32000
52	7	18.1			15800	10300	68200
52	8	10.1			8800	5700	38000
52	9	4.2			3700	2400	16000
53	6	24.4	3		21400	13900	92100
53	7	4.2	1		3700	2400	16000
53	8 and 9	9.8		1	8600	5600	37000
54	8 and 9	8.5			7400	4800	32000
Total		100.0			87500	56900	377600
Uncertainty (± 1 SD) kg					13200	4300	12500

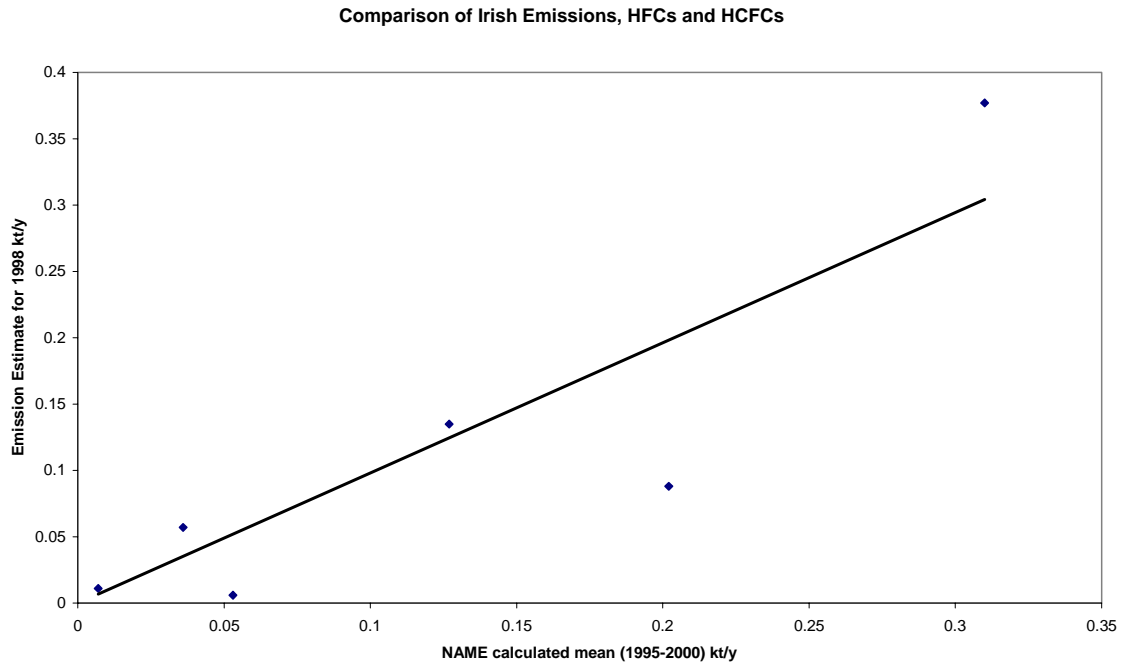


Figure 6.2. Intercomparison of paired values of calculated emissions of HFC-152a, HCFC-142b, HFC-125, HFC-134a, HCFC-141b and HCFC-22 (in that order from left to right) from Ireland.

for Ireland from the conventional methodology, the data for 1998 represent close to a mean value, assuming that any changes are linear.

The average ratio of the emissions calculated from the two methodologies is 0.98, with a coefficient of variance

for the trend line of 0.79 (i.e. $R^2 = 0.79$). While the differences for the individual components are large, the close agreement on average is remarkable and this gives confidence that the conclusions on the absolute extent of the emissions of these compounds from Ireland are robust.

7 Conclusions

1. European emissions calculated from activity data and emission functions have been verified against those calculated from atmospheric analyses and back-trajectory calculations using the NAME model.
2. Emissions from Ireland have been calculated as a subset of the European emissions and distributed geographically by population density.
3. The Irish emissions inventory has been verified against that calculated using NAME. On average, there is very little difference between the two (2%) but this hides substantial differences for individual compounds. Nevertheless, it is clear that the absolute values of these emissions are placed in similar size categories by both methods. In view of the wide differences in methodology, this adds confidence to the estimates.
4. It has been demonstrated that, using the NAME Lagrangian model, it is possible to determine the fraction of air arriving at Mace Head from different regions (on a European scale) at different times over a 6-year period. Using this matrix of data along with observations of a range of pollutants at Mace Head, it is possible, using the best-fit algorithm called simulated annealing, to derive estimates of emissions over Western Europe. The algorithm starts from a randomly generated emission map and iterates towards the best solution; the process is repeated many times to build up an ensemble of different solution possibilities, all local minima to the equations. The errors due to inaccuracies in the modelled meteorology and dispersion and the observations are difficult to quantify and vary from species to species.
5. The contributions by Ireland to European emissions of HFCs, PFCs and SF₆ are very small. The HFC contribution in both 1995 and 1998 was 0.8% of the total emission of manufactured HFC (i.e. *excluding* HFC-23). Similarly the SF₆ contribution was 0.2% of the total. These results show a small growth in PFC emissions, from 0.25 to 0.33%, but the increase is not significant.

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CLIMATE CHANGE

Emissions of Industrial Greenhouse Gases
(HFCs, PFCs and Sulphur Hexafluoride)

LS-5.1.3b

Prepared for the Environmental Protection Agency
by
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Executive Summary

An inventory of emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆) has been estimated for Ireland for 1998.

Such inventories are required to be reported under the United Nations Framework Convention on Climate Change (UNFCCC).

This inventory has been compiled through data obtained from relevant sectors and in accordance with UNFCCC guidelines. Contact has been made by phone with 154 companies in Ireland, the UK and Europe.

Each of the industrial gases has different global warming potentials. Therefore, overall estimates are reported in terms of kilotonnes of carbon dioxide equivalent. Estimates in terms of tonnes of gas are also included within the report.

Estimated usage, which is also termed ‘potential emissions’, for each of the gases in Ireland in 1998 across all sectors is shown in [Table E-1](#) in terms of kilotonnes of carbon dioxide equivalent.

Estimated actual emissions for each of the gases in Ireland in 1998 across all sectors are shown in [Table E-2](#) in terms of kilotonnes of carbon dioxide equivalent.

The estimated industrial gas emissions account for 0.4% of all greenhouse gas emissions in Ireland in 1998.

The above usage (potential emissions) and actual emissions figures are broken down into the individual sources in [Table E-3](#). The major users of the gases in Ireland in 1998 in terms of carbon dioxide equivalent are the refrigeration and air-conditioning industry, the semi-conductor manufacturing industry, electricity utilities, and certain manufacturing industries that use them for leak detection (one major user to phase out usage during 2002 and switch to helium).

It was found that none of the industrial gas source categories are key source categories, i.e. when all source categories for the six gases are summed together in descending order of magnitude, the threshold of 95% of total greenhouse gas emissions is reached before the industrial gas source categories are reached. Therefore, Tier 1 methodologies are sufficient according to the IPCC but Tier 2 is encouraged. Tier 2 methodologies have in fact been used in the estimation of emissions for the majority of sources.

Changes in the use of industrial gases since 1998 include increased usage in refrigeration, in metered dose inhalers and an increase in semi-conductor production, with a corresponding increase in gas usage, together with

Table E-1. Estimated usage of industrial gases 1998.

Estimated Usage (or Potential Emissions) 1998 (kilotonnes of carbon dioxide equivalent)				
	HFCs	PFCs	SF ₆	Total
All sectors	1091	117	121	1329

Table E-2. Estimated actual emissions of industrial gases 1998.

Estimated Actual Emissions 1998 (kilotonnes of carbon dioxide equivalent)				
	HFCs	PFCs	SF ₆	Total
All sectors	104	62	91	257

Table E-3. Estimated usage (potential emissions) and actual emissions in Ireland 1998 (kilotonnes of CO₂ equivalent).

Source category	HFCs		PFCs		SF ₆	
	Potential	Actual	Potential	Actual	Potential	Actual
Metal production						
Primary aluminium smelting			N.O.	N.O.		
Magnesium and aluminium industry:						
magnesium					N.O.	N.O.
aluminium					0	0
Production of halocarbons and SF₆						
Production of SF ₆					N.O.	N.O.
Emissions from HCFC-22 manufacture	N.O.	N.O.				
Production of HFCs and PFCs	N.O.	N.O.	N.O.	N.O.		
Consumption of halocarbons and SF₆						
Stationary refrigeration	1078	54	N.E.	N.E.		
Mobile air conditioning	in stat fig	29				
Foam production	0	0				
Foam use	N.E.	2.7				
Fire protection	75	6.7	0	0		
General aerosols	7.4	7.4	0	0		
Metered dose inhalers	0.08	0.08	0	0		
Solvent uses	0	0	0	0		
Electrical transmission & distribution equip.					25	25
Semi-conductor manufacture	5.3	3.9	117	62	77	53
Other applications for SF ₆ :						
Gas-air tracer in research and leak detectors					18.3	12.2
Medical purposes					N.E.	N.E.
Equipment used in accelerators, lasers and night-vision goggles					N.E.	N.E.
Military applications					N.E.	N.E.
Sound-proof windows					1.2	0.6
Applications using adiabatic properties: car tyres, tennis balls, shoe soles, etc.					N.E.	N.E.
Other applications for HFCs and PFCs:						
Electronics testing	N.E.	N.E.	N.E.	N.E.		
Heat transfer	N.E.	N.E.	N.E.	N.E.		
Dielectric fluid	N.E.	N.E.	N.E.	N.E.		
Medical applications	N.E.	N.E.	N.E.	N.E.		

N.O., the activity is not occurring in Ireland; N.E., not estimated (expected to be negligible); 0, the activity does occur in Ireland, but emissions are estimated to be zero.

decreased emissions from electrical transmission and distribution equipment.

Issues in relation to the use of industrial gases in Ireland include the absence of tracking of usage of the gases, the difficulty in obtaining usage and emissions data from companies (although it should be noted that several companies were very forthcoming with useful

information), the need to increase collection rates of the spent gases, issues in relation to export of the spent gases for recovery or destruction, and isolated reports of deliberate gas release. The latter two issues are also relevant to HCFCs and CFCs, not just HFCs. The elimination of the use of the industrial gases in certain non-essential applications – silly string and klaxons – should be considered for non-marine-safety applications.

1 Introduction

The overall objective of the project was to establish an inventory of emissions of hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆) in Ireland for 1998 in accordance with guidelines set out by the United Nations Framework Convention on Climate Change (UNFCCC).

HFCs are a family of compounds containing fluorine, hydrogen and carbon, while PFCs are a family of compounds that only contain fluorine and carbon. Some of the HFC and PFC compounds in use throughout the world are listed in Appendix 1. Some of the substances on this list are more common than others, e.g. HFC-134a, HFC-125, HFC-143a, HFC-227ea, PFC-116, and PFC-14.

HFCs and PFCs are sometimes referred to as halocarbons. HFCs, PFCs, and SF₆ are together referred to as industrial gases.

1.1 Scope

All HFCs, PFCs, and SF₆ emissions within Ireland across all relevant sectors were included in the scope of the

project. There is a wide variation, for example, from use of the gases in the electronics industry manufacturing processes to those emitted from consumer products such as klaxon horns.

1.2 Methodology

The project involved extensive data gathering through contact with the relevant gas manufacturers, distributors, users, and retail outlets in Ireland and abroad.

The methodologies outlined in the Revised 1996 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories (IPCC, 1996) and the 2000 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000) were utilised in determining the data to be sourced, and in the calculation of the associated emissions. Inventory results were compiled in accordance with the format required for UNFCCC reporting.

2 Background to IPCC Reporting

2.1 Background

The United Nations Framework Convention on Climate Change (UNFCCC) aims to stabilise the concentrations of greenhouse gases in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The greenhouse gases controlled by the Convention are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆).

One of the obligations for signatories to the Convention is to develop, update periodically, publish and make available to the Conference of the Parties (COP) their national inventories of anthropogenic emissions by sources and removal by sinks of greenhouse gases. This project involved the compilation of such a national inventory of emissions for three of the six greenhouse gases: HFCs, PFCs, and SF₆. The inventory was compiled for the year 1998.

Ireland has developed and updated inventories for the three main greenhouse gases: CO₂, CH₄, and N₂O. This is the first time an Irish inventory has been prepared for the so-called industrial gases: HFCs, PFCs, and SF₆.

2.2 IPCC Methodology

Emissions of all greenhouse gases are divided into sectoral 'source categories'. Methodologies to calculate emissions inventories for each source category are outlined in the revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996).

The 2000 Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000) then recommends particular approaches for each source category, depending on the data available and the importance of the source to a particular inventory. The 2000 Good Practice Guide also expands on the methodologies available in the 1996 Revised Guidelines in terms of providing more detailed information on the existing methodologies and adding in new additional methodologies. The 2000 Good Practice Guide does not

supersede the 1996 Revised Guidelines but rather acts as a complement to the earlier publication.

The glossary at the end of this report defines some of the general terms in use by the IPCC.

2.2.1 Potential and actual emissions

A potential emission is defined as the amount of virgin chemical consumed in the country minus the amount of chemical recovered for destruction or export in the year of consideration. The method does not take into account accumulation.

An actual emission takes 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.

2.2.2 Tiered approach

The IPCC presents more than one emissions estimation methodology for certain source categories. These methodologies are classified according to a tier system, depending on the level of data that is utilised in the estimation. The simplified approach is referred to as Tier 1, and the more detailed methodology as Tier 2. Occasionally, and for certain source categories, several options are provided within Tier 1, e.g. Tier 1a, Tier 1b, and Tier 1c. The main reason for the range of options being provided at this level is data availability. Additional tiers have also been described in some cases, e.g. Tier 3a, Tier 3b, where more detailed or alternative methods are known.

2.2.3 National key source categories

Areas of the inventory that have the most effect on the inventory in terms of quantity of emissions and accuracy are denoted by the IPCC as *national key source categories*.

Key source categories are defined by the IPCC as those categories particularly significant in terms of their contribution to the overall uncertainty of the inventory in

terms of the absolute level of emissions, the trend in emissions, or both (IPCC, 2000).

Key source categories are those which, when summed together in descending order of magnitude, add up to over 95% of total greenhouse gas emissions in terms of carbon dioxide equivalent units.

2.2.4 Tier selection

The tiered approach as described should be interpreted as follows, according to the IPCC:

- “If the source category is not a key source category, but the data and resources of the inventory agency allow an emission calculation to be performed with Tier 2 or higher methods, the inventory agency is, of course, encouraged to do so (instead of applying the Tier 1 approach).”

- “If the source category is a key source category, but the inventory agency is unable to collect the data and use the method (or tier) suggested for good practice, it is considered good practice to use the Tier 1 method for the emission calculation and document the reason for using that method.” (IPCC, 2000)

2.2.5 Key source analysis

The IPCC recommends as good practice the identification of national key source categories in a systematic and objective manner, referred to as key source analysis. The IPCC has suggested a list of source categories that should be assessed in key source analysis (IPCC, 2000). All six greenhouse gases are considered in determining key source categories.

3 Global Sources of HFC, PFC, and SF₆ Emissions

3.1 Introduction

This chapter outlines the sources of emissions of the industrial gases on a worldwide basis. Not all of these sources are relevant to Ireland. The categories that are applicable to Ireland will be discussed in [Chapter 5](#).

In general, the sources of emissions of the industrial gases HFCs, PFCs, and SF₆ are outlined in [Table 3.1](#) (this is based on information contained in IPCC (1996) and IPCC (2000)).

The subsequent sections to this chapter describe the sources of emissions of the industrial gases on a worldwide basis for each of the categories in [Table 3.1](#).

3.2 Metal Production

PFC-14 and PFC-116 are emitted from the process of primary aluminium smelting. This is an electrolytic process. The PFCs are formed during the phenomenon known as the anode effect (AE), when the aluminium

Table 3.1. Global sources of emissions of industrial gases.

Source category	HFCs	PFCs	SF ₆
Metal production			
Primary aluminium smelting		•	
Magnesium and aluminium production			•
Production of halocarbons and SF₆			
Production of SF ₆			•
Emissions from HCFC-22 manufacture	•		
Production of HFCs and PFCs	•	•	
Consumption of halocarbons and SF₆			
Stationary refrigeration	•	•	
Mobile air conditioning	•		
Foam	•		
Fire protection	•	•	
Aerosols and metered dose inhalers	•	•	
Solvent uses	•	•	
Electrical transmission and distribution equipment			•
Semiconductor manufacture	•	•	•
Other applications for SF ₆ :			
Gas-air tracer in research and leak detectors			•
Medical purposes			•
Equipment used in accelerators, lasers and night-vision goggles			•
Military applications			•
Sound-proof windows			•
Applications using adiabatic properties: car tyres, tennis balls, shoe soles, etc.			•
Other applications for HFCs and PFCs:			
Electronics testing	•	•	
Heat transfer	•	•	
Dielectric fluid	•	•	
Medical applications	•	•	

• indicates that a particular gas is emitted from the source in question. This is global and not specific to Ireland.

oxide concentration in the reduction cell electrolyte is low.

SF₆ is used in the magnesium industry, usually in a mixture with other gases, as a cover gas in foundries to prevent oxidation or ignition of the molten magnesium or the formation of nitrides. Relevant areas of the industry include primary magnesium production, die casting, gravity casting, and reprocessing (secondary production). The gas is inert in the process and is usually emitted.

SF₆ is also sometimes used in aluminium casting as a cover gas, and as a refining agent to remove impurities such as hydrogen (which increases porosity), solids and oxides.

3.3 Production of Halocarbons and SF₆

Emissions from the process of manufacture of SF₆ are through inadvertent losses during production and handling.

HFC-23 is formed as a by-product in the process of manufacturing HCFC-22, and is subsequently emitted.

Emissions from the process of manufacturing HFCs and PFCs are through inadvertent losses during production and handling.

3.4 Consumption of Halocarbons and SF₆

3.4.1 Introduction

HFCs, PFCs and SF₆ are used in a variety of different areas. They are often used as substitutes for substances phased out under the Montreal Protocol. Such uses include stationary refrigeration, mobile air conditioning (MAC), foam blowing, fire protection, and metered dose inhalers (MDIs).

3.4.2 Stationary refrigeration

HFCs and PFCs are used as replacements for CFCs and HCFCs in refrigeration and air-conditioning equipment. The applications of refrigeration equipment include domestic refrigerators and freezers, commercial applications including stand-alone units and medium and larger units, industrial refrigeration including food processing and cold storage, commercial and residential

air conditioning, heat pumps, chillers, and refrigerated transport.

Refrigerants are supplied to:

- original equipment manufacturers for inclusion in new systems at the factory where built;
- refrigeration contractors for:
 - inclusion in new equipment after installation;
 - the servicing of existing equipment;
 - conversion of existing equipment to the replacement gases.

Various types of equipment are also imported and exported with the refrigerant already in place.

Emissions from stationary refrigeration can be broken down into:

- Assembly emissions: these occur during the assembly of equipment, including equipment destined for export.
- Operation emissions: these are associated with leakages from all refrigeration equipment in use. Rates vary significantly depending on the type of equipment. Any emissions that occur during servicing are also included in operation emissions.
- Disposal emissions: these are emissions that occur during the scrapping of systems in the country.

3.4.3 Mobile air conditioning

Mobile air conditioning provides cooling for passengers in cars, trucks, trains, trams and buses. The automotive industry has used HFC-134a for MAC in new vehicles since 1995. In addition, some trucks cool their cargo area with an automotive system (compressor mounted to the engine) using HFC-134a.

Emissions can be broken down into:

- First-fill emissions: fugitive gas that escapes when a MAC system is first charged, in the motor factory or by the after-market installer.
- Operation emissions: leakages during operation and emissions during servicing. MAC systems are

relatively leaky systems, with 10–20% of the charge lost per annum (IPCC, 1996). There are also losses during servicing. In the past, the procedure for servicing MAC systems had been to release the refrigerant to the atmosphere. The practice of recovery of refrigerants is becoming more common, so emissions during servicing are reduced. One of the main sources of refrigerant loss during MAC system operation is during accidents, since the systems are usually located towards the front of the engine.

- Disposal emissions: associated with the scrapping of vehicles containing MAC systems.

3.4.4 Foam blowing

HFCs are being used as replacements for CFC and HCFC blowing agents in the production of insulating, cushioning, and packaging foam. However, many foam producers are now using other blowing agents such as water and CO₂ (WS Atkins Consultants Ltd, 2000). The higher cost of HFCs means that they are only used in limited applications. These include certain polyurethane and polyolefin foams, and certain expanded polystyrene foams. HFC compounds that may be used include HFC-134a and HFC-152a.

The occurrence of emissions depends on the foam type.

- In open-cell foam (such as packaging), the majority of HFC emissions occur during the manufacturing process.
- In closed-cell foam, emissions occur over a longer time period (e.g. 20 years) during the actual use of the foam. Therefore, products containing closed-cell foam that was blown with HFCs will cause emissions when imported into a country.

3.4.5 Fire protection

HFCs are used as partial substitutes for halons in fire-protection equipment applications. There are other halon substitutes in use besides HFCs, such as inert gases. There are two general types of fire-protection equipment:

- Portable (streaming) equipment.
- Fixed (flooding) equipment. HFCs are mainly used as substitutes for halons in this application, most often in fire protection for electronic equipment.

Emissions will occur from fire-protection equipment during use in fire incidents, leakages and accidental releases.

3.4.6 Aerosols and metered dose inhalers

There are five different categories under this section:

- metered dose inhalers for treatment of asthma and chronic obstructive pulmonary diseases;
- personal care products (e.g. hair care, deodorant, shaving cream);
- household products (e.g. air-fresheners, oven and fabric cleaners);
- industrial products (e.g. special cleaning sprays, lubricants, pipe-freezers);
- other general products (e.g. silly string, tyre inflators, klaxons).

HFCs are used in MDI applications, gradually replacing CFCs. Most aerosol packages for the other applications listed above contain hydrocarbon (HC) as a propellant rather than HFCs. However, a small fraction of the total HFCs may be used as propellants or solvents in certain applications.

The HFCs currently used as propellants are HFC-134a, HFC-227ea and HFC-152a. HFC-43-10mee and PFC-614 are used as solvents in industrial aerosol products.

Emissions will occur during the use of such products. All gas contained in the aerosol will be emitted on use.

3.4.7 Solvent uses

HFCs and PFCs are used as solvents in four main areas as follows:

- precision cleaning
- electronics cleaning
- metal cleaning
- deposition applications

The use of HFCs or PFCs as solvents is still in its infancy. Solvents that have been or may be used include HFC-43-10mee and PFC-614.

Emissions will depend on the type of equipment in use and the level of recovery in place.

3.4.8 SF₆ emissions from electrical transmission and distribution equipment

SF₆ is used for electrical insulation, arc quenching, and for current interruption in equipment used in the transmission and distribution of electricity. Most of the SF₆ used in electrical equipment is used in gas-insulated switchgear (GIS) and circuit breakers, though some SF₆ is used in high voltage gas-insulated transmission lines and other equipment. SF₆ emissions from electrical equipment are the largest global source category of SF₆ emissions (IPCC, 2000).

Emissions are as follows:

- manufacturing emissions: during the manufacture of the equipment;
- installation emissions: some equipment is only charged in situ, and there are associated emissions;
- use emissions: through leakages and servicing;
- disposal emissions: any emissions from retired equipment.

3.4.9 PFC, HFC, and SF₆ emissions from semiconductor manufacture

The semiconductor industry uses PFCs, HFCs, and SF₆ in manufacturing processes, in addition to nitrogen trifluoride (NF₃). The PFCs in use typically include PFC-14 (CF₄), PFC-116 (C₂F₆), PFC-218 (C₃F₈), and c-C₄F₈, while HFC-23 (CHF₃) is the HFC in use. NF₃ is currently not recognised by the IPCC as a greenhouse gas although it is considered to have a global warming potential. In future it is likely to be recognised by the IPCC as a greenhouse gas.

These gases are used in two important steps in semiconductor manufacturing:

- plasma etching thin films;
- cleaning chemical vapour deposition (CVD) tool chambers.

During use, a fraction of the fluorocarbons used in the production process is converted into PFC-14 (CF₄). Emissions are associated with the use of these compounds. Abatement systems are sometimes used to reduce emissions.

3.4.10 SF₆ emissions from other sources

Other sources of SF₆ emissions, in addition to those described above, include:

- gas-air tracers in research and leak detectors;
- medical purposes;
- equipment used in accelerators, lasers and night-vision goggles;
- military applications;
- sound-proof windows;
- applications using adiabatic properties: car tyres, tennis balls, shoe soles, etc.

3.4.11 Other applications for HFCs and PFCs

Other sources of HFC and PFC emissions in addition to those described above include:

- electronics testing
- heat transfer
- dielectric fluid
- medical applications.

4 IPCC Methodology

4.1 Introduction

This chapter outlines the IPCC methodology for calculating emissions for each source category.

4.2 Metal Production

The IPCC method for PFC emissions estimation from aluminium production is to use information on quantities of aluminium production, and if available, smelter-specific information. The IPCC method for SF₆ emissions estimation from magnesium and aluminium processing is to use information on consumption of SF₆ by the industry. These methods will not be discussed any further since these sources are not relevant to Ireland (see [Chapter 5](#)).

4.3 Production of Halocarbons and SF₆

Emissions estimation from production of SF₆ is carried out using information on production quantities together with emission factors. For production of HCFC-22, the IPCC method for HFC-23 emissions estimation is to use information on production quantities, and if available, plant-level data. A similar method is used for emissions estimation from production of HFCs/PFCs. These methods will not be discussed any further since these sources are not relevant to Ireland (see [Chapter 5](#)).

4.4 Consumption of Halocarbons and SF₆

The consumption of halocarbons and SF₆ occurs in Ireland.

4.4.1 Introduction

There are several methods available for the calculation of emissions for each sub-source under consumption of halocarbons and SF₆. The method chosen is dependent on the data available and the importance of the source to the overall inventory.

The Tier 1 method for consumption of halocarbons and SF₆ uses the following formula:

$$\text{Potential emissions} = \text{production} + \text{import} - \text{export} - \text{destruction} \quad (4.1)$$

Tier 1a looks at only the import/export of bulk chemical in the above formula, whereas Tier 1b also looks at chemical contained in imported/exported equipment.

4.4.2 Stationary refrigeration

The methods recommended as good practice by the 2000 Good Practice Guide (IPCC, 2000) for estimating actual emissions from this sub-source are a Tier 2 top-down approach or a Tier 2 bottom-up approach (latter also described in the 1996 Revised Guidelines (IPCC, 1996)). The top-down approach looks at sales data. The bottom-up approach, which looks at individual product groups, is more data intensive and is considered by the IPCC to be unlikely to improve accuracy compared to the top-down approach.

The IPCC Tier 2 top-down approach is as follows:

$$\text{Actual emissions} = (\text{annual sales of new refrigerant}) - (\text{total charge of new equipment}) + (\text{original total charge of retiring equipment}) - (\text{amount of intentional destruction}) \quad (4.2)$$

where *annual sales of new refrigerant* is all chemical used to fill or refill equipment, whether the chemical is charged into equipment at the factory, charged into equipment after installation, or used to recharge equipment at servicing. It does not include recycled chemical. *Total charge of new equipment* is the sum of the full charges of all the new equipment that is sold in the country in a given year. It includes both the chemical required to fill equipment in the factory and the chemical required to fill the equipment after installation. It does not include charging emissions or chemical used to recharge equipment at servicing. *Original total charge of retiring equipment* is the sum of the original full charges of all the equipment that is retired in the country in a given year. It includes both the chemical that was originally required to fill equipment in the factory and the chemical that was originally required to fill the equipment after installation. It does not include charging emissions or chemical used to recharge equipment at servicing.

The IPCC Tier 2 bottom-up approach is as follows:

$$\text{Total emissions} = \text{assembly emissions} + \text{operation emissions} + \text{disposal emissions} \quad (4.3)$$

where

$$\text{Assembly emissions} = (\text{total HFC and PFC charged in year } t^1) (\text{IPCC factor for \% released}) \quad (4.4)$$

$$\text{Operation emissions} = (\text{amount of HFC and PFC stock in year } t) (\text{annual leak rates}) \quad (4.5)$$

$$\text{Disposal emissions} = (\text{HFC and PFC charged in year } t - n^2) (\text{IPCC factor for \% gas remaining in equipment}) (\text{factor for recovery efficiency}) - (\text{amount of intentional destruction}) \quad (4.6)$$

Standard annual leak rates, equipment lifetimes, and percentage gas remaining in equipment are provided by the IPCC and are dependent on equipment type.

4.4.3 Mobile air conditioning

The methods recommended as good practice by the 2000 Good Practice Guide (IPCC, 2000) for estimating actual emissions from this sub-source are the Tier 2 top-down approach or the Tier 2 bottom-up approach.

The IPCC general Tier 2 method is as follows:

$$\text{Annual emissions} = \text{'first-fill' emissions} + \text{operation emissions} + \text{disposal emissions} - \text{intentional destruction} \quad (4.7)$$

For the Tier 2 top-down approach:

$$\text{First-fill emissions} = (\text{IPCC emission factor}) (\text{annual virgin HFC for first fill of new MAC units}) \quad (4.8)$$

$$\text{Operation emissions} = (\text{total annual virgin HFC sold to the MAC industry}) - (\text{total annual virgin HFC for first fill of new MAC units}) \quad (4.9)$$

$$\text{Disposal emissions} = [(\text{annual scrap rate of vehicles with MAC systems using HFCs}) (\text{number of vehicles with MAC systems using HFCs}) (\text{average HFC charge/vehicle})] - \text{destruction} \quad (4.10)$$

¹ Where t is the inventory year.

² Where n is the lifetime of the equipment.

For the Tier 2 bottom-up approach:

First-fill emissions: same as the top-down approach.

$$\text{Operation emissions} = (\text{amount of HFC stock in year } t) (\text{IPCC factor for annual emissions rate}) \quad (4.11)$$

$$\text{Disposal emissions} = (\text{HFC charged in year } t - n) (\text{IPCC factor for \% gas remaining in equipment}) (\text{factor for recovery efficiency}) \quad (4.12)$$

Standard average HFC charge per vehicle, first-fill emission rates, annual leak rates, equipment lifetimes, and percentage gas remaining in equipment are provided by the IPCC.

4.4.4 Foam blowing

The Tier 2 method is recommended as good practice by the 2000 Good Practice Guide (IPCC, 2000) for estimating actual emissions from this sub-source. The method differentiates between the two types of foam, open-cell foam and closed-cell foam.

$$\text{Emissions from open-cell foam} = \text{total annual HFCs and PFCs used in manufacturing open-cell foam} \quad (4.13)$$

$$\text{Emissions from closed-cell foam} = [(\text{total HFCs and PFCs used in manufacturing new closed-cell foam in year } t) (\text{first-year loss emission factor})] + [(\text{original HFC or PFC charge blown into closed-cell foam manufacturing between year } t \text{ and year } t - n) (\text{annual loss emission factor})] + [(\text{decommissioning losses in year } t) - (\text{HFC or PFC destroyed})] \quad (4.14)$$

where n is the product lifetime of closed-cell foam. The IPCC provides default factors in the above equations.

4.4.5 Fire protection

The method recommended as good practice in the 2000 Good Practice Guide (IPCC, 2000) is a top-down Tier 2 approach, and is as follows (similar to the stationary refrigeration method):

$$\text{Emissions} = \text{annual sales of HFCs/PFCs for fire protection} - (\text{HFCs/PFCs used to charge new fire-protection equipment} - \text{HFCs or PFCs originally used to charge retiring fire-protection equipment}) \quad (4.15)$$

The method that is given in the 1996 Revised Guidelines (IPCC, 1996), but which can lead to error, is as follows:

Emissions of HFCs or PFCs in year t = (HFCs/PFCs used to charge new fire-protection equipment) (emission factor) (4.16)

4.4.6 Aerosols and metered dose inhalers

The method recommended as good practice in the 2000 Good Practice Guide (IPCC, 2000) is a Tier 2 approach as follows:

Emissions in year t = [(quantity of HFC and PFC contained in aerosol products sold in year t) (50%)] + [(quantity of HFC and PFC contained in aerosol products sold in year (t – 1)) (50%)] (4.17)

According to the 2000 Good Practice Guide (IPCC, 2000), activity data for this sub-category can be collected using either a bottom–up or a top–down approach, depending on the availability and quality of the data, and in many cases, a mix of bottom–up and top–down data may be necessary. The bottom–up approach requires data on the number of aerosol products sold and imported, and the average charge per container. The top–down approach involves collecting aerosol and MDI chemical sales data directly from chemical manufacturers. The factor of 50% is a default value.

The same method is used for MDIs as well as general aerosols.

4.4.7 Solvent uses

The method recommended as good practice in the 2000 Good Practice Guide (IPCC, 2000) is a Tier 2 approach as follows (similar to the aerosols sub-category):

Emissions in year t = [(quantity of solvents sold in year t) (50%)] + [quantity of solvents sold in year (t – 1) (50%)] (4.18)

The 2000 Good Practice Guide (IPCC, 2000) notes that in certain applications with new equipment, it is possible that much lower loss rates will be achieved and that emissions will occur over a period of more than 2 years. Alternative emission factors can be developed in such situations, using bottom–up data on the use of such

equipment and empirical evidence regarding alternative emission factors.

The required data can be collected using either top–down or bottom–up methods, depending on the character of the national solvent industry. According to the 2000 Guide, in most countries the end-users will be extremely diverse and a top–down approach would be practical.

4.4.8 SF₆ emissions from electrical transmission and distribution equipment

The 1996 Guidelines (IPCC, 1996) include methods for estimating both potential (Tier 1 method) and actual (Tier 2 method) emissions from electrical equipment. The 2000 Guide (IPCC, 2000) describes good practice as using the Tier 1 method and two variants of the Tier 2 method. Three variants of a more accurate approach (termed Tier 3 method) are also given in the 2000 Guide. Emissions estimates developed using the Tier 3 method would be the most accurate. Estimates developed using the Tier 1 method would be the least accurate because these figures reflect apparent consumption rather than emissions.

Tier 1 method – potential approach

Potential SF₆ emissions from all uses = production + (imports – exports) – destruction (4.19)

The fraction of the total SF₆ that is sold to utilities and electrical equipment manufacturers must then be determined either directly or indirectly:

Direct approach: SF₆ emissions from electrical equipment = sales of SF₆ to equipment manufacturers + sales of SF₆ to utilities + [SF₆ in imported equipment – SF₆ in exported equipment] (4.20)

Indirect approach: SF₆ emissions = production + [imports – exports] – destruction – consumption by other SF₆ uses (4.21)

In equation 4.21, ‘other uses’ means magnesium smelting, semiconductor manufacturing, etc.

The Tier 1 method represents an upper bound, since it assumes that the use of the gas replaces released gas, when in fact some of the gas may be used to fill a net increase in capacity.

Tier 2a method – life-cycle emission factor approach

$$\text{Total emissions} = \text{manufacturing emissions} + \text{installation emissions} + \text{use emissions} + \text{disposal emissions} \quad (4.22)$$

where *manufacturing* emissions are based on SF₆ purchased by equipment manufacturers or capacity of new equipment charged, together with emission factors; *equipment installation* emissions are based on SF₆ purchased by utilities for new equipment, or capacity of new equipment charged by utilities (not equipment manufacturers), together with emission factors; *equipment use* emissions are based on total capacity of installed equipment, together with emission factors for leakage, and servicing and maintenance that is typically carried out every 12 years; and *equipment disposal* emissions are based on capacity of retiring equipment and assumed fraction of SF₆ in end-of-life equipment. If SF₆ is being recovered, a recovery factor should be built in (default is zero).

Tier 2b method – IPCC default emission factors

$$\text{Emissions of SF}_6 \text{ in year } t = (2\% \text{ of the total charge of SF}_6 \text{ contained in the existing stock of equipment of operation in year } t) + (95\% \text{ of the nameplate capacity of SF}_6 \text{ in retiring equipment}) \quad (4.23)$$

Tier 3a method – emissions based on equipment life cycle

This approach is useful for inventory agencies or facilities that, in addition to estimating their total emissions of SF₆ from electrical equipment, wish to determine how and when such emissions occur during the lifecycle of the equipment:

$$\text{Total emissions} = \text{manufacturing emissions} + \text{installation emissions} + \text{use emissions} + \text{disposal emissions} \quad (4.24)$$

Each *equipment manufacturer's* emissions can be calculated as follows:

- Collect data on the annual change in the SF₆ inventory.
- Add the amount of SF₆ obtained during the year (that purchased from producers/distributors, any returned

from equipment users, and any returned by users after recycling).

- Subtract the amount of SF₆ transferred to others during the year (SF₆ in new equipment delivered to customers, the amount delivered to equipment users in containers, and the amount returned to SF₆ producers, sent to recycling firms, or destroyed).

Equipment installation emissions can be estimated by subtracting the nameplate capacity of all new equipment filled from the actual amount of SF₆ used to fill new equipment.

Equipment use emissions are determined by the amount of SF₆ used to service equipment. If SF₆ is being recovered from equipment before servicing and returned after servicing, it is important that this amount is not included in the estimate.

Emissions from *equipment disposal* are estimated by subtracting the amount of SF₆ recovered from retired equipment from the nameplate capacity of the retired equipment and also subtracting the amount of SF₆ destroyed.

Tier 3b method – manufacturer-level and utility-level mass-balance method

$$\text{Total emissions} = \text{manufacturer emissions} + \text{utility emissions} \quad (4.25)$$

Equipment manufacturer emissions are estimated as for the Tier 3a method.

Utility emissions are calculated by performing mass balances for each utility considering SF₆ stored, purchased in bulk and in equipment, returns to suppliers, SF₆ sent to/received from recyclers, SF₆ destroyed, and SF₆ in retired and new equipment.

Tier 3c method – country-level mass-balance method

Emissions are calculated at a national level:

$$\text{Emissions} = \text{annual sales} - (\text{net increase in nameplate capacity}) - (\text{SF}_6 \text{ destroyed}) \quad (4.26)$$

where *annual sales* is new SF₆ used for filling or refilling electrical equipment, both in bulk and in equipment itself, and *net increase in capacity* is the capacity of new

equipment, including both equipment that is filled in the factory before shipment and equipment that is filled after installation, minus the capacity of all retiring equipment.

4.4.9 PFC, HFC, and SF₆ emissions from semiconductor manufacture

The 1996 Guidelines (IPCC, 1996) do not include any methods for estimating emissions from semiconductor manufacture. The 2000 Good Practice Guide (IPCC, 2000) outlines a Tier 1 method, a Tier 2a method, a Tier 2b method, and a Tier 2c method.

Tier 2a method: process-specific parameters

This method is appropriate where company-specific or plant-specific values are available for the following parameters: the amount of gas fed into each process or tool (or into small subsets of processes or tools), the fraction of purchased gas remaining in the shipping container after use (heel), the fraction of the gas ‘used’ (destroyed or transformed) in the semiconductor manufacturing process, the fraction of the gas converted to CF₄ during semiconductor manufacture, the fraction of the gas fed into processes with emission control technologies, and the fraction of the gas destroyed by those emission control technologies.

$$\text{Emissions of gas } i = (1 - h) \sum_p \{FCi,p (1 - Ci,p) [1 - (ai,p)(di,p)]\} \quad (4.27)$$

where h is the fraction of gas remaining in the shipping container (heel) after use; p is the process or process type (etching or CVD chamber cleaning); i is the gas species CF₄, C₂F₆, C₃F₈, C₄F₈, CHF₃, NF₃ or SF₆; FCi,p is the mass of gas i fed into process/process type p , kg; Ci,p is the use rate (fraction destroyed or transformed) for each gas i and process/process type p , kg; ai,p is the fraction of gas volume fed into processes with emission control technologies (company or plant-specific); and di,p is the fraction of gas i destroyed by the emission control technology (if more than one emission control technology is used in process/process type p , this is the average of the fraction destroyed by those emission control technologies, where each fraction is weighted by the quantity of gas fed into tools using that technology).

Also for CF₄ by-product emissions for each gas i :

$$\text{CF}_4 \text{ by-product emissions} = (1 - h) \sum_p \{(Bi,p) (FCi,p) [1 - (ai,p) (dCF_{4,p})]\} \quad (4.28)$$

where Bi,p is the fraction of gas i transformed into CF₄ for each process/process type, and $dCF_{4,p}$ is the fraction of CF₄ by-product destroyed by the emission control technology.

Tier 2b method: process type-specific parameters

The Tier 2b method uses the same equations as the Tier 2a method. However, instead of distinguishing among processes or small sets of processes, it distinguishes only between process types (etching vs. CVD chamber cleaning). Consequently, the Tier 2b method requires data on the aggregate quantities of each gas fed into all etching processes and all cleaning processes (FCi,p), as opposed to the quantities of each gas fed into each individual process.

Industry-wide generic default values are used for any or all of the following: the fraction of the gas remaining in the shipping container (h), the fraction of the gas ‘used’ (destroyed or transformed) per process type (Ci,p), and the fraction of the gas converted into CF₄ in the process type (Bi). Defaults are also presented for the fraction of the gas destroyed by the emissions control technology (di,p and $dCF_{4,p}$).

Company or plant-specific emission factors may be substituted for default values when available. The equations account for the plant-specific use of emission-control devices, but do not account for differences among individual processes or tools or among manufacturing plants in their mix of processes and tools.

Tier 2c method: gas-specific parameters

This method calculates emissions for each gas used on the basis of company-specific data on gas sales or purchases, and on emission control technologies. It uses industry-wide generic default values for the fraction of the purchased gas remaining in the shipping container after use (h), the fraction of the gas ‘used’ (destroyed or transformed) in the semiconductor manufacturing process, and the fraction of the gas converted into CF₄ in semiconductor manufacture.

As is the case with the Tier 2a and 2b methods, total emissions are equal to the sum of emissions from the gas

i used in the production process plus the emissions of by-product CF_4 resulting from use of the gas i . The Tier 2c method does not distinguish between processes or process types.

$$\text{Emissions of gas } i = (1 - h) \{FCi (1 - Ci) [1 - (ai) (di)]\} \quad (4.29)$$

where FCi is the sales/purchases of gas i , kg; Ci is the use rate of gas (fraction destroyed or transformed in process); ai is the fraction of gas i volume used in processes with emission control technologies (company or plant-specific); and di is the fraction of gas i destroyed by the emission control technology.

$$\text{By-product emissions of } CF_4 \text{ for } FCi = (1 - h) \{(Bi) (FCi) (1 - (ai)(dCF_4))\} \quad (4.30)$$

where Bi is the CF_4 created per kg of gas i used, kg; and dCF_4 is the fraction of CF_4 by-product destroyed by the emission control technology.

Tier 1 method – default

The Tier 1 method is the least accurate estimation method. It should be used only in cases where company-specific data are not available. This method calculates emissions for each gas used on the basis of national gas sales or purchase data. It uses industry-wide generic default values for the fraction of the purchased gas remaining in the shipping container after use, the fraction of the gas ‘used’ (transformed or destroyed) in the semiconductor manufacturing process, and the fraction of the gas transformed into CF_4 in semiconductor manufacture. As is the case with the Tier 2 method, emissions are equal to the sum of emissions from each gas used in the production process plus the emissions of by-product CF_4 resulting from use of the gases.

$$\text{Emissions of gas } i = (1 - h) [FCi (1 - Ci)] \quad (4.31)$$

$$\text{By-product emissions of } CF_4 = (1 - h) (Bi) (FCi) \quad (4.32)$$

4.4.10 SF_6 emissions from other sources

There is no method provided in the 2000 IPCC Good Practice (IPCC, 2000) or 1996 Revised Guidelines (IPCC, 1996) for gas-air tracer in research and leak detectors, emissions associated with medical purposes, emissions from equipment used in accelerators, lasers

and night-vision goggles, or emissions from military applications. The recommendation is to treat them as per semi-prompt emissions, e.g. aerosol use.

Sound-proof windows

There is no method provided in the 1996 Revised Guidelines. In the 2000 IPCC Good Practice (IPCC, 2000), the following is provided.

Double-glazed soundproof windows: approximately 33% of the total amount of SF_6 purchased is released during assembly (i.e. filling of the double-glass window). Of the remaining stock contained inside the window, an annual leakage rate of 1% is assumed (including glass breakage). Thus, about 78% of initial stock is left at the end of its 25-year lifetime. The application of SF_6 in windows began in 1975, so disposal is only beginning to occur.

$$\text{Assembly emissions} = 0.33 (\text{window capacity}) \quad (4.33)$$

$$\text{Leakage emissions in year } t = 0.01 (\text{existing stock in the window}) \quad (4.34)$$

$$\text{Disposal emissions} = (\text{amount left in window at end of lifetime}) (1 - \text{recovery factor}) \quad (4.35)$$

Unless country-specific data are available, a default recovery factor value of zero should be assumed.

Applications using adiabatic properties

Applications using adiabatic properties include car tyres, tennis balls, shoe soles, etc. In the 2000 IPCC Good Practice (IPCC, 2000), a delay in emissions of 3 years is assumed for car tyres:

$$\text{Emissions in year } t = \text{sales in year } t - 3 \quad (4.36)$$

For the other adiabatic applications, tennis balls, shoe soles, etc., there is no method provided in the 2000 IPCC Good Practice or 1996 Revised Guidelines. The recommendation is to treat them as per car tyres.

4.4.11 Other applications for HFCs and PFCs

There is no method provided in the 2000 IPCC Good Practice (IPCC, 2000) or the 1996 Revised Guidelines (IPCC, 1996) for electronics testing, heat transfer, dielectric fluid applications, or medical applications.

5 Inventory of HFCs, PFCs, and SF₆ Emissions for Ireland

5.1 Overall Inventory

The estimated usage, which is also termed ‘potential emissions’, for each of the industrial gases HFCs, PFCs, and SF₆, in Ireland in 1998 across all sectors is shown in [Table 5.1](#), both in terms of kilotonnes of carbon dioxide equivalent and in tonnes of gas.

Estimated actual emissions for each of the industrial gases in Ireland in 1998 across all sectors are shown in [Table 5.2](#), both in terms of kilotonnes of carbon dioxide equivalent and in tonnes of gas.

The above estimates are broken down into individual sources in [Tables 5.3](#) and [Table 5.4](#). [Table 5.3](#) outlines the estimated usage (or potential emissions), and estimated actual emissions for each source in terms of tonnes of gases. [Table 5.4](#) outlines estimated usage (or potential emissions), and estimated actual emissions for each source in terms of kilotonnes of carbon dioxide equivalent.

The subsequent sections in this chapter describe the estimates of emissions of industrial gas in Ireland for each of the source categories in [Tables 5.1–5.4](#).

5.2 Metal Production

Based on communications with the aluminium casting industry and the aluminium recovery industry, there is no primary aluminium smelting in Ireland. There is one secondary aluminium production company located in the country, involved in the recycling of aluminium. This company utilises a thermal process, so the generation of PFCs is not relevant to the site. Therefore, PFC emissions from the aluminium production source category are not relevant to Ireland.

Based on discussions with experienced people in the industry, there is no magnesium casting taking place in Ireland. Therefore, SF₆ emissions from magnesium casting are not relevant to Ireland. Casting of aluminium is carried out in the country. However, based on discussions with both IPC-licensed and other relevant aluminium casting companies, SF₆ is not used in aluminium casting in Ireland. Discussions with the industry have shown that gases are only used in specific casting applications. For most applications, flux covers are used, which create a layer on top of the molten metal. Therefore, SF₆ emissions from the magnesium and aluminium processing source category are not relevant to Ireland.

Table 5.1. Estimated usage of industrial gases in Ireland in 1998.

	Estimated usage (or potential emissions) 1998			Total
	HFCs	PFCs	SF ₆	
	(kilotonnes of carbon dioxide equivalent)			
All sectors	1091	117	121	1329
	(tonnes of gas)			
All sectors	583	14	5	602

Table 5.2. Estimated actual emissions of industrial gases in Ireland in 1998.

	Estimated actual emissions 1998			Total
	HFCs	PFCs	SF ₆	
	(kilotonnes of carbon dioxide equivalent)			
All sectors	104	62	91	257
	(tonnes of gas)			
All sectors	52	7	4	63

Table 5.3. Estimated usage (potential emissions) and actual emissions in Ireland 1998 (tonnes of gas).

Source category	HFCs		PFCs		SF ₆	
	Potential	Actual	Potential	Actual	Potential	Actual
Metal production						
Primary aluminium smelting			N.O.	N.O.		
Magnesium and aluminium industry:	magnesium				N.O.	N.O.
	aluminium				0	0
Production of halocarbons and SF₆						
Production of SF ₆					N.O.	N.O.
Emissions from HCFC-22 manufacture	N.O.	N.O.				
Production of HFCs and PFCs	N.O.	N.O.	N.O.	N.O.		
Consumption of halocarbons and SF₆						
Stationary refrigeration	550	28	N.E.	N.E.		
Mobile air conditioning	in stat fig	13.2				
Foam production	0	0				
Foam use	N.E.	2.1				
Fire protection	26	2.3	0	0		
General aerosols	5.7	5.7	0	0		
Metered dose inhalers	0.06	0.06	0	0		
Solvent uses	0	0	0	0		
Electrical transmission & distribution equip.					1.1	1.1
Semiconductor manufacture	1	0.6	13.8	7.4	3.2	2.2
Other applications for SF ₆ :						
	Gas-air tracer in research and leak detectors				0.8	0.5
	Medical purposes				N.E.	N.E.
	Equipment used in accelerators, lasers and night-vision goggles				N.E.	N.E.
	Military applications				N.E.	N.E.
	Sound-proof windows				0.05	0.02
	Applications using adiabatic properties: car tyres, tennis balls, shoe soles, etc.				N.E.	N.E.
Other applications for HFCs and PFCs:						
	Electronics testing		N.E.	N.E.	N.E.	N.E.
	Heat transfer		N.E.	N.E.	N.E.	N.E.
	Dielectric fluid		N.E.	N.E.	N.E.	N.E.
	Medical applications		N.E.	N.E.	N.E.	N.E.

N.O., the activity is not occurring in Ireland; N.E., not estimated (expected to be negligible); 0, the activity does occur in Ireland, but emissions are estimated to be zero.

Table 5.4. Estimated usage (potential emissions) and actual emissions in Ireland 1998 (kilotonnes of CO₂ equivalent).

Source category	HFCs		PFCs		SF ₆	
	Potential	Actual	Potential	Actual	Potential	Actual
Metal production						
Primary aluminium smelting			N.O.	N.O.		
Magnesium and aluminium industry:					N.O.	N.O.
magnesium						
aluminium					0	0
Production of halocarbons and SF₆						
Production of SF ₆					N.O.	N.O.
Emissions from HCFC-22 manufacture	N.O.	N.O.				
Production of HFCs and PFCs	N.O.	N.O.	N.O.	N.O.		
Consumption of halocarbons and SF₆						
Stationary refrigeration	1078	54	N.E.	N.E.		
Mobile air conditioning	in stat fig	29				
Foam production	0	0				
Foam use	N.E.	2.7				
Fire protection	75	6.7	0	0		
General aerosols	7.4	7.4	0	0		
Metered dose inhalers	0.08	0.08	0	0		
Solvent uses	0	0	0	0		
Electrical transmission & distribution equipment					26	26
Semiconductor manufacture	5.3	3.9	117	62	77	53
Other applications for SF ₆ :						
Gas-air tracer in research and leak detectors					18.3	12.2
Medical purposes					N.E.	N.E.
Equipment used in accelerators, lasers and night-vision goggles					N.E.	N.E.
Military applications					N.E.	N.E.
Sound-proof windows					1.2	0.6
Applications using adiabatic properties: car tyres, tennis balls, shoe soles, etc.					N.E.	N.E.
Other applications for HFCs and PFCs:						
Electronics testing	N.E.	N.E.	N.E.	N.E.		
Heat transfer	N.E.	N.E.	N.E.	N.E.		
Dielectric fluid	N.E.	N.E.	N.E.	N.E.		
Medical applications	N.E.	N.E.	N.E.	N.E.		

N.O., the activity is not occurring in Ireland; N.E., not estimated (expected to be negligible); 0, the activity does occur in Ireland, but emissions are estimated to be zero.

5.3 Production of Halocarbons and SF₆

There are only a few manufacturers of industrial gases globally. Two are in the UK, Ineos Fluor (formerly ICI) and Rhodia (formerly Rhone Poulenc). There are several other manufacturers on mainland Europe including DuPont in the Netherlands, Celanese GmbH (formerly Hoechst) and Solvay in Germany, Atofina in France, and Ausimont in Italy. Most have distribution offices in the UK. There are also manufacturers in the USA and Japan. HCFC-22, HFCs, PFCs, and SF₆ are not produced in Ireland. Therefore, these source categories are not relevant to Ireland.

5.4 Consumption of Halocarbons and SF₆

5.4.1 Introduction

Data on the consumption of industrial gases in Ireland were obtained from a combination of sources, including Irish gas distributors, manufacturers' sales offices in the UK and Europe, gas manufacturers in the UK and Europe, Irish users of the gases, and Irish and European suppliers of products containing the gases.

Bulk gases are supplied to the Irish market for use in stationary refrigeration, MAC, fire protection, the manufacture of MDIs, electrical transmission and distribution equipment, semiconductor manufacture, use as a tracer gas, use as a carrier gas, window sound-proofing applications, and surgery.

There are also products on the Irish market that contain the gases. These include imported refrigeration and air-conditioning equipment, vehicles with manufacturer-installed air conditioning, MDIs for consumption, electrical transmission and distribution equipment, and aerosols used for specific applications. There is also the export of transport refrigeration systems from an Irish manufacturing facility.

In all, there are six major suppliers of halocarbons and SF₆. All were contacted, together with their suppliers. Additionally, 13 importers (representing almost all imports) were contacted. The information supplied from suppliers, agents, and importers has been collated, with the following conclusions.

The suppliers mainly sell HFCs as refrigerants, as propellants for MDIs, and for use in the semiconductor industry. PFCs are sold to the semiconductor industry. SF₆ sales are to the semiconductor industry, for use in electricity transmission and distribution equipment, and as a tracer in leak detection. The gases for refrigeration are almost all HFCs, consisting of pure gases and blends. One blend contains a PFC, but in 1998 there were no sales of this product in Ireland, while in 2000 this gas accounted for only a very small proportion of sales in Ireland. The gas used for MDIs is usually HFC-134a, but CFCs are also supplied for this application. Overall sales of HFCs and PFCs in tonnes have increased between 1998 and 2000. All suppliers except one confirmed that they do not supply any HFCs to Ireland for use as solvents. The one exception does supply small amounts of HFCs for use as a carrier gas and as a solvent; however, there were no HFC sales in 1998. All suppliers confirmed that they do not supply any HFCs to Ireland for use as foam-blowing agents.

CSO data have been obtained. Bulk imports of HFCs and PFCs in 1998 are given as 101.441 t. According to industry sources, this is underestimated. In addition, the CSO data do not differentiate between individual HFCs and PFCs. The CSO data on SF₆ are unusable, since it is only one of 31 different substances in one category.

5.4.2 Stationary refrigeration

HFCs are being used as replacement gases for HCFCs, which are now being phased out. In 1998 the quantity of HCFCs sold for use as refrigerants was much larger than HFCs. In 1998, as well as today, the major HFC/PFC refrigerant gas sold was HFC-134a, on its own or within blends such as R404a. HFC refrigerants that have also been on the increase in recent years are HFC-143a and HFC-125. Other HFC refrigerant gases include HFC-32 and HFC-23. Some of these gases are sold in blends, such as R404a, R407a, R407c, R410a, R507 and R508. PFCs that are used for refrigeration in Ireland include small amounts of PFC-116 as part of blends.

5.4.2.1 Data sourcing for stationary refrigeration

Information on industrial gases supplied to the refrigeration sector was obtained from chemical suppliers and manufacturers. One of the major refrigerant suppliers estimated the total HFC/PFC refrigerant sales to the

refrigeration and air-conditioning industry in Ireland in 1998 to be between 500 and 600 t. Actual sales data from four companies were obtained, which account for 25% of the estimated sales in 1998. The composition of these actual sales data in terms of specific HFCs was extrapolated for all sales.

Some, but not all, of the companies in the contracting refrigeration industry keep information on quantities of industrial gases used.

While quantities of gases used as refrigerants have been determined, differentiation between the type of refrigeration application, i.e. stationary versus mobile, and differentiation between that used in servicing existing systems and in filling new systems has been difficult. No Irish supplier contacted was able to provide such estimates, as customers do not indicate usage, while companies in the contracting refrigeration industry were unable to provide such a breakdown since they do not keep such information. An additional complication is that HFC/PFC gases sold to the industry are not only used for new equipment or to replace losses to the atmosphere, but also as interim or long-term replacement gases for existing CFC/HCFC equipment.

An estimate of the split between servicing existing systems and filling new systems has been provided by one of the contracting companies as being about 60% service and 40% new installations. However, according to one UK gas manufacturer, the majority of their sales of HFC/PFC refrigerants are used in new installations, with a small amount used in service applications, estimated at less than 5% of the total HFC/PFC sales. According to the manufacturer, this estimate is based on current leakage rates. A major contracting refrigeration company also agreed with 5% as the industry standard for accidental leakages.

There is an Irish manufacturer of transport refrigeration systems, who manufactures a large number of refrigeration units per year for trucks, buses, trailers, and sea-going containers. The majority of these are exported. The company was contacted and has supplied data on actual usage, and emissions associated with the filling of the refrigeration systems. These units are self-contained

systems, which is why they have been included in the stationary refrigeration sector of the industry.

5.4.2.2 Emissions estimation from stationary refrigeration

Tier 1: basic or potential method

The equation for potential emissions has already been outlined in equation 4.1 as:

$$\text{Potential emissions} = \text{production} + \text{import} - \text{export} - \text{destruction}$$

Production: No production of the industrial gases in Ireland.

Import: For Tier 1a bulk chemical only: CSO data are unreliable; therefore, the total sales of the gases for stationary refrigeration applications by manufacturers/distributors to Ireland have been used to calculate bulk imports. This includes gases used by the Irish contracting refrigeration industry as well as those used by the manufacturer of transport refrigeration systems for export.

For Tier 1b chemical contained in products: import of the various types of stationary refrigeration equipment has not been considered.

Export: For Tier 1a bulk chemical only: the only bulk export of HFC gases in relation to stationary refrigeration will be the return of spent HFC gases to manufacturers for recovery or destruction by some but not all users. This figure has been unobtainable.

For Tier 1b chemical contained in products: the only export is in relation to the refrigerated transport systems of one Irish manufacturer, where the majority of the product is exported. There is no known export of any other HFC refrigeration/air-conditioning systems. In any case, it is expected to be negligible since the other refrigeration companies are involved in the domestic market rather than export.

Destruction: From the point of view of stationary refrigeration, destruction does not take place in Ireland. Any recovered gas is either reused in the equipment, stored on site, or sent abroad for recovery or destruction. One term that is relevant to Ireland, but which is not in the above equation, is accumulation of the spent gases on supplier and contractor sites.

For HFCs, using equation 4.1:

$$\text{Potential emissions from stationary refrigeration} = 0 \text{ t production} + (621 \text{ t import}) - (71 \text{ t export}) - 0 \text{ t destruction} \quad (5.1)$$

$$\text{Potential emissions from stationary refrigeration} = 550 \text{ t}$$

The breakdown of the different types of HFC in use in the refrigeration industry is as follows: HFC-134a 55%; R32 7%; R125 23%; R143a 15% (based on data received from four of the suppliers extrapolated to the whole of the refrigeration industry). The main refrigerants are the blends R404a and HFC-134a.

In speciated format, the imports in equation 5.1 break down as shown in Table 5.5.

In speciated format, the exports contained in products in equation 5.1 break down as shown in Table 5.6.

In speciated format, the potential emissions of equation 5.1 from stationary refrigeration can be broken down as shown in Table 5.7.

Tier 2: advanced or actual method

Since the bottom-up approach is more data intensive and considered unlikely by the IPCC to improve accuracy compared to the top-down approach, the top-down approach has been used to estimate HFC emissions from stationary refrigeration. The exception to this will be in the case of the manufacture of transport refrigeration equipment, where the bottom-up approach will be used. This is justified in that emissions are only associated with assembly since the majority of systems are exported, and any systems that are operational in Ireland will already be included in the top-down approach.

Tier 2b: top-down approach

As shown already in equation 4.2:

$$\text{Actual emissions} = (\text{annual sales of new refrigerant}) - (\text{total charge of new equipment}) + (\text{original total charge of retiring equipment}) - (\text{amount of intentional destruction})$$

Each of the terms of this formula is calculated as follows:

$$\text{Annual sales} = \text{domestically manufactured chemicals} + \text{imported bulk chemicals} - \text{exported bulk chemicals} \quad (5.2)$$

which, for Ireland, is as follows:

$$\text{Annual sales} = \text{imported bulk chemicals only} \quad (5.3)$$

Table 5.5. HFC imports for use in the refrigeration and air-conditioning industry.

Bulk imports (t)	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-143a	Total
Refrigeration and air-conditioning industry	0.03	40	155	308	118	621

Table 5.6. HFC exports for use in refrigeration and air-conditioning products.

Exports in products (t)	HFC-125	HFC-134a	HFC-143a	Total
Stationary refrigeration and air conditioning	30	6	35	71

Table 5.7. Potential HFC imports from stationary refrigeration and air conditioning.

Potential emissions from stationary refrigeration (t)	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-143a	Total
	0.03	40	125	302	83	550

Total charge of new equipment = chemicals to charge domestically manufactured equipment + chemicals to charge imported equipment that is not factory charged
(5.4)

Total charge of retiring equipment = original chemical charge to domestically manufactured retiring equipment + chemical to charge retiring imported equipment that is not factory charged + chemical contained in factory-charged retiring imported equipment – chemical contained in factory-charged retiring exported equipment
(5.5)

Amount of intentional destruction: both the chemical suppliers and the refrigeration contracting companies have been asked for information regarding waste refrigerant practices. Within the contracting industry, reclaim units that recover the gas for reuse in the same or another system are common, often being supplied by the gas supplier. In certain cases the gas cannot be reused. Such spent gases are classified as hazardous waste. Practices vary in respect of such spent gases, with some chemical suppliers accepting returns from customers, which are subsequently returned to the manufacturers for purification or destruction, while other chemical suppliers and manufacturers do not provide such a service. This often depends on the volume of gas being returned or on the value of the customer. Also, accumulating storage of gases (in some cases including CFCs) on some contractor sites and supplier sites is an issue. There occasionally appears to be a (perceived) difficulty in the export of such spent gases for destruction, which is mainly in relation to costs and paperwork.

When surveyed in 2000, 14 local authorities in Ireland had separate collection of waste white goods in operation, and three more local authorities had plans to set up separate collection. However, in 1998 not all such facilities were in operation. Some local authorities operate reclaim units and de-gas refrigerators themselves, while others use private contractors for degassing. Several local authorities report that fridges are often punctured (and the gas has escaped) before arrival.

Some companies within the contracting refrigeration industry also receive old refrigeration equipment from customers.

The majority of any gas removed from waste refrigeration equipment in 1998 is not likely to be HFC based since HFCs were only introduced in 1990.

The only terms in the above equations for which data can be obtained for Ireland are imported bulk chemicals, and chemicals to charge domestically manufactured equipment. An alternative approach in calculating actual emissions, similar to the above top-down equation 4.2, will be taken instead.

Actual emissions of HFCs = (imported bulk chemicals) (industry estimate of % of sales used to replace emissions)
(5.6)

Actual emissions of HFCs = (550 t) (5%)
= 28 t (36 kt CO₂ equivalent)

The bottom-up approach will be used in the case of the manufacture of transport refrigeration equipment, since it is mainly used in the manufacture of systems destined for export, rather than servicing existing systems in Ireland. Actual emissions are associated with assembly losses in the manufacture of transport refrigeration systems. The following equation, which is similar to equation 4.4 but which uses a company-specific emission factor, is used.

Actual emissions of HFCs = (transport refrigeration equipment company specific assembly loss factor) (HFCs charged)
(5.7)

The results of this equation have been included with the figures in [Table 5.8](#). Emissions associated with the manufacture of transport refrigeration systems are very small relative to emissions from stationary refrigeration and air-conditioning operation in Ireland.

In speciated format, the actual emissions from stationary refrigeration and air conditioning can be broken down as shown in [Table 5.8](#).

PFCs used in refrigeration

Data on the total amount of PFC refrigerant sales were not available. However, based on information from the

Table 5.8. Actual HFC imports from stationary refrigeration and air conditioning.

Actual emissions (t)	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-143a	Total
Stationary refrigeration and air conditioning	0.002	2	6.22	15.3	4	27.54

industry, the use of PFC refrigerants is negligible compared to HFCs, so the associated emissions would also be very much lower.

5.4.3 Mobile air conditioning

The extent of air-conditioning systems in cars has been on the increase over the past number of years. The vast majority of air-conditioning systems are already in place in cars when imported into Ireland. However, there are after-market installers in the country, with approximately a dozen companies in Ireland involved in the installation of air-conditioning systems in cars. These range from small garage-type operations to larger commercial companies. These companies also service MAC systems.

5.4.3.1 Data sourcing for mobile air conditioning

Ten companies involved in MAC were contacted as part of this study. Of these, one company was not relevant since they were not operational in 1998 (although the company does currently use HFC-134a).

Of the remaining nine companies, eight used HFC-134a and five of them provided information regarding the quantities of HFC-134a used on site in 1998. The quantity used by each company varied from 10 kg/year to 500 kg/year. HFC-134a was used by the majority of companies, but one company also uses a HFC blend (HFC-404a).

5.4.3.2 Emissions estimation from mobile air conditioning

Tier 1: basic or potential method

Once again, equation 4.1 for potential emissions is as follows:

$$\text{Potential emissions} = \text{production} + \text{import} - \text{export} - \text{destruction}$$

In the case of MAC, the elements of equation 4.1 are as follows:

Production: No production of the industrial gases in Ireland.

Import: For Tier 1a bulk chemical only: CSO data are unreliable; therefore, the total sales of the gases by manufacturers/distributors in Ireland have been used to calculate bulk imports. However, a split of gas sales between stationary and MAC applications was not possible from either the distributors or the manufacturers. Therefore, imported gas used for MAC is included in the stationary refrigeration figure.

For Tier 1b chemical contained in products: a large percentage of MAC systems are present in cars when imported. No estimate has been obtained for this figure.

Export: For Tier 1a bulk chemical only: the only bulk export of the gases in relation to MAC will be returns of spent gases to manufacturers for recovery or destruction. No estimate has been obtained for this figure.

For Tier 1b chemical contained in products: there is no export of such systems from Ireland. The Irish manufacturer of refrigerated transport systems is included under stationary refrigeration since the systems are enclosed.

Destruction: From the point of view of MAC, gas destruction does not take place in Ireland. Any recovered gas is either reused in the equipment, accumulated at the site, or sent abroad for recycling or destruction.

Therefore, potential emissions (Tier 1a) from MAC are included in the stationary refrigeration figure.

Tier 2: advanced or actual method

The IPCC general Tier 2 method was outlined in equation 4.7 as follows:

$$\text{Annual emissions of HFC} = \text{'first-fill' emissions} + \text{operation emissions} + \text{disposal emissions} - \text{intentional destruction}$$

A combination of both the top-down and bottom-up approaches will be used in this equation. The top-down approach will be used for estimating emissions associated with the first fill of MAC systems in Ireland. The bottom-up approach will be used for estimating emissions associated with MAC systems operating in Ireland, regardless of where they were first filled. ‘Disposal emissions’ is not relevant, and it has not been possible to calculate ‘intentional destruction’, as described later.

Tier 2: top-down approach: ‘first-fill’ emissions

For the top-down approach the ‘first-fill’ emissions element of equation 4.7 is calculated as per equation 4.8 as follows:

$$\text{First-fill emissions} = (\text{IPCC emission factor}) (\text{virgin HFC for first fill of new MAC units in 1998}) \quad (5.8)$$

Virgin HFC for first fill of new MAC units in 1998: the MAC industry in Ireland consists of after-market installers only, since no car manufacturing occurs in the country. Chemical manufacturers and suppliers were unable to determine the split of sales between usage in both stationary and mobile air conditioning. Instead, the MAC installation industry was contacted in order to estimate usage of virgin HFC in 1998.

Usage information was obtained from four MAC installers of a range of company sizes. This usage value was scaled up by a factor of three to account for other companies (estimated at about a dozen). Therefore, total virgin HFCs sold to the MAC industry in 1998 has been estimated and is outlined in Table 5.9.

The MAC installation industry was unable to provide the split between gas used in new systems and that used in the service of existing MAC systems. According to one UK gas manufacturer, the majority of their sales of HFC refrigerants are used in new installations, with a small

Table 5.9. Total virgin HFCs sold to the MAC (mobile air-conditioning) industry.

Mobile air-conditioning equipment	Total sales to the MAC industry 1998 (t)
HFC-134a	1.2
HFC-125	0.5
HFC-143a	0.5

amount used in service applications, estimated at less than 5% of the total HFC sales. This estimate is based on current leakage rates. Therefore, 95% of HFC sales will be used to fill new MAC systems. One of the gas manufacturers estimates that only a very small amount of HFC-134a sold (for all refrigeration uses) is used for MAC service. The figure calculated below is in keeping with this estimate.

During servicing, most Irish car air-conditioning companies now recover the gas. The only case where the gas is not recovered is with crashed vehicles. Air-conditioning systems are almost always damaged and the gas is lost in crashes as the condenser is located just inside the front grill. Such losses will be included implicitly in the above equation.

IPCC emission factor: the IPCC first-fill emission factor of 0.5% will be used.

Therefore, using equation 5.8, emissions for individual gases from MAC equipment are shown in Table 5.10.

Tier 2: bottom-up approach: MAC systems operating in Ireland

For the bottom-up approach, the ‘operation emissions’ element of equation 4.7 is calculated as per equation 4.11 as follows:

$$\text{Operation emissions} = (\text{amount of HFC stock in year } t) (x / 100) \quad (5.9)$$

where x, the MAC system emission rate, is 10–20% (IPCC, 2000). A lower rate of 10% will be chosen for 1998, in accordance with Section 3.7.5.1 of the IPCC Good Practice Guide (IPCC, 2000), since most Irish car air-conditioning companies now recover the gas during servicing. In addition to this, the oldest system containing HFCs in 1998 will be approximately 5 years old and

Table 5.10. First-fill emissions from mobile air-conditioning systems, all vehicles.

MAC equipment	Virgin HFC first-fill new MAC systems 1998 (t)	First-fill emissions (t)
HFC-134a	1.1	0.006
HFC-125	0.4	0.002
HFC-143a	0.5	0.003

hence not as leaky as older systems (IPCC, 2000). In addition to this, more recent MAC systems are not as leaky as older systems (IPCC, 2000). For the earlier years, 1993–1997, slightly higher rates will be chosen to take into account the possibility of recovery practices not being as widespread, and older MAC types.

Amount of HFC stock in 1998 = (number of vehicles with MAC systems using HFCs operational in 1998) (IPCC average charge per vehicle) (5.10)

The IPCC average charge per vehicle is 0.8 kg for private vehicles, and 1.2 kg for light trucks (IPCC, 2000).

The number of vehicles with MAC systems using HFCs that were operational in 1998 will be determined as follows. Discussions with installers of systems in the country indicated that HFCs were first used in MAC installations in Ireland in 1993. Car air-conditioning companies convert older systems to the new refrigerant type HFC-134a in most cases, but this is not possible in every system. Installers also provided estimates on the percentage of new vehicles that contained air-conditioning systems in 1995 and 1998 as 20% and 60%, respectively. Installers also provided an estimate of the percentage of these MAC systems that were HFC based in 1995 and in 2000, as 30% and 90%, respectively. These figures have been interpolated for other years and

it was assumed that figures were similar for freight/commercial vehicles. Information was also obtained on the total number of new registrations and imported used vehicles in each of the years between 1993 and 1998 for all vehicles (DOELG, 2000). Vehicles include both private vehicles (private cars and small public service vehicles) and freight/commercial vehicles (goods vehicles and large public service vehicles). Hence the HFC stock in 1998, and the subsequent operation emissions, can be calculated as follows, using equation 5.10, with an average charge per vehicle of 0.8 kg and an emissions rate of 10%. The results are shown in [Table 5.11](#).

For freight/commercial vehicles, [Table 5.12](#) shows estimated operational emissions using an average charge per vehicle of 1.2 kg and an emissions rate of 10%.

Note that in [Tables 5.11](#) and [5.12](#), 'new' refers to both new registrations and imported used vehicles. It will be assumed that the above percentage for new vehicles with MAC systems and the above percentage for MAC systems with HFCs also apply to the imported used vehicle industry.

Note that the above estimate does not take into account retiring vehicles. Since the time frame between the introduction of HFCs into MAC systems (1993) and the

Table 5.11. Operational emissions from mobile air-conditioning systems, private vehicles.

Year	No. new vehicles during year	% new vehicles with MAC systems	% of MAC systems with HFCs	No. of vehicles with HFC MAC systems for year	Cumulative no. of vehicles with HFC MAC systems	HFC stock (t)	HFC emissions (t)
1998	179,094	60	66	70,921	148,866	107	11
1997	168,005	47	54	42,337	77,944	57	6
1996	154,592	33	42	21,643	35,607	26	3
1995	125,323	20	30	7,519	13,964	10	1.3
1994	117,256	20	20	4,690	6,445	5	0.7
1993	87,735	20	10	1,755	1,755	1.4	0.2

Table 5.12. Operational emissions from mobile air-conditioning systems, freight/commercial vehicles.

Year	No. new vehicles during year	% new vehicles with MAC systems	% of MAC systems with HFCs	No. of vehicles with HFC MAC systems for year	Cumulative no. of vehicles with HFC MAC systems	HFC stock (t)	HFC emissions (t)
1998	29,588	60	66	11,717	22,869	25	2
1997	24,201	47	54	6,099	11,152	12	1.3
1996	21,713	33	42	3,040	5,053	6	0.7
1995	18,013	20	30	1,081	2,013	2	0.3
1994	16,632	20	20	665	932	1	0.1
1993	13,359	20	10	267	267	0.3	0.05

year of the inventory (1998) is only 5 years, this is not relevant. In the longer term, retiring vehicles must be built into the estimate for total stocks of HFCs in MAC systems.

Emissions for all vehicles on a speciated basis are shown in [Table 5.13](#).

Tier 2: disposal emissions

Disposal emissions can be calculated by either the bottom-up or the top-down approaches. The bottom-up equation 4.12 is then:

$$Disposal\ emissions = (HFC\ charged\ in\ year\ t - n) (y / 100) (1 - z / 100) \tag{5.11}$$

where *n* is the average vehicle lifetime, 12 years (IPCC, 2000); *y* is the typical remaining charge, 40% (IPCC, 2000); and *z* is the fraction recovered, 0% (IPCC, 2000).

The top-down equation 4.10 is:

$$Disposal\ emissions = (annual\ scrap\ rate\ of\ vehicles\ with\ MAC\ systems\ using\ HFCs) (number\ of\ vehicles\ with\ MAC\ systems\ using\ HFCs) (average\ HFC\ charge/vehicle) - destruction$$

Table 5.13. Operational emissions from mobile air-conditioning systems, all vehicles.

Mobile air-conditioning equipment	Operational emissions 1998 (t)
HFC-134a	7.3
HFC-125	2.7
HFC-143a	3.2

HFCs were only introduced to air conditioning in cars in 1993–1996. For the bottom-up approach, the IPCC average vehicle lifetime of 12 years means that, for 1998, cars manufactured in 1986 are to be considered. Cars from 1986 will not have HFC-based MAC systems. However, some conversions took place, although it is presumed that cars disposed of in 1998 were unlikely to have been converted to HFCs in the final 2–3 years of their lifetime. Similarly, for the top-down approach, vehicles being scrapped in 1998 that had MAC systems in place were unlikely to be HFC based.

Therefore, disposal emissions in 1998 are estimated as zero.

Tier 2: intentional destruction

An estimate for destruction has not been obtained. In the Irish MAC industry, the gas recovered during servicing is either recharged to the system or, if it needs purification or is beyond use, it is either returned to the Irish wholesaler who then sends it back to the manufacturers (mostly in the UK, but all abroad), or it is stored on site. The manufacturers either purify the gas or send it for destruction. Not every Irish wholesaler takes back spent gas. In such cases companies tend to accumulate the gas on site. Therefore, as a worst-case scenario, destruction will be assumed to be zero.

Overall Tier 2 emissions from MAC systems

The combination of the bottom-up and top-down approaches using equation 5.11 yields the following overall estimate for actual emissions from MAC systems, as shown in [Table 5.14](#).

As can be seen, first-fill emissions are negligible in comparison to operational emissions.

Table 5.14. Total emissions from mobile air-conditioning systems, all vehicles.

Mobile air conditioning	'First-fill' emissions (t)	Operational emissions (t)	Disposal emissions (t)	Intentional destruction (t)	Total (t)
HFC-134a	0.006	7.262	0	0	7.268
HFC-125	0.002	2.739	0	0	2.741
HFC-143a	0.003	3.237	0	0	3.24

5.4.3.3 Overall Tier 2 emissions from stationary refrigeration/air-conditioning and MAC systems

Table 5.15 shows speciated actual emissions from stationary refrigeration/air-conditioning and MAC systems.

Note that in the above table, only operational emissions associated with MAC equipment have been included, since emissions associated with 'first fill' of MAC equipment are implicitly included in the estimate for stationary refrigeration/air conditioning. This is because the total estimate for sales of HFCs for refrigeration/air conditioning includes that sold to the MAC industry.

5.4.4 Foam blowing

There are open-cell and closed-cell foam manufacturers in operation in Ireland, making foams for packaging, insulation, furniture, mattresses, cushions, pillows, and toys. Foam, foam-containing products, and products packaged in foam are also imported into the country.

5.4.4.1 Data sourcing for foam blowing

Thirty-five companies involved in the foam plastic industry, including flexible and rigid polyurethane foams, expanded polystyrene, and bubble-cushioned plastic were contacted as part of this study. Of these, 25 companies were not relevant since they did not blow foam on their sites.

Of the remaining 10 companies, 8 provided information regarding the blowing agents in use at their site. These companies use water, carbon dioxide, methylene chloride, air, pentane, and HCFC-141b as blowing agents. One of the companies using HCFC-141b is switching over to pentane in 2002 (phase-out of HCFC use in foam blowing is required by 2004 under the Montreal Protocol). None of the companies contacted use HFCs or PFCs as propellants. This was reinforced in that the gas manufacturers and suppliers contacted confirmed that they do not supply any HFCs to Ireland for use in foam blowing. The fact that foam producers are now increasingly using water and CO₂ as blowing agents was also borne out in the UK inventory (WS Atkins Consultants Ltd, 2000).

Data on global sales of HFC-134a for closed-cell foam applications were obtained from the AFEAS website (AFEAS, 2001).

5.4.4.2 Emissions estimation from foam blowing

Tier 2 method: advanced or actual method

Open-cell foam

As per equation 4.13:

$$\text{Emissions from open-cell foam} = \text{total annual HFCs and PFCs used in manufacturing open-cell foam} \quad (5.17)$$

HFCs and PFCs used in manufacturing open-cell foam: none of the Irish foam-manufacturing companies that

Table 5.15. Overall emissions from stationary refrigeration/air-conditioning and mobile air-conditioning systems.

	Stationary refrigeration/air conditioning (t)	Mobile air conditioning (t)	Total (t)
HFC-23	0.002	-	0.002
HFC-32	2	-	2
HFC-134a	15.3	7.3	22.5
HFC-125	6.2	2.7	8.9
HFC-143a	4.0	3.2	7.3
Total	27.5	13.2	40.7

were contacted use HFCs/PFCs as blowing agents. Therefore, emissions from open-cell foam amount to 0 t.

Closed-cell foam

As per equation 4.14:

emissions from closed-cell foam = [(total HFCs and PFCs used in manufacturing new closed-cell foam in year t) (first-year loss emission factor)] + [(original HFC or PFC charge blown into closed-cell foam manufacturing between year t and year t – n) (annual loss emission factor)] + [(decommissioning losses in year t) – (HFC or PFC destroyed)]

where *n* is the product lifetime of closed-cell foam, default 20 years (IPCC, 2000).

Each of the terms in equation 4.14 is as follows for Ireland:

Total HFCs and PFCs used in manufacturing new closed-cell foam: closed-cell foam manufacturing takes place in Ireland. However, HFCs or PFCs are not used as blowing agents in the Irish closed-cell foam manufacturing. Therefore, this term is zero.

Original HFC or PFC charge blown into closed-cell foam manufacturing between 1978 and 1998: the survey of companies identified some closed-cell foams that are imported into Ireland for use in applications such as furniture manufacture and packaging. Some of the relevant closed-cell foam-containing products that are imported into Ireland include refrigerators (insulation), insulated trucks, other insulated products, insulation material, cars, furniture, mattresses, toys, etc., as well as some packaging and cushioning foams on products. Not all such foam has necessarily been blown with HFCs. In addition to this, companies may be able to supply data on product sales, but are unlikely to have any knowledge on the types or quantities of blowing agents used to make the foam contained in their products. Due to the diverse range of products and companies involved, data gathering from individual companies was judged to be too cumbersome from the point of view of the likelihood of data availability, the likely significance of the source, the possible improvement in accuracy by obtaining such data, and the resources available.

It is acknowledged by the IPCC Good Practice Guide (IPCC, 2000) that import statistics for closed-cell foam products are extremely difficult to collect. It is recommended that countries whose emissions occur only from imported closed-cell foam use expert judgment or use international HFC/PFC production and consumption data sets to develop estimates of chemical contained in imported closed-cell foam. The Alternative Fluorocarbon Environmental Assessment Study (AFEAS) data set is given as an example by the IPCC for use in emissions estimation.

Therefore, emissions estimation has been carried out based on global sales of HFC-134a for closed-cell foam blowing applications. Sales figures which represent 98% of all HFC-134a manufactured globally have been obtained from the IPCC recommended data set (AFEAS, 2001). A regional breakdown of sales is not available at present. The bank of HFCs present in closed-cell foam/foam products in Ireland is estimated based on Irish GDP relative to the GDP of all OECD countries. HFC-134a was first sold for closed-cell foam blowing applications in 1991 (very small). Therefore, based on global HFC-134a sales from 1991 to 1998 for this application, and apportioning according to GDP share, it is estimated that at the end of 1998, the quantity of HFC-134a originally charged to closed-cell foam-based products present in Ireland was 47 t HFC-134a.

Annual loss emission factor: a default value of 4.5% of the original HFC/PFC charged per year will be used (IPCC, 2000).

Decommissioning losses in 1998: since product lifetime is estimated at 20 years and HFCs have only been in use since 1991 for foam-blowing applications, there will be little if any loss from the decommissioning of closed-cell foams in 1998.

HFC or PFC destroyed: no destruction of HFCs/PFCs from such foam is carried out in Ireland. A HFC issue for the future, which is currently on the agenda regarding CFCs and HCFCs, is in relation to HFC blown foam in waste white goods received by local authorities and old refrigeration equipment returned to the contracting refrigeration industry from customers.

Therefore, using equation 4.14:

$$\begin{aligned} \text{emissions from closed-cell foam} = & [(0 \text{ t HFCs/PFCs used} \\ & \text{in manufacturing new closed-cell foam in 1998) (first-} \\ & \text{year loss emission factor)] + [(47 \text{ t original HFC or PFC} \\ & \text{charge blown into closed-cell foam manufacturing} \\ & \text{between 1978 and 1998) (4.5\% annual loss emission} \\ & \text{factor)]} + [(0 \text{ t decommissioning losses in 1998)} - \\ & (0 \text{ t HFC/PFC destroyed)}] \end{aligned} \quad (5.12)$$

HFC emissions from closed-cell foam use in Ireland amounted to 2.1 t HFC-134a.

Note that since these figures only concern HFC-134a, the other gases used in foam blowing are not included in the above estimate (HFC-152a, HFC-245fa, HFC-365mfc). However, HFC-134a is the major HFC used in this application.

5.4.5 Fire protection

Some HFC-based fire-protection systems are installed in Ireland for specific applications, both at present and in 1998. HFCs are used in systems where halons would previously have been used. However, HFCs are not the only replacements for halons. Other systems that use inert gas mixtures such as argon/nitrogen are installed in Ireland. The systems are installed by both Irish and UK fire-protection companies for fixed flooding applications and, to a much lesser extent, hand-held applications. The systems installed by Irish companies are supplied by the UK fire-protection companies. Typical applications for HFC-based fire-protection systems include high value assets in locations that may be occupied, such as computer rooms, operator rooms, processing rooms, switchboard rooms, file storage, marine applications, aircraft applications, power stations, art storage, galleries, museum archives and libraries.

5.4.5.1 Data sourcing for fire protection

Four Irish companies and three UK companies involved in the installation and supply of fire-protection equipment were contacted. The UK suppliers supply the Irish installers and also install systems directly in Ireland. One of the UK distributors based in Dublin has provided a very approximate estimate of the current total HFC usage in the Irish fire-protection industry and the HFC-

system growth rates since installations first occurred in the early 1980s in Ireland.

Under the Montreal Protocol, halons can no longer be used in new fire-suppression systems since January 1994. Fire-suppression systems that existed before 31 December 1993 were not required to change under the 1994 EU Regulations implementing the Montreal Protocol (EU, 1994). However, the 2000 EU Regulations require fire-protection systems and fire extinguishers containing halons to be decommissioned before 31 December 2003, and the halons recovered (i.e. collected and stored) (EU, 2000). Such recovered halons must then be sent for destruction by acceptable methods, or for reclamation. Hence, since the 2000 Regulations came into force, and until December 2003, there will be an increased usage of halon substitutes in replacing existing halon systems. According to equipment suppliers, where changeovers from halons to substitute systems take place there should be no associated emissions as long as the changeover is carried out correctly.

The major commercially available alternatives to halons for use in fire equipment are HFC-based products, mainly HFC-227ea, and inert gas products based on argon and nitrogen mixtures.

In 1998, HFC-227ea and halons (for refilling existing systems) would have been the only gases in use in this sector. Now there are some other HFC-based fire-protection products on the market. However, even today, HFC-227ea is the main HFC used in fire-protection applications. Fixed systems also account for the majority of HFC use, with use in portable extinguishers being much less.

Systems based on inert gases have been reported as requiring a larger volume of storage space (a problem where space is at a premium), they are at a higher pressure, thus requiring an external vent (can be difficulties with leased premises), and are slower to discharge. But advantages reported include reuse of halon system components, the same ability as the HFC systems to be used in occupied areas, an absence of gas supply monopoly, and a suitability for refilling by most gas-filling companies.

All fire-protection companies offer both the HFC gas and inert gas products, and actively promote the inert gas systems where applicable. The distributor based in Dublin for one of the UK suppliers estimates that the split in usage of gases in the relevant fire-protection applications in Ireland is 80% HFC gases (usually HFC-227ea) and 20% inert gases.

5.4.5.2 Emissions estimation from fire protection

Discussions with both the Irish and the UK suppliers determined that it is difficult to estimate HFC usage in the industry, and very difficult to estimate HFC emissions associated with fire-protection equipment. Discharges rarely occur, and leakages are even rarer. It was confirmed that losses are small, especially from fixed applications, since automatic triggering reduces accidental trips.

One Irish company provided a very approximate estimate of usage of HFCs in fire-protection systems in Ireland, as currently running at 40 t/year. HFC-227ea is the principal HFC with some others, but they are not commonly used. HFC-227ea was introduced into fire protection in Ireland in 1983/1984 with a certain amount of installations taking place until the market took off in the early 1990s (1993–1995). Estimated yearly growth rates since this initial market growth were provided. This information was used to generate an estimate of the total quantity of HFC-227ea present in fire-protection systems in 1998; this was approximately 230 t. Also, based on the above, the usage of HFC-227ea in fire-protection systems in Ireland in 1998 was approximately 26 t.

The above data will be used in the bottom-up approach to estimate HFC-227ea emissions from fire-protection systems in Ireland in 1998:

$$\text{Annual HFC-227ea emissions from fire-protection systems} = (\text{quantity of HFC-227ea installed in such systems}) (\text{emission factor \% per annum}) \quad (5.13)$$

With regard to the emission factor for percentage emitted per annum, there is an IPCC default factor of 5%. However, discussions with the industry indicate that emissions are negligible and that this is an overestimate. Systems are non-emissive unless a discharge occurs. Accidental emissions from fixed systems are very rare

due to the type of detection in place. Discharge events are very few and far between, as even in real fire events discharge may not occur. Very little business is carried out in refilling HFC-227ea systems. A US estimate indicates that between 1% and 3% of the installed base is emitted annually in fire-related and non-fire-related incidents (Little, 1999). European industry experience in the first few years of fluorocarbon usage in fire-protection systems suggests that emissions are less than 1% per annum of the installed quantities (EUROFEU, 1999). Therefore based on these factors and the above discussions, a factor of 1% will be taken to estimate emissions from fire-protection systems. It may be that this is still an overestimate. Therefore using equation 5.13:

$$\text{HFC-227ea emissions from fire-protection systems in 1998} = (230 \text{ t HFC-227ea installed in such systems}) (1\% \text{ per annum emissions}) \quad (5.14)$$

2.3 t HFC-227ea were emitted from fire-protection systems in 1998.

5.4.6 Aerosols and metered dose inhalers

5.4.6.1 Metered dose inhalers

Metered dose inhalers are used in the treatment of asthma and chronic obstructive pulmonary diseases such as emphysema and chronic bronchitis. They are used in Ireland. There is also one MDI manufacturing facility in the country.

Data sourcing for metered dose inhalers

The use of CFCs in MDIs has been allowed under legislative exemptions under the Montreal Protocol. Hence, the changeover from CFCs has been later than other sectors. Those contacted within the industry envisage a changeover from CFCs to HFCs, which will be even more rapid than initially predicted. It is expected that a complete changeover to HFCs will occur over the next couple of years. It is ultimately expected that a changeover to dry powder inhalers and nebulisers will occur in the longer term.

Usage of MDIs in Ireland

There are three companies supplying the majority of the Irish MDI market. One of the three has an MDI filling facility located in Ireland, whereas the other companies import the MDIs.

Only one of the three major suppliers had Irish sales of HFC-based MDIs in 1997 and 1998. The others were selling CFC-based inhalers at the time. According to this supplier, sales of HFC-based MDIs in 1997/1998 were low due to the different taste and feel of the product compared to CFC-based inhalers, as well as a lack of interest in changing at the time. The company selling HFC-based MDIs in Ireland in 1997/1998 has provided data on sales of HFC-based MDIs for those years, together with the typical charge of gas per unit. This company also provided an estimate of the total market for MDIs in Ireland both today (2001) and in 1998, and the fraction occupied by HFC/CFC-based inhalers.

Manufacture of MDIs in Ireland

The Irish manufacturer of MDIs currently utilises CFCs, as allowed under legislative exemptions, and HFC-134a. Conversion to HFC-134a is taking place, with a new HFC plant at the facility commencing production at the time of writing. Before this, HFC-134a usage was very low, used just in developmental work in a pilot plant. This company has supplied a single figure for the quantity of HFC-134a in MDIs sold in Ireland from 1998 to 2000, but since they are the only company in Ireland that manufacture MDIs, they do not want usage data reported separately. They export the majority of their product.

Two additional pharmaceutical companies based in Ireland who are makers of asthma preparations were contacted. However, both of these companies make the active ingredient only and do not fill any MDIs at their Irish sites.

Emissions estimation from metered dose inhalers

Usage of MDIs in Ireland

The only supplier of HFC-based MDIs in 1997 and 1998 supplied data on the number of inhalers sold in both years and the typical charge of gas per unit. These data were then used to calculate the total quantity of HFC contained in MDIs sold in Ireland. HFC-134a is the gas used by the company in its HFC-based MDIs.

The Tier 2 bottom-up approach of equation 4.17, using the number of aerosol products sold and the average charge per container, is as follows:

$$\text{Emissions of HFCs in 1998} = [(0.065 \text{ t HFC contained in MDIs sold in 1998}) (50\%)] + [(0.06 \text{ t HFC contained in MDIs sold in 1997}) (50\%)] \quad (5.15)$$

Emissions of HFCs in 1998 from MDI use amounted to 0.062 t HFC-134a.

This supplier also provided an estimate of the total market for MDIs in Ireland both in 2001 and in 1998, and the fraction occupied by HFC/CFC-based inhalers. A portion of the market involves dry powder inhalers and nebulisers; these have been excluded from the following estimate. Today, both CFCs and HFCs are in use in inhalers sold in Ireland. Ultimately, CFCs will be replaced by HFCs, with an expected complete changeover by approximately 2005.

Potential future emissions (2005 plus) of HFCs from MDI use in Ireland (once conversion from CFCs occurs and based on market size in 2001) is 13.4 t HFC-134a.

Manufacture of MDIs in Ireland

According to the Irish MDI manufacturing company's environmental representative, fugitive emissions associated with the process are negligible. Any waste gas is returned to the manufacturer in the UK. In 1998, the company was only using HFCs in developmental work so fugitive emissions associated with MDI manufacture are not relevant.

Mass balances have been carried out by the company on CFCs, with typical unaccounted values of 3%. The company also plans to carry out mass balances on HFCs. Of course, as accepted within the discipline of mass balancing, not all of this 3% is necessarily fugitive emissions. Unaccounted values can also be attributed to other reasons such as inaccuracies in measurement. Since the company is IPC licensed, such mass balances will be reported to the EPA. For future inventories, such results can be used in the emission inventories for industrial gases.

In 1998, the manufacture of MDIs was not a significant source of HFC emissions in Ireland since the company was only carrying out HFC pilot plant trials. As conversion to HFCs increased with the commencement of a HFC plant in 2001, the company's reporting of fugitive emissions as part of their IPC licence should be

used in future inventories to estimate emissions associated with the manufacture of MDIs in Ireland. The volume of gases being used in MDI manufacture may make fugitive emissions relevant for consideration in the inventory in future years.

5.4.6.2 Aerosols

Literature reviews of this sector, together with possible sources listed by IPCC, identified four groups of aerosol products:

- i. Personal-care products (e.g. hair care, deodorant, shaving cream);
- ii. Household products (e.g. air fresheners, oven and fabric cleaners);
- iii. Industrial products (e.g. special cleaning sprays, lubricants, pipe freezers);
- iv. Other general products (e.g. silly string, tyre inflators, klaxons).

All of these aerosol product groups are relevant to Ireland.

Data sourcing for aerosols

- i. *Personal-care products (e.g. hair care, deodorant, shaving cream)*

Manufacturers and distributors of aerosols for personal care products (including shaving products, deodorants, hair sprays and hair mousse) to the Irish market were identified by visual inspection of personal-care products at two large supermarkets and by examination of the Kompass Directory.

Twelve manufacturers and distributors in Ireland and the UK were contacted as part of this study. Seven companies provided information regarding the propellants used in their aerosols. Of these, one company stated that its products were manual pump and therefore did not use a propellant. The remaining six companies use butane, isobutane, propane, pentane or DME as the propellant. None of the companies contacted in these sectors use HFCs as a propellant.

- ii. *Household products (e.g. air fresheners, oven and*

fabric cleaners)

Manufacturers and distributors of aerosols for household products (including furniture polish, fly sprays, air fresheners, oven cleaners, shoe polish and cleaning mousse) to the Irish market were identified by visual inspection of household products at two large supermarkets and by examination of the Kompass Directory.

Eleven manufacturers and distributors in Ireland and the UK were contacted as part of this study. Four companies provided information regarding the propellants used in their aerosols. These companies use butane, propane, carbon dioxide, light petroleum distillate or LPG as the propellant. None of the companies contacted in these sectors use HFCs as a propellant.

- iii. *Industrial products (e.g. special cleaning sprays, lubricants, pipe freezers) and other general products (e.g. silly string, tyre inflators, klaxons)*

Car sprays

Manufacturers of car spray aerosols (dashboard spray, tyre inflators and windscreen cleaner) to the Irish market were identified by visual inspection of these products at a car accessories store. Two companies were contacted as part of this study. Both of these companies are UK based. These companies use butane, isobutane, and propane as propellants. None of the companies contacted use HFCs as a propellant.

Pipe freezer aerosols

Manufacturers of pipe freezer aerosols for the Irish market were identified by visual inspection of these products at two plumbing wholesalers. The packaging did not contain any information regarding the ingredients of the aerosols. There are two main suppliers of pipe freezer aerosols to the Irish market. Both of these companies are UK based and were contacted as part of this study. Only one company supplied information. This company confirmed that pipe freezer aerosols do contain HFC-134a and gave percentage composition of canisters, as well as the number of unit sales for two different canister sizes in Ireland for 1997 and 1998. For confidentiality reasons, sales data provided by this company cannot be given.

Silly string aerosols

Manufacturers of silly string aerosols for the Irish market were identified by visual inspection of these products at party and joke shops. The packaging did not contain any information regarding the ingredients of the aerosols. Three companies were contacted as part of this study. All three companies are UK based. Two companies provided information regarding the concentration of HFC-134a propellant used in their aerosols. These companies sell the silly string to distributors in the UK, therefore Irish sales data for these products were not available. One Irish sales outlet provided an estimate of the average number of units sold per week. Typical container volumes/weights were noted in the sales outlets.

Klaxons

Manufacturers of klaxons for the Irish market were identified by visual inspection of these products at ship chandlers and recreational sports stores. In one case, the packaging stated "contains HFC-134a". The remaining packaging did not contain any information regarding the ingredients of the aerosols. A typical container net weight was noted in one of the sales outlets. Five companies were identified as suppliers of klaxons on the Irish market. Two of these companies are UK based, the remaining three companies are based in Italy. Four companies were contacted as part of this study. Two companies provided information regarding the propellants used in their aerosols. These companies use 100% HFC-134a in their klaxons. Irish sales data for these products were not available. Literature on the Internet stated that for marine and safety alarms the propellant is the sole chemical ingredient in the can. Three Irish sales outlets, one chandlery and two sports shops, provided an estimate of unit sales per month. It should be noted that there are some klaxons available on the Irish market that do not utilise HFC-134a, relying on operation through manual blowing.

The figure for HFC emissions from pipe freezer aerosols, silly string and klaxons was difficult to determine because neither the top-down nor bottom-up approach can be easily applied in these cases. Sales data are not available for these products in Ireland because:

- They are generally imported directly by individual retail outlets. European distributors do not record the number of units sold to Ireland.
- There are many manufacturers and distributors for a relatively small number of units. Therefore, quantity sold in Ireland is difficult to calculate.
- The distributors are generally based in Europe. The Irish market for these products is relatively small and is not recorded.
- UK suppliers were reluctant to provide data on sales.

Consultation with the UK HFC inventory agency confirmed that the above three sectors – pipe freezer aerosols, silly string aerosols and klaxons – contributed the greatest HFC emissions from aerosols.

Emissions estimation from aerosols

Pipe freezer aerosols

The sales data provided by the pipe freezer aerosol company cannot be given for confidentiality reasons, but the data have been used to generate an overall estimate of HFC-134a emissions associated with pipe freezers sold in Ireland by all companies in 1998 of 0.4 t HFC-134a (0.5 kt CO₂ equivalent).

Silly string aerosols

The two UK companies that provided information use between 70% and 93% HFC-134a in their silly string product. One Irish sales outlet estimated that an average of 12 units is sold per week. Containers contain 83–85 ml each. Comparison of the pressurised canisters has shown that a 1 ml volume roughly corresponds to 1 g of gas. A rough estimate of the number of such sales outlets in Ireland is 75 outlets³. This gives an overall estimate of HFC-134a emissions associated with silly string sold in Ireland by all companies in 1998 of 3.2 t HFC-134a.

Klaxons

One typical canister on the market contained 345 g net contents. The three Irish sales outlets' estimate of sales was two units per month. A rough estimate of the number of chandlers and sports shops selling klaxons in Ireland is 250 outlets³. This gives an overall estimate of HFC-134a

³ These rough estimates are based on scaling up on a population basis from a survey in Cork City.

emissions associated with klaxons sold in Ireland by all companies in 1998 of 2.1 t HFC-134a.

Overall aerosols

Therefore the overall estimate of HFC-134a emissions associated with the use of silly string, klaxons and pipe freezers in 1998 is 5.7 t HFC-134a.

5.4.7 Solvent uses

There is minor usage of HFCs in cleaning applications in Ireland in various industries.

5.4.7.1 Data sourcing for solvent uses

Apart from those electronics companies involved in semiconductor manufacture (see [Section 4.4.9](#)), four additional electronics companies were contacted regarding usage of HFCs or PFCs as solvents. None of these four electronics companies use any of the gases. One of the four initially considered that it may be a user of PFCs in clean rooms but later confirmed they were not in use – the only HFCs used were on site in refrigeration systems. In any case, this company was not in operation in 1998.

One Irish chemical supplier supplies HFC products for use in cleaning applications. These cleaning applications are in various industries. The chemical supplier was unsure if the cleaning operations are enclosed or not. In any case, the supplier did not have any such sales in 1998. The other chemical suppliers contacted do not supply any HFCs/PFCs to Ireland for use as solvents.

5.4.7.2 Emissions estimation from solvent uses

Since the chemical suppliers contacted do not supply any HFCs for this application, it will be assumed that cleaning operations using HFCs were not occurring in 1998.

5.4.8 SF₆ emissions from electrical transmission and distribution equipment

There is electrical transmission and distribution equipment containing SF₆ in place in Ireland, mainly gas-insulated switchgear. Gas-insulated transmission lines are not prevalent in Ireland. These are transmission lines that are either buried or laid in tunnels where overhead lines are not feasible or are of insufficient capacity.

5.4.8.1 Data sourcing for electrical equipment

There are four main companies in Ireland supplying gas-insulated switchgear and circuit breakers. Each company would have similar sales volumes. One of these companies has a manufacturing facility in Ireland, but this plant does not produce SF₆-containing equipment. These companies mainly supply such equipment to the Electricity Supply Board (ESB) but would also supply some of the larger industries. These companies did not have records of the amount of SF₆-insulated equipment sold in 1998, only financial records. Some equipment is supplied with the gas and some has the gas filled in situ.

According to one of the equipment supplier companies, all gas is recovered during maintenance, recycled and put back into the equipment. Only if there was a fault would the gas have to be sent back to the suppliers. Historically the gas would have been vented, but recovery commenced during the mid-1980s. The major SF₆ manufacturers, together with maintenance equipment manufacturers, have developed a system for the reuse of SF₆ in electrical equipment. In 1998, SF₆ would have been recovered from electrical equipment.

The ESB has provided an estimate for annual emissions from electrical equipment for 1998 through leakages. A leak reduction programme has been implemented by the ESB, which commenced in 1997. This has since brought leakage rates down from 4.5% to 1%.

5.4.8.2 Emissions estimation from electrical equipment

The ESB estimates SF₆ emissions due to leakage to be 1.1 t SF₆ in 1998. This corresponded to a leakage rate of 4.5%.

Based on the above, the SF₆ bank in electrical equipment in 1998 was 24.4 t SF₆.

5.4.9 PFC, HFC, SF₆ emissions from semiconductor manufacture

Semiconductor manufacturing occurs in Ireland with use of the industrial gases for etching and chamber cleaning. Abatement systems are in place.

5.4.9.1 Data sourcing for semiconductor manufacture

Three semiconductor manufacturing facilities and an electronics research company were contacted.

Of the three chip fabrication companies, two companies utilise the industrial gases in their processes, mainly PFCs and SF₆, and a smaller amount of one HFC. Data were provided by both companies on usages and emissions. Both companies utilise abatement systems.

The third company involved in semiconductor manufacture utilises chemicals other than industrial gases as a result of the type of semiconductor manufactured. This company ceased manufacture at the end of 2001.

There are also several electronics/semiconductor research companies that utilise the industrial gases. However, amounts used by these companies are considerably lower than those used by the manufacturers.

There are several suppliers of the gases to the electronics industry, some of whom are based on site at the electronics companies.

PFC-116 (C₂F₆) is the most used gas for both of the semiconductor manufacturers. PFC-14 (CF₄), HFC-23 (CHF₃) and SF₆ are also used by the two companies. HFC-134a, HFC-407c, and NF₃ are each used by one company. NF₃ is a global warming gas, but is not yet included in IPCC emissions reporting requirements. The gases are used both for etching and for chamber cleaning.

5.4.9.2 Emissions estimation from semiconductor manufacture

Emissions are calculated using the Tier 2C method, although some of the parameters used are company specific rather than IPCC industry-wide generic values.

In the case of one company, a breakdown of use between applications is not possible. This company calculates emissions based on a percentage (72%) of usage, which is accepted by the IPCC as more accurate than monitoring.

Both companies have abatement measures in place. However, one company says that not all such systems are designed to abate fluorocarbons. This company does not

take abatement into account in their method of emissions calculation, which they report on a corporate basis (they plan to take it into account in future). The second company does take abatement into account in its emissions estimates. Emission estimates are provided using the first company's own estimates with abatement not taken into account, and also by applying an IPCC default for this company of 0.9 for the fraction of gas destroyed by abatement.

The second company estimates that approximately 75% of the C₂F₆ is used in a plasma cleaning operation, and is then sent for abatement (thermal treatment). This company also uses small amounts of C₂F₆ as process gas. Such gas is not sent for abatement, and accounts for the majority of emissions of C₂F₆. Approximately 40% of C₂F₆ gas used as process gas is consumed by the process reaction. This second company estimates that between 2 and 5% of C₂F₆ gas used is emitted based on efficiencies of its thermal treatment systems. For the gases CF₄, SF₆ and CHF₃, where emissions have not been estimated by the company for 1998, the company's estimate of 60% usage being emitted, as reported for 1990–1996 for these gases, will be used. Also for the 1997 projected usage of HFC-134a and HFC-407c in 1998, 60% of usage will also be taken as emissions.

Emissions and usages for both companies are as shown in [Table 5.16](#). The first set of emission figures does not take abatement into account for one of the companies as outlined above. The second set of emission figures uses an IPCC default of 0.9 for the fraction of gas destroyed by abatement for this company.

In reality, actual emissions will be in between these upper and lower figures since not all gas is abated and efficiency may not be as high as the IPCC factor. The higher emissions with abatement not taken into account for one company were taken as a worst-case scenario (also in accordance with the two companies reporting practice) for UNFCCC reporting purposes.

5.4.10 SF₆ emissions from other sources

5.4.10.1 Gas-air tracer in research and leak detectors

The use of SF₆ as a tracer gas for leak detection occurs in Ireland.

Table 5.16. Usage and emissions of industrial gases from the manufacture of semiconductors (1998).

	Usage (t)	(Abatement not taken into account for one company)	(Abatement for both companies – using IPCC default destruction for one company)
		Emissions (t)	Emissions (t)
Individual gases			
C ₂ F ₆	10.5	5.1	0.66
CF ₄	3.2	2.3	0.31
CHF ₃	0.4	0.3	0.07
SF ₆	3.2	2.2	0.44
NF ₃	0.5	0.3	0.03
HFC-134	0.4	0.3	0.3
HFC-32	0.014	0.008	0.008
HFC-125	0.015	0.009	0.009
Categories of gas			
PFCs	13.8	7.4	1.0
HFCs	1.0	0.6	0.6
SF ₆	3.2	2.2	0.4

SF₆ is used for leak detection in the testing of seals on cans containing tennis balls. The company concerned provided SF₆ usage data for 1998. In total, 765 kg of SF₆ at 99.9% purity were used (18.3 kt CO₂ equivalent). The gas is then diluted for use. The company estimates that about one-third of the diluted gas goes into the product container while the remainder escapes into the atmosphere during the process of filling the canisters. The gas in the product container will also be released when the container is opened. However, the majority of the product is exported, so these releases will be abroad. Therefore, SF₆ emitted from this company in 1998 is estimated as 0.51 t SF₆. At the time of writing this company was planning to phase out usage during 2002 and switch to helium.

There is a second tennis ball manufacturer but the company has confirmed that they do not use any SF₆. Information from gas suppliers has not identified any additional companies who use SF₆ in leak detection.

A research application for SF₆ is its use as a tracer gas in the measurement of methane emissions from cattle. The devices containing SF₆, which are placed in the stomachs of cattle, are imported from the US. The amounts of SF₆ involved are minuscule.

The planned switch during 2002 from SF₆ to helium for leak detection by the company outlined above will virtually eliminate SF₆ emissions from leak detection sources, with only very minor amounts being used at the laboratory research scale.

5.4.10.2 Medical purposes

SF₆ is supplied for use in eye surgery in Ireland. However, according to the supplier concerned, this usage is very small relative to SF₆ sales for other purposes. Data were not received from the supplier.

5.4.10.3 Equipment used in accelerators, lasers and night-vision goggles

Applications for SF₆ in this area include the insulation of super-voltage generators in particle-accelerating machines, such as in Van de Graaf accelerators, betatrons, neutron generators and other such plant used for radiation applications in scientific institutions, medicine and industry, as well as use in voltage stabilisers in electron microscopes and in X-ray equipment used in production control and in the non-destructive testing of materials.

Quantification of SF₆ emissions from these applications has not been carried out. However, the SF₆ gas would be sealed in all such applications and associated emissions

would be low. Global estimates of emissions from scientific accelerators in which SF₆ is used as insulating gas are small (Harnisch and Prinn, 1999). Based on inventories for other countries, it is unlikely to be a significant source of emissions for Ireland. Information from gas suppliers has not identified any of these applications using SF₆ in Ireland.

5.4.10.4 Military applications

Likely to be negligible. Information from gas suppliers has not identified any SF₆ military applications in Ireland.

5.4.10.5 Sound-proof windows

There are manufacturers of double-glazing units in Ireland. In occasional applications where sound-proofing is required, such units are filled with gas. Both SF₆ and argon have been used in such applications by Irish manufacturers. However, in the majority of double-glazing units produced in Ireland these gases are not used, with just air being trapped in the space between the glass panes. Sound-proofing of windows using gas tends to occur in specialist applications such as certain public buildings (e.g. galleries), and industrial applications.

Data sourcing for window sound-proofing

A major Irish manufacturer of windows and doors was contacted. It was determined that window and door manufacturers buy pre-manufactured double-glazing units. The four major manufacturers of double-glazing units in Ireland were contacted. All four manufacturers only occasionally use gas for sound-proofing applications. Companies estimated that between 80 and 99% of the time, gases are not used in double glazing. One company reported that usage of the gases has only started in recent years; for example, there would have been no usage in 1988.

Two of the four glazing manufacturers only use argon, rather than SF₆, to fill double-glazing units. The remaining two companies use both argon and SF₆. However, use of argon would be much greater than SF₆ in both companies. The usage of SF₆ by both companies is very small. For example, when contacted during 2001, neither company had used SF₆ within the last 6 months and one company had no SF₆ in stock. Estimates of usage could not be provided. One of the companies did not use

any SF₆ in 1998 or 1999, and used a very small amount in 2000 and 2001, i.e. used only one “small bottle” (size unknown) over this 2-year period.

Argon usage has been reported as increasing. Both companies using SF₆ report that the choice of gas is often architect dependent. One company encourages customers to avoid gas-filled glazing, citing other ways of achieving noise reduction, such as varying glass thickness or laminated glass. Reports from other countries back up this claim – for example, in Denmark the use of SF₆ as a noise-proofing gas in windows will be prohibited from 1 January 2003, since the noise-proofing effect is already achieved in other ways.

To fill an insulating-glass unit, the air is displaced slowly from the bottom upwards by the much heavier SF₆ gas (the density of which is approximately five times greater). The gas is dosed with the aid of simple flow meters where production quantities are small. Automatic filling devices are used in larger production facilities.

It should be noted that there are also several manufacturers of double-glazing units in Northern Ireland. The Irish manufacturers said that it is possible that the import of pre-filled units could occur, e.g. a multinational company could specify its own contractor from mainland Europe. However, all of the major Irish glazing companies have on-site gas-filling facilities.

The revision to Part L of the Building Regulations specifies increased heat-insulation requirements. Therefore, one of the companies anticipates increased gas usage, but expects the majority of this to be argon. Consumption of SF₆ for sound insulation in windows has been falling in Denmark as it has been reported that SF₆ might have a negative impact on the heat-insulating properties of windows.

Emissions estimation from window sound-proofing

One major European manufacturer supplies SF₆ in cylinders of 5, 10, 20, 40, 50 and 52 kg. The next available quantity is 600 kg in special high-capacity loaned containers. As a worst case, it will be assumed that the “small” cylinder referred to by one glazing unit manufacturer is the 52 kg cylinder (corresponding to 50 litres at the pressure supplied by the manufacturer). This

company estimates its usage as about half of such a cylinder per year, typically in one application. The glazing manufacturer provided the size of a typical glazing unit as 12–14 mm × 1 m × 1.5 m. This corresponds to a volume of 21 litres, which backs up the assumption that a 52 kg cylinder is used over 2 years.

Assembly emissions

According to the IPCC, approximately 33% of the total amount of SF₆ purchased is released during assembly (i.e. filling of the double-glass window).

One of the two relevant glazing companies did not use SF₆ in 1998. It will be assumed that the second company uses similar quantities per year. In addition to this, there may be additional Irish companies using SF₆ that were not identified. Therefore, as a worst case, the usage of one 52 kg cylinder per year will be presumed. Therefore, using equation 4.33:

$$\text{Assembly emissions} = (52 \text{ kg } 0.33) \text{ (window capacity)} \quad (5.16)$$

$$= 17 \text{ kg SF}_6 \text{ assembly emissions}$$

Leakage when installed

Of the stock contained inside the window, an IPCC annual leakage rate of 1% is assumed (including glass breakage).

Based on discussions with the industry, it will be presumed as a worst case that SF₆ has been used in glazing applications in Ireland for 8 years up to 1998 at the same annual rate outlined above. In addition to glazing manufactured in Ireland, there may also be imported glazing units. In the absence of any data it will be presumed that the quantity of imported glazing units is the same as that manufactured in Ireland. Therefore,

$$\begin{aligned} \text{Existing stock in windows at end of 1998} &= (9 \text{ years}) [(52 \text{ kg used in Irish manufacture}) - (17 \text{ kg assembly emissions}) + (52 \text{ kg used in for imports})] - (31 \text{ kg for previous 8 years' leakage}) \end{aligned} \quad (5.17)$$

$$= 751 \text{ kg existing SF}_6 \text{ stock in windows at end of 1998.}$$

Using equation 4.34:

$$\text{Leakage emissions in 1998} = (0.01) (751 \text{ kg existing stock in windows}) \quad (5.18)$$

$$= 7.5 \text{ kg SF}_6 \text{ leakage emissions}$$

Disposal emissions

As per equation 4.35:

$$\text{Disposal emissions} = (\text{amount left in windows at end of lifetime}) (1 - \text{recovery factor})$$

According to the IPCC, average window lifetimes are 25 years. The application of SF₆ in windows began in 1975. However, Irish companies indicated that the application in Ireland only started in the early 1990s. Therefore, disposal had not yet commenced in 1998. Hence disposal emissions in 1998 are assumed to be zero.

Overall actual emissions in Ireland in 1998 from glazing manufacture and existing glazing installations is estimated to be approximately 0.0245 t SF₆.

Overall potential emissions in Ireland in 1998 from glazing manufacture are 0.052 t SF₆, i.e. quantity used in manufacturing.

5.4.10.6 Applications using adiabatic properties: car tyres, tennis balls, shoe soles, etc.

Car tyres

Certain car manufacturers use SF₆ to fill tyres on new models. In Germany the filling of car tyres with SF₆ and the use of SF₆ in sound-insulating double glazing had approximately the same relevance as the electrical sector in 1995. However, in the UK both applications are reported as minor (Harnisch and Hendriks, 2000).

Thus, it is possible that SF₆ has been used to fill the tyres of German-manufactured cars imported into Ireland. The actual manufacturers who carry out this practice, and whether this is carried out on cars exported to Ireland, have not been determined. An estimate of emissions associated with car tyres has not been obtained, but is expected to be low.

The use of SF₆ in car tyres “will soon be abandoned” (Harnisch and Hendriks, 2000). Therefore, this source will not be a significant source of emissions in future.

Tennis balls

There are two manufacturers of tennis balls in Ireland. Both companies were contacted. Neither company uses SF₆ as a filling gas for tennis balls since pressureless tennis balls are made by both companies. However, one of the companies does use SF₆ as a tracer gas in leak detection. Emissions associated with this are dealt with in [Section 5.4.10.1](#). One of the companies envisages using air rather than SF₆, should the company start manufacturing pressurised balls.

There will be emissions of SF₆ associated with leakages from any SF₆-pressurised tennis balls imported into Ireland. It is not possible to estimate the quantity of imported SF₆-filled tennis balls, but emissions associated with these are not likely to be significant.

Shoe soles

Certain ranges of sports shoes contain SF₆ as a cushioning pocket in the sole. The use of SF₆ in sports shoes "will soon be abandoned" (Harnisch and Hendriks, 2000). Nitrogen is being brought in as a replacement by Nike, and accounted for 25% of gas used in 2000. Nike

was to have fully phased out the use of SF₆ by the end of 2001. There will be emissions of SF₆ associated with discarded sports shoes in Ireland. This is unquantified.

5.4.11 Other applications for HFCs and PFCs

The application of HFCs and PFCs in electronics testing, heat transfer, or as a dielectric fluid are not likely to be significant for Ireland based on inventories for other countries. Information from gas suppliers has not identified any companies who use HFCs or PFCs in these applications.

Regarding medical applications, one Irish chemical supplier supplies HFCs for use as a carrier gas for silicone deposition in medical device manufacture (needles and syringes). The chemical supplier is unsure if the carrier gas is emitted. It was also determined, through contact with Enterprise Ireland's list of relevant companies, that needle and syringe manufacture only occurs in Northern Ireland. In any case, the supplier had no HFC sales for such an application in 1998. Hence, it will be assumed that HFC use as a carrier gas was not occurring in 1998.

6 Changes since 1998 and Implications for Future Inventories

Markets for the industrial gases have been evolving since 1998 and will continue to do so for the foreseeable future.

Some of the sources where industrial gas usage is likely to have increased since 1998 include:

- Metered dose inhalers (MDIs): in 1998, there was only one company supplying a relatively small number of MDIs containing HFCs to the Irish market. Today all the major companies have HFC-containing products on the market, although CFC products are still marketed as well. Eventual changeover to HFCs will occur over the next few years. Other forms of product, such as dry-powder inhalers and nebulisers, will also increase and take some of the potential HFC share.
- Refrigeration: HFC and PFC refrigerant products as replacements for CFCs and HCFCs have continued to become available and have widespread use.
- Semiconductor manufacture: there has been an increase in gas usage since 1998 by the two semiconductor manufacturers who utilise industrial gases, as a result of growth in manufacturing.
- Fire protection: the 'dry' fire extinguishing industry has experienced growth since 1998 with the arrival of various hi-tech and telecoms companies utilising such systems in switch rooms, computer rooms, etc. Growth in HFC-based system installation was

approximately 10–15% per annum between 2000 and 2002. Also, fire-protection systems containing halons must be decommissioned before December 2003. Therefore, since 2000 there has been an increased usage of halon substitutes in existing or replacement halon systems, some of which are HFC based. This will continue until the end of 2003. However emissions associated with this application are very low.

Sources with decreased usage since 1998:

- A company using SF₆ in leak detection is to phase out usage during 2002 and switch to helium. As far as can be ascertained, this will virtually eliminate SF₆ emissions from leak detection sources, with only very minor amounts being used at laboratory research scale. This company's actual emissions correspond to almost 6% of the total actual emissions of HFCs, PFCs and SF₆ estimated for Ireland in 1998 in terms of thousands of tonnes of carbon dioxide equivalent.
- Emissions from electrical transmission and distribution equipment have decreased since 1998, even taking into account capacity expansion, and are projected to continue to decrease in future (up to 2010) as a result of the ESB's ongoing leak reduction programme, which commenced in 1997.

7 Issues in Relation to Industrial Gas Use in Ireland

7.1 General

- There is little control on the use of the industrial gases in Ireland. Better tracking should be considered.
- In many instances it was found to be very difficult to obtain data on industrial gas usage and emissions because of the lack of tracking of the gases and in certain cases companies were unwilling to divulge information. However, there were exceptions to this where companies were forthcoming and provided useful information.

7.2 Spent Gases

- There should be a programme for the collection of spent gases for recycling, treatment or disposal, if not already facilitated by the supplier/manufacturer. This is particularly relevant to smaller operators within the refrigeration industry.
- In the course of discussions with various manufacturers, suppliers and users, it emerged in several cases that problems were encountered in the shipment of spent gas returns from Ireland. The spent industrial gases are classified as hazardous waste. The gas users are usually willing to collect gases. Correspondingly, the gas manufacturers are willing to take return, and, in the case of some manufacturers, give credits to customers where the gas can be reprocessed (less costs for shipping and processing), or else charge customers for destruction. One mainland Europe manufacturer reported returns from all countries in Europe and the Middle East, with the exception of Ireland because of the shipment problems. As a result, spent gases are in several cases being accumulated on the sites of contractors and suppliers.

This may only be a perceived problem as some other Irish companies, usually the larger ones, return spent gases to the overseas manufacturer. Basically, transfrontier shipment documentation is needed for each shipment. Costs may be a factor in terms of economy of scale. Value of customers may also come

into play, with some distributors willing to bear the costs for their main users. Clarification of existing procedures is needed, or amendment of such procedures if necessary, in order to facilitate returns for all companies concerned. In future, disposal in Ireland should be considered (e.g. hazardous waste incineration) for gases that are not suitable for recovery, as part of the overall aim of self-sufficiency in the disposal of hazardous waste. The lack of incineration capacity here, as well as Ireland's island status, has led to considerable expense involved in disposal of the gases. One refrigerant supplier stated that the cost of disposal of the waste gases far exceeds the cost of purchase of the virgin gases. All of the above also apply to CFCs and HCFCs. One refrigerant supplier also mentioned that a waste licence would have to be obtained by distributors collecting the spent gases. This has not been substantiated.

7.3 Refrigeration

- Technician skill is a factor in the successful recovery of the gases from stationary refrigeration systems and MAC systems during maintenance, repair and disposal. Appropriate training, especially for small-medium enterprises, should be considered.
- In the course of gathering data, there have been unconfirmed, isolated reports of deliberate release of gases (CFCs, HCFCs, HFCs) by more dubious operators. This does not apply to the majority of industrial gas users in Ireland.
- There are still some R12 (CFC) stationary refrigeration systems in use, for example on farms.

7.4 Use (not Manufacture) of Closed-cell Foams

- Irish companies utilising imported closed-cell foams in their products should be encouraged to consider foams that have been blown with alternative blowing agents (Irish blown foams do not use HFCs).

7.5 Fire Protection

- The use of the non-HFC-based halon alternatives commercially available in Ireland, e.g. those based on argon/nitrogen mixtures, should be encouraged where technically and economically feasible. Companies who have commissioned the installation of such systems should be made aware of the global-warming potential of the gases.

7.6 Non-essential Uses

- The elimination of the use of the industrial gases in certain non-essential applications should be considered. The use of the gases in silly string and in klaxons used for recreational purposes (for example at sporting events) are non-essential applications, as opposed to their use in marine safety applications.

8 Key Source Analysis for Ireland

Existing inventory data are not available for industrial gas emissions for Ireland since this is the first time the inventory has been compiled. According to the IPCC methodology (see [Section 2.1](#)), since existing inventory data are not available, the key source categories should be determined using a Tier 1 Level Assessment. The IPCC trend assessment is not possible due to the lack of existing inventory data for these gases.

All of the source categories relevant to industrial gases, apart from fugitive emissions associated with HFC/PFC production, are suggested by the IPCC as source categories that should be assessed in key source analysis. Therefore, all source categories relevant to industrial gases have been assessed. In any case, HFC/PFC production does not occur in Ireland.

Published emissions estimates for 1998 for the other greenhouse gases (CO₂, N₂O and CH₄) were utilised in the key source analysis (DOELG, 2000), together with the actual emissions estimates for the industrial gases in this report. It was found that none of the industrial gas source categories are key source categories, i.e. when all source categories for the six gases are summed together in descending order of magnitude, the threshold of 95% of total greenhouse gas emissions is reached before the industrial gas source categories are reached. Therefore, Tier 1 methodologies are sufficient according to the IPCC but Tier 2 is encouraged. Tier 2 methodologies have in fact been used in the estimation of emissions for the majority of sources.

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10 Glossary

Central Statistics Office, CSO

Hydrofluorocarbon, HFC

Intergovernmental Panel on Climate Change, IPCC

Mobile air conditioning, MAC

Metered dose inhaler, MDI

Perfluorocarbon, PFC

Sulphur hexafluoride, SF₆

United Nations Framework Convention on Climate Change, UNFCCC

Appendix 1

Table A-1. HFCs and PFCs in use worldwide.

	Name (alternative names)	Chemical formula
HFCs		
HFC-23	trifluoromethane (carbon trifluoride; R-23; freon 23; halocarbon 23)	CHF ₃
HFC-32	difluoromethane (R-32)	CF ₂ H ₂
HFC-125	pentafluoroethane (R-125; FC-125)	C ₂ HF ₅
HFC-134a	1,1,1,2-tetrafluoroethane (fluorocarbon 134a; R-134a; FC-134a; HFA-13a)	C ₂ H ₂ F ₄
HFC-143a	1,1,1-trifluoroethane (freon 143a)	C ₂ H ₃ F ₃
HFC-152a	1,1-difluoroethane (ethylidene difluoride; R-152a; fluorocarbon 152a; freon 152a)	C ₂ H ₄ F ₂
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane (2H-heptafluoropropane; FC-227ea)	C ₃ HF ₇
HFC-236fa	1,1,1,3,3,3 hexafluoropropane	C ₃ H ₂ F ₆
HFC-43-10mee	1,1,1,2,2,3,4,5,5,5-decafluoropentane (2H,3H-perfluoropentane)	C ₅ H ₂ F ₁₀
PFCs		
PFC-14	carbon tetrafluoride (tetrafluoromethane; FC 14; R 14; halocarbon 14)	CF ₄
PFC-116	hexafluoroethane (perfluoroethane; carbon hexafluoride; F116; halocarbon 116; freon 116)	C ₂ F ₆
PFC-218	perfluoropropane (octafluoropropane)	C ₃ F ₈
PFC-614	perfluorohexane (tetradecafluorohexane; N-perfluorohexane; perfluoro- <i>n</i> -hexane; perfluoro-compound FC-72)	C ₆ F ₁₄