OPPORTUNITIES TO MINIMISE EMISSIONS OF

HYDROFLUOROCARBONS (HFCs)

FROM THE EUROPEAN UNION

Final Report

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CONTENTS

EXECUTIVE SUMMARY

BACKGROUND

1. This report is the result of a study of the current and future usage of HFCs in the EU. The study was carried out by March Consulting Group on behalf of DGIII-C-4 of the European Commission during the period April to August 1998.

2. The study was carried out to provide information to help prepare EU policies in respect of meeting commitments in the Kyoto Protocol.

3. The work was based on an in-depth review of relevant literature and on detailed interviews with the suppliers and users of the various fluids.

4. The EU has a commitment to reduce emissions of global warming gases by 8% from 1990 levels. This must be met at some time in the period 2008 – 2012 (the Kyoto Protocol "commitment period").

5. There are 6 gases covered by the Kyoto Protocol. These are CO_2, CH_4, N_2O, PFCs, SF_6 and HFCs. Total EU emissions in 1995 were 3900 Mtonnes CO_2 equiv. Current emission levels are dominated by CO_2, representing over 82% of the total. CH_4 and N_2O represent a further 16%. The 3 "new" gases introduced at Kyoto currently represent 1.6% of the total EU global warming emissions.

6. HFCs, PFCs and SF_6 have been included in the Kyoto Protocol because they are powerful global warming gases. HFCs have GWPs (global warming potentials) that are typically between 1000 and 3000 times higher than that of CO_2.

HFC MARKETS

7. HFCs accounted for 1% of EU emissions in 1995, estimated at 41 Mtonnes CO_2 equiv.

8. HFCs were virtually unused prior to 1990. The market for HFCs has grown as a response to phase out of CFCs and HCFCs under the Montreal Protocol.

9. There are 6 main markets in which HFCs are used currently or are likely to be used in the future. These are refrigeration/air-conditioning, foam blowing, general aerosols, metered dose inhalers (MDIs), solvent cleaning and fire fighting.

10. From an emissions perspective the main sources of atmospheric HFCs are these 6 user markets together with 2 other important emitters. These are chemical plants making HCFC 22 (from which HFC 23 is emitted as a by-product) and plants making HFCs.

11. For the purposes of this study these emission sources have been sub-divided into 25 distinct market sub-segments. This has enabled a detailed evaluation of emission reduction opportunities to be carried out.

12. The report provides a detailed background to the 25 market sub-segments together with a review of technologies that can be used to reduce levels of HFC emission. These include alternative fluids, not-in-kind technologies and emission prevention techniques.

EMISSIONS IN A BUSINESS-AS-USUAL SCENARIO

13. A computer model of the 25 market sub-segments has been developed to predict future levels of HFC emissions under a wide variety of control scenarios. The model calculates emissions on an annual basis from 1990 to 2020.

14. An emissions forecast has been made for a "base case", against which other scenarios can be compared. This is referred to as the Business-as-Usual Scenario. It represents the best estimate of emissions assuming that current public and private sector initiatives to limit the impact of global warming are followed.

15. The Business-as-Usual Scenario shows a 2010 HFC emission of 66 Mtonnes CO_2 equiv. This is a 62% increase on 1995 emissions. Refrigeration and air-conditioning represents 43% of this emission with foam blowing representing 21%. HFC 23 emissions from HCFC 22 manufacture are also significant, at 15% of the total.

16. The report provides estimates of future emissions in each of the 25 market sub-segments. An "emissions league table" shows clearly which are the most important emitters. The top 5 emitters account for 66% of the total, and the top 10 account for 85% of the total. The largest single sub-segment is HFC 23 from HCFC 22, which represents 15% of the total. The other members of the "top 5" are supermarket refrigeration, mobile air-conditioning, general aerosols and extruded polystyrene foam.

EMISSION REDUCTION OPPORTUNITIES

17. Information is provided on the advantages and disadvantages of a range of control mechanisms such as voluntary agreements, fiscal measures and end use emission regulations. These are discussed individually for each of the main market sub-segments.

18. A wide range of control scenarios is proposed for each market sub-segment. A total of 90 scenarios are analysed to assess emission reduction potential and Cost Effectiveness (this is defined as the cost of achieving a 1 tonne reduction in CO_2 equivalent emissions, using total costs and emissions for the time period 2000 - 2012). Many of these scenarios have been defined in both "low impact" and "high impact" terms. A low impact scenario only achieves a small proportion of the technical potential whereas a high impact scenario assumes a higher proportion is achieved.

19. The analysis shows excellent technical potential for reducing emissions from the Business-as-Usual Scenario level. With a selection of low impact scenarios emissions in 2010 fall to 39 Mtonnes CO_2 equiv. This is 41% below the 2010 Business-as-Usual Scenario and 5% below 1995 emissions. Adopting all the high impact scenarios could reduce emissions to 22 Mtonnes CO_2 equiv., which is a 45% reduction on 1995 emissions.

20. The above analysis has been carried out for EU-15. There are significant variations in emissions between Member States. In particular, only 7 countries are HCFC 22

producers. Most of these countries had a substantial HFC 23 emission in 1995 and will find it relatively easy to reduce emissions by well over 8%. The other 8 Member States will find it much harder to reduce emissions from very low 1995 levels.

COSTS OF EMISSION REDUCTION

21. The Cost Effectiveness of each control scenario has been evaluated. Some measures can be achieved at relatively low costs, in the range of 1 to 10 ECU/tonne CO_2 equiv. Some measures have a medium level of cost, in the region 10 to 50 ECU/tonne CO_2 equiv. Others are less attractive, being in the range of 50 to 400 ECU/tonne CO_2 equiv.

22. The largest single reduction is a 2010 saving of 9.2 Mtonnes CO_2 equiv. related to HFC 23 emissions from HCFC 22 plants. This can be achieved at just 2 ECU/tonne CO_2 equiv. Good levels of saving can be also made in supermarket refrigeration, mobile air-conditioning, general aerosols and XPS foam with Cost Effectiveness ranging from 9 to 16 ECU/tonne CO_2 equiv. If these were all fully implemented the emission in 2010 would fall to 41 Mtonnes CO_2 equiv., which is equal to the 1995 level of emission. If these best measures are aggregated, the emission reductions can be achieved with an average Cost Effectiveness of around 7 ECU/tonne CO_2 equiv.

23. A further emission reduction of about 6 Mtonnes CO_2 equiv. can be achieved by implementing a number of measures with a Cost Effectiveness in the range 20 – 30 ECU/tonne CO_2 equiv. Together with the measures described in Paragraph 21 this would achieve a 15% emission reduction compared to 1995 – well in excess of the Kyoto target of 8%.

24. We recommend that measures with a Cost Effectiveness significantly above 30 ECU/tonne CO_2 equiv. should not be implemented.

25. A number of energy efficiency measures related to indirect CO_2 emissions from refrigeration and air-conditioning systems were evaluated. These all have "negative Cost Effectiveness" which implies these energy efficiency measures should provide end users with a net financial benefit.

CONTROL MECHANISMS

26. The control mechanisms required to achieve these savings must be based on the characteristics of each market sub-segment. It is not considered appropriate to implement "blanket mechanisms" across the whole HFC market. This would have a detrimental impact on many market sub-segments for which there may not be a cost effective or safe alternative to HFCs.

27. For the key low cost measures described in Paragraph 21 above it is likely that voluntary agreements with selected organisations could prove highly effective. Each voluntary agreement should be tailored to a specific market sub-segment. The most important agreements will be with chemical producers, supermarkets, car manufacturers and XPS manufacturers.

28. For one of the low cost measures and some of the medium cost measures the market sub-segment characteristics are not well suited to voluntary agreements. These include

general aerosols, industrial refrigeration, small commercial refrigeration and solvents. In these markets some form of fiscal measure may prove most effective.

29. Emissions reporting, based on the 25 market sub-segments used in this study rather than a "top down" methodology will help ensure that an effective emission reduction strategy is being implemented. It will also help ensure that "unregulated" markets do not increase their consumption and emissions of HFCs.

COMPARISONS WITH OTHER GLOBAL WARMING GASES

30. The report discusses the importance of comparing the Cost Effectiveness of HFC emission reduction measures with opportunities to reduce the emissions of other global warming gases. Data is given for the refrigeration market to show the costs and benefits of improving energy efficiency and hence reducing indirect CO_2 emissions. Because of the on-going electricity savings all the efficiency opportunities have a net cost benefit to the end user over the life of the equipment. Hence many energy efficiency opportunities are intrinsically more cost effective than direct HFC reduction measures which usually have no "up-side".

31. HFCs must not be treated in isolation. The Kyoto Protocol is based on a "basket of gases". The most economically beneficial response must be based on a review of the whole basket of emission reduction opportunities together.

OTHER COMMENTS

32. Providing the approach described above is adopted it is believed that market flexibility will be maintained. This will ensure the most economically beneficial measures will be implemented. It will also minimise any threats to international competitiveness. A well structured emission reduction programme could help EU companies establish new export markets to help other countries achieve their Kyoto targets.

33. Care should be taken interpreting the emissions data for the foam market sub-segments. By the end of the Kyoto commitment period (2012) there will be no "disposal emissions" from HFC blown foam products because none will have reached the end of their life. Many foam insulation products have a life of 50 years, hence disposal emissions will not occur until well into the next century.

34. Production capacity for most HFCs should not prove a major barrier to the development of HFC markets. This is either because sufficient capacity already exists (e.g. HFC 134a) or because the quantities required are relatively modest. However, there could be a very significant requirement for HFC 245fa and/or HFC 365mfc for foam blowing applications. Chemical companies will find it hard to make the complex investment decisions required without a clear understanding of regulatory responses to the Kyoto Protocol.

1. INTRODUCTION

This report gives the results of a study to investigate the potential use and emissions of HFCs (hydrofluorocarbons) in the EU. The study reviews the emissions of HFCs in relation to EU global warming gas emission restrictions under the Kyoto Protocol. The report provides a detailed analysis of ways of minimising emissions of HFCs. The study was carried out by March Consulting Group during the period March to August 1998.

1.1 Background to HFC Usage and Emissions

Prior to 1990, there was very little use of HFCs in Europe. Indeed the only significant atmospheric emission of HFCs was in the form of HFC 23 released as a by-product in the manufacture of HCFC 22. Since 1990 there has been a significant growth in the market for HFCs because they have been identified as providing effective alternatives to CFC and HCFC fluids.

Existing and possible future legislation on ozone depleting substances will place increasing pressures on CFC and HCFC end users to start using alternative fluids and technologies. HFCs are important alternative fluids for many end users. Refrigeration, foam blowing, general aerosols and metered dose inhalers are all potentially large markets. HFCs are highly attractive for these and other applications due to certain physical and chemical characteristics, particularly their low toxicity and low flammability (see Chapter 2).

Unfortunately, HFCs have an environmental drawback, related to global warming. Whilst they have a zero ODP (ozone depletion potential), HFCs have a significant GWP (global warming potential). This is typically in the range of 1000 to 3000 times the GWP of CO_2. At the 1997 Kyoto meeting, HFCs were included as one of a basket of six global warming gases being targeted for emission reductions.

The GWPs of various pure HFCs and HFC blends are tabulated in Appendix C. All GWPs used in this study are based on the 100-year time horizon. Global warming emissions are presented throughout this report in "Mtonnes CO_2 equiv." (million tonnes CO_2 equivalent, based on the 100-year time horizon). This unit of measurement is the same as "million GWP tonnes". It should be noted that the unit "million tonnes carbon equivalent" is 0.27 times the Mtonnes CO_2 equiv.

The opportunities to reduce global warming emissions from HFC end use markets can be split into 4 categories:

a) minimise HFC emissions throughout the lifecycle of a product

b) use a zero/low GWP alternative fluid

c) use an alternative or "not in kind" (NIK) technology

d) minimise "indirect" emissions of CO_2 from energy used by HFC users.

Each of these technical opportunities needs to be considered from the viewpoints of practical feasibility, environmental effectiveness and economic impact before the most cost-effective emissions reduction strategy can be developed. In addition it is necessary to consider the various "control mechanisms" that can be used by Government to ensure the most effective technical opportunities are implemented.

In some end use markets, such as refrigeration, there may be significant opportunities for adoption of emissions reduction techniques. In other more emissive markets, such as aerosols, emission reduction is clearly not a viable option. These examples stress the necessity to distinguish between intrinsically emissive applications and potentially non-emissive applications. For intrinsically emissive applications the only viable strategy is to minimise use through alternative fluids or technologies. For markets with the potential for low emissions it is necessary to compare the cost effectiveness of emissions reduction techniques with alternative fluids/technologies.

HFC emissions should be considered in relation to emissions of other global warming gases, not in isolation. In some situations the use of HFCs can reduce CO_2 emissions, hence an appraisal of "overall global warming impact" must be made to properly understand the best fluids or technologies to use. The best example of this is the use of HFCs for producing insulating foam. If the insulating properties are improved through use of HFC blown foam, then energy related CO_2 emissions would be cut. It is also necessary to consider all the benefits of using HFCs in particular applications. If these are significant and there is no alternative currently available, then some level of emissions may be deemed acceptable.

Low or zero GWP alternatives to HFCs exist in many markets but the alternative fluids often have other properties that make them difficult and/or expensive to utilise. For example, the use of hydrocarbons as alternative refrigerants can add a significant safety risk and may require extra capital investment. Use of hydrocarbons or CO_2 for foam blowing leads to a foam with inferior insulation properties which could lead to a higher overall global warming impact when energy is taken into account.

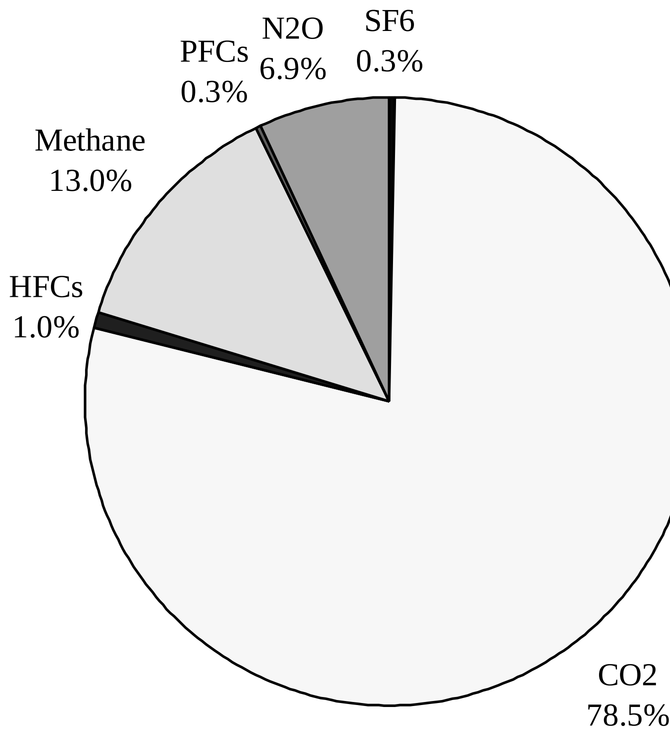
The choice between HFCs and their alternatives is far from simple and must take into account various conflicting factors. There is a great need to provide comprehensive and up to date information about the economic and environmental implications of using HFCs and their alternatives. These are the topics addressed in this study.

1.2 1995 Global Warming Emissions from the EU

Figure 1.1 shows the relative levels of global warming emissions from the EU in 1995. Total emissions were about 3900 Mtonnes CO_2 equiv. (source: FCCC1997). It is clear that CO_2 emissions dominate, with significant contributions from methane and N_2O. The 3 "new" gases added to the global warming basket at the Kyoto meeting (HFCs, PFCs and SF_6) represented only 1.6% of 1995 EU emissions.

HFC emissions were not insignificant in 1995 even though consumption in the end user markets was close to zero. HFC emissions are estimated to be around 41 Mtonnes CO_2 equiv. This relatively high figure is because there was high level of HFC 23 emissions from plants manufacturing HCFC 22. These manufacturing emissions represented 75% of 1995 HFC emissions.

Figure 1.1 EU Global Warming Emissions, 1995
Mtonnes CO2 equiv.



Sources

CO_2, CH_4, N_2O: FCCC 1997 HFCs, PFCs, SF_6: EU Ad Hoc Expert Group 1998

1.3 Study Methodology

The project activities were split into three broad tasks. These are:

Task 1: Background research on the potential market for HFCs. The starting point for the project was to consider the way in which the market for HFCs would develop without further regulation. Discussions with equipment manufacturers, end users and chemical producers helped us to identify potential HFC market sectors and quantify the way in which HFC use and atmospheric emissions could grow. This provides a "Business-as-Usual Scenario" against which we can make both economic and environmental comparisons. Task 1 included the development of a computer model for predicting use and emissions of HFCs in each market sub-sector. This model is also used during Task 3 to analyse control scenarios.

Task 2: Comparison of the use of HFCs and their alternatives in each market. For each potential HFC market identified in Task 1 we have identified the alternative fluids or technologies. A technical and economic assessment of the advantages and disadvantages of HFCs versus these alternatives has been carried out in terms of:

- Total environmental impact. This takes into account all possible environmental impacts including direct global warming, indirect global warming (related to energy consumption), health and safety etc.

- Economic impact. This will address the differences in cost in applying HFCs versus alternative options.

Task 3: Analysis of control scenarios. Based on data available from Tasks 1 and 2 we have proposed a variety of control scenarios that have the potential to limit emissions of HFCs to a greater or lesser extent. These include voluntary controls and economic/fiscal controls as well as more traditional regulatory controls. We have assessed the impacts of each of these control scenarios in terms of:

- Future use and emissions of HFCs.

- Economic impact for end user markets within the EU (capital and operating costs).

- International competitiveness of the HFC producing industries.

- International competitiveness of HFC users.

1.4 Report Structure

The main body of this document summarises the results of all aspects of the study. Where appropriate, more details are provided in a series of technical appendices.

Chapter 2 provides general background about the use of HFCs in all end use sectors, together with a discussion of alternative fluids and technologies. Chapter 3 presents the results of emissions forecasting in both unregulated and regulated markets. Chapter 4 describes the structure of the HFC manufacturing industry and gives comments about emissions from HFC and HCFC manufacture. Chapter 5 provides a discussion of the economic impact of each control scenario. Appendix A introduces the emissions modelling technique used in this study and gives details of modelling assumptions made. Appendix B provides details of the analysis of emission reduction potential. Appendix C gives fluid property details for various HFCs.

2. HFC END USE MARKETS

This Chapter of the report gives background information about the end-use markets for HFCs. Prior to the phase out of ozone depleting substances there was virtually no market for HFCs. All the markets in which HFCs are currently being considered have historically used fluids such as CFCs, HCFCs and halons. The key markets are:

- Refrigeration and air-conditioning
- Foam blowing
- General aerosols
- Medical aerosols (metered dose inhalers, MDIs)
- Solvent cleaning
- Fire fighting

In this chapter of the report we discuss the potential use of HFCs in each market segment and we identify sources of HFC emissions and ways in which emissions can be minimised, either through use of alternative fluids/technologies or through emissions minimisation. Wherever possible we have split the markets into sub-segments to help identify the relative size of the emissions problem and to identify the relative cost of emission reduction techniques. The importance of energy related "indirect" emissions of CO_2 are also discussed for each market segment.

Each of the following sections is split into 5 sub-sections as follows:

1. Market Sub-segments
2. Alternative Fluids
3. Alternative Technologies
4. Emissions Reduction Opportunities
5. Energy Efficiency Issues

It is not the intention to provide a detailed background about the historical use of ozone depleting substances in each end user sector; this has been well addressed in previous publications. For detailed coverage of more general issues the reader should refer to a recent EC study (DGIII, 1997), a UK Government study (DoE, 1996) and the UNEP Technical Option Committee reports (UNEP, 1994 and UNEP, 1998).

2.1 Refrigeration and Air-conditioning

2.1.1 Refrigeration Market Sub-Segments

There are numerous different types and size of refrigeration system used in the EU. These are described in reasonable detail in the references quoted at the beginning of this chapter. For the purposes of this HFC study it was important to sub-divide refrigeration plant usage into appropriate segments for detailed appraisal. The segments chosen were as follows:

- R1 Domestic refrigeration
- R2 Other small hermetic refrigeration units (including through the wall air-conditioners, retail equipment, drinking water coolers etc)
- R3 Small commercial distributed systems (including pub cellar coolers, small chill and cold stores)
- R4 Supermarket systems
- R5 Industrial systems
- R6 Building air-conditioning systems (direct use of refrigerant)
- R7 Building air-conditioning chillers (indirect use of refrigerant)
- R8 Refrigerated transport (refrigerated lorries, containers etc.)
- R9 Mobile air-conditioning (air-conditioning for cars and other vehicles)

2.1.2 Alternative Refrigerant Fluids

Prior to the Montreal Protocol, the refrigeration market was dominated by the use of CFC and HCFC refrigerants. Only the industrial market sub-segment was making any appreciable use of other refrigerants. Industry had maintained a significant usage of ammonia, which often proved the most cost effective option in large systems. There was also a niche market for specialised fluids such as propane and ethylene – usually in chemical plants where these fluids were part of the process. Fluorocarbons were popular because of three important properties:

- Zero flammability
- Low toxicity
- Good materials compatibility.

These properties make it reasonably easy to design safe refrigeration systems that can be used in locations where untrained members of the public may be in the vicinity of a refrigeration plant.

There are numerous new refrigerants on the market that have been specifically developed to address phase out of CFCs and HCFCs. Alternative refrigerants fall into 4 main groups:

1. **HFCs and HFC blends**. They have a zero ODP and are considered long term alternative fluids from the ozone perspective. The favourable properties of zero flammability and low toxicity displayed by most HFCs makes them a popular alternative in both existing and new systems. All pure HFCs and most HFC blends require use of synthetic lubricating oils in place of the more conventional mineral oils used for CFCs and HCFCs. This makes retrofill more expensive, but it is still a practical proposition in many situations. Using HFCs to retrofill CFC or HCFC plant will be the lowest cost option for many refrigeration users.

2. **Ammonia.** This traditional refrigerant has excellent thermodynamic properties and can be used in many types of system. It was widely used prior to the 1930s, but was superseded in many markets by CFCs and HCFCs. Ammonia is highly toxic and slightly flammable and must be used with care. It is incompatible with copper, which is a major draw back for smaller systems. Ammonia is already a very popular refrigerant in the industrial segment. It can usually only be used in new equipment. Ammonia is a reasonable alternative for HFCs in markets where the safety and materials compatibility problems can be overcome. It can be used in many industrial installations currently using fluorocarbons. It can also be applied in other market segments suited to central systems with secondary refrigerants – e.g. building air-conditioning or supermarkets using a secondary circuit. In most situations ammonia will be more expensive than an HFC alternative.

3. **Hydrocarbons.** Certain HCs have good thermodynamic properties as refrigerants. They have good material compatibility, but suffer from the major disadvantage of high flammability. Prior to the Montreal Protocol, HCs were only used in specialised chemical industry applications. During the 1990s they have emerged as a new alternative, particularly in small hermetic systems where very low refrigerant charge limits the potential flammability risk. In some EU countries HCs have taken a dominant position in the domestic market (e.g. in Germany, nearly all domestic refrigerators use HCs).

4. **Other Refrigerants.** A number of other fluids can also be considered as refrigerants. In particular water and CO_2 are suited to certain applications. Water has obvious environmental advantages but can only be used for systems above 0^oC. The very low density of water vapour (at temperatures in the region of 0 to 10^oC) means that water systems require very large compressors. Water has been successfully applied in some industrial applications such as deep mine air-conditioning. CO_2 was used in early refrigeration systems but was largely superseded by CFCs and ammonia. CO_2 has the disadvantage of very high working pressure. CO_2 is currently a strong contender for an alternative to HFC 134a in mobile air-conditioning.

Table 2.1 summarises the potential refrigerant alternatives in each refrigeration market sub-segment. The table shows the popular refrigerants used prior to the Montreal Protocol – clearly illustrating the dominance of CFCs and HCFCs. Alternative refrigerants are divided between "popular" options that already hold a significant market share and "possible" options that are technically feasible in the short to medium term. The popular options currently account for over 90% of new non-HCFC systems. The table shows the current dominance of HFC options in many of the refrigeration sub-segments. Adapting to use of HCs in small hermetic systems (R1, R2) has proved relatively easy as the safety issues are mainly confined to the factory making new refrigeration units. In other markets, such as R4 and R7, adapting to the use of ammonia or HCs is more difficult, because end-users must address new safety issues. In doing this they may encounter higher capital costs and may need to adopt a different type of refrigeration system (e.g. supermarkets could not use a large distributed system with HCs or ammonia). Table 2.2 shows the applicability of the 3 types of refrigerant in more general terms.

Table 2.1 Refrigerant Alternatives

Market Segment	Popular Refrigerants used prior to Montreal Protocol	"Popular" Refrigerant Alternatives[1]	"Possible" Refrigerant Alternatives[2]
Domestic	CFC12	HFC134a, HCs	
Other small hermetic	CFC12, CFC502, HCFC22	HFC134a, HFC blends, HCs	
Small commercial	CFC12, CFC502, HCFC22	HFC134a, HFC blends	HCs
Supermarkets	CFC12, CFC502, HCFC22	HFC blends, HFC134a	Ammonia, HCs
Industrial	CFCs, HCFC 22, ammonia	HFCs, Ammonia	HCs, water
Air-conditioning, DX Systems	HCFC22	HFC blends	HCs
Air-conditioning, Water Chillers	CFC11, CFC 12, HCFC22	HFC134a, HFC blends	Ammonia, HCs
Ref. Transport	CFC502, CFC12	HFC134a, HFC blends	HCs, CO_2
Mobile air-con.	CFC12	HFC134a	HCs, CO_2

Notes to Table 2.1:
1 "Popular" refrigerants currently account for at least 90% of the market for new non-HCFC equipment in the market sub-segment.
2 "Possible" refrigerants have little current market share, but are technically feasible in the short to medium term.

Table 2.2 - General Applicability of Refrigerants
(for cost-effective and safe usage)

Refrigeration Application Category	Ammonia	HCs	HFCs
1. Very Small Systems e.g. domestic refrigerators, icemakers, through the wall a/c. Hermetic systems, very low refrigerant charge.	✗	✓	✓
2. Distributed Systems used in public areas e.g. supermarkets, split system a/c, small cold stores. Refrigerant charge larger and leaks affect untrained people.	✗	✗	✓
3. Distributed Systems used in restricted areas e.g. food factories, cold stores. Usually large industrial systems.	✓	✗	✓
4. Secondary Refrigerant Systems e.g. water chillers, glycol chillers. Refrigerant in restricted plant room with no public access.	✓	✓	✓

Source EFCTC 1997

Key: ✓ Refrigerant can be used cost effectively and safely

✗ Safe use of refrigerant requires excessive cost

2.1.3 Alternative Refrigeration Technologies

There are a number of NIK technologies that can be considered in place of conventional vapour compression refrigeration. These include the following:

Elimination or reduction of refrigeration load. Refrigeration systems are sometimes installed when they are not needed at all or could be designed to serve a much smaller cooling load. This "NIK" option is always worth considering when developing plans for a new refrigeration plant. If refrigeration can be eliminated there are obvious and significant environmental benefits. No refrigerant fluid is used so the GWP is irrelevant. Perhaps more importantly, no energy is used hence there will be a significant reduction in the overall global warming impact. There are numerous examples of elimination or reduction of refrigeration load, ranging from use of ambient free cooling, to reductions in load from better process integration to completely new approaches to processing (e.g. use of irradiated food instead of refrigerated food). This option is not often given the attention it deserves. In many cases the elimination or reduction of a refrigeration load not only saves energy, but also saves capital cost! This opportunity certainly needs to be included in global warming emission reduction strategies.

Absorption refrigeration. Absorption refrigeration is a well established technology that currently maintains a small share of the overall refrigeration and air conditioning market. The refrigerants used for absorption refrigerant (ammonia/water or water/lithium bromide) have a zero GWP. Absorption refrigeration could feasibly have an increased role in future refrigeration systems although great care would need to be taken in properly appraising the global warming impact. Absorption refrigeration systems are driven by heat and tend to have quite low energy efficiency. It is necessary to compare the primary energy usage of an absorption system with the primary energy used by an electric vapour compression alternative (i.e. taking into account power station efficiency). In most applications absorption systems are likely to use more primary energy, hence the zero GWP refrigerant would be of no advantage. If electricity is generated with low levels of carbon emission (e.g. high levels of nuclear or hydroelectric power), vapour compression will be even more favourable. Conversely, in countries with high levels of coal based power generation, an absorption system may be more favourable. The situation where absorption refrigeration is likely to have a positive global warming impact is when waste heat can be used to operate the refrigeration plant. Then primary energy use could be significantly reduced. When low energy use is combined with a zero GWP refrigerant good benefits will accrue. An interesting waste heat option is to use an absorption refrigeration plant in conjunction with a CHP (combined heat and power) system.

Air cycle refrigeration. Air cycle is another well established refrigeration technology that has a niche application in aircraft air conditioning systems. Air cycle could potentially be applied to a wide range of refrigeration applications but, like absorption refrigeration, suffers from a lack of energy efficiency when compared to more conventional vapour compression systems.

Other future technologies. There are a number of other refrigeration technologies that are currently being researched. These include specialised cycles such as Stirling Cycle refrigeration and alternative refrigeration techniques such as thermoelectric refrigeration. None of these technologies are currently on the market in efficient or commercially viable forms and we do not believe they will have any impact on global warming emissions in the medium term period up to 2010.

2.1.4 Emissions Reduction Opportunities

There are highly significant emissions reduction opportunities related to the use of HFC refrigeration and air conditioning equipment. Prior to the Montreal Protocol, CFC and HCFC refrigeration systems tended to suffer from relatively high levels of refrigerant leakage. Replacement refrigerant was cheap and users did not realise they were harming the environment, so leaky systems were considered acceptable. New HFC refrigeration systems tend to have somewhat lower levels of leakage partly because HFCs are more expensive and also because users are reasonably well aware of the global warming issue. Nevertheless, leakage levels are currently at a level well above the minimum that can be cost effectively achieved.

It is interesting to note that if ammonia or hydrocarbon systems are used, it is essential that the leakage levels be minimised for safety reasons. If the same low level of leakage is achieved on HFC systems then the global warming impact from HFCs will be significantly reduced. It is vital that global warming emission reduction strategies compare the effectiveness of investment in low leakage techniques for HFC refrigeration systems with the investment required to buy hydrocarbon or ammonia alternatives.

Methods of achieving low levels of leakage are well described in a number of publications (e.g. EFCTC 1997, IOR 1996). It is worth noting that reduction in refrigerant charge is often a crucial part of leakage reduction strategy. The enormous potential for leakage reduction and the impact of charge reduction is best illustrated by an example. A typical of 1990 large supermarket in the UK used a distributed HCFC 22 refrigeration plant containing 2000 kg of refrigerant. Leakage rates were typically in excess of 30% per annum, leading to an annual emission of 650 kg of refrigerant. Some of the latest designs use more localised refrigeration systems that would require only 300 kg of refrigerant to serve the same sized supermarket. Achieving an annual leakage rate of less than 10% on such systems is relatively easy; 5% is a technically achievable target. Assuming the higher 10% leakage rate, the annual emissions will be 30 kg. This is a factor of 20 times less than the historical level of emissions.

2.1.5 Energy Efficiency Issues

The indirect emissions of CO_2 from power stations dominate the total global warming impact of refrigeration systems. The ratio of direct global warming impact, from refrigerant emissions, to indirect global warming impact, from CO_2 emissions, is highly application dependent. For example in market segment R1, domestic refrigeration, energy represents about 98% of the global warming impact. For other applications such as segment R4, supermarkets, where historical levels of leakage are higher, energy represents a somewhat smaller percentage, but it is still dominant at around 70% of the total global warming impact. Assuming that leakage reductions are made from future HFC supermarket systems as described in the example in Chapter 2.1.4 above, then the energy usage percentage could rise to around the 90% level. Clearly it is vital that energy is included in refrigeration global warming emission reduction strategies.

There is really excellent scope for improvement in the efficiency of refrigeration systems. In many existing systems 20% can be saved at relatively low cost. The overall technical potential may be as high as 40%. Whilst there are some signs of efficiency improvements over the last five years, there is still a massive untapped potential. For more detail on achieving efficiency improvements the reader should refer to publications such as EFCTC 1997, EEBPP (various) and UK DoE 1990.

The opportunities for improving the efficiency of refrigeration systems can be sub-divided into five groups. The following sections describe the potential in each group. The overall saving potential specified for each group is based on March Consulting Group estimates. The % savings are not additive.

1. **Reduction of cooling demand.** When considering any new refrigeration application the essential first step is to review the cooling demand and make every effort to reduce the size of the cooling load. There are numerous ways to do this. In a domestic refrigerator, insulation effectiveness can be increased. In a building air-conditioning system efforts can be made to shade the building from solar gain or to use free cooling at those times of the year when ambient temperatures are low enough. In many refrigeration applications auxiliary loads such as evaporator fans, refrigerant pumps and cold store lighting can be better designed and controlled to reduce power input. It is surprising how many refrigeration systems are built without a proper review of these cooling load reduction opportunities. The overall technical potential for reducing cooling demands is in excess of 25%.

2. **Improved system design.** Once the cooling load has been minimised there are usually numerous system options available to the plant designer. Historically, many high efficiency design options have been ignored or overlooked. A particularly common mistake is to design a plant to be efficient at the "design point" (maximum cooling load under summer time operating conditions). Most systems actually spend much of the time running with lower cooling loads and cooler ambient conditions, but rarely does the design enable performance to be optimised at all these different conditions. Another common design fault is to oversize the system, leading to poor part load efficiency. Many existing plants employ very poor control systems and these can have a great influence on efficiency. There are numerous other system design opportunities such as the use of sophisticated cycles (e.g. two stage systems) and use of techniques such as thermal storage. The overall technical potential for improved system design is in excess of 20%.

3. **Improved component design and selection.** The individual components in a refrigeration system require careful selection if efficiency is to be optimised. The most important opportunity is compressor efficiency. Many existing plants utilise compressors of relatively poor efficiency. Improvements of 10% can often be made at no extra cost. Use of extra evaporator or condenser surface area can often be a worthwhile investment. Other detailed issues such as pipe line and valve pressure drop, defrost system design, oil separation effectiveness etc. all have an influence on efficiency. The overall technical potential for improved component design and selection is probably in excess of 15%.

4. **Improved operation and maintenance practices.** Even if a plant is designed to have very high efficiency, there is no guarantee that this level of performance will be achieved during the operating life of the equipment. Because refrigeration systems are relatively complex, many end users find it difficult to ensure that efficient operation is maintained. When existing refrigeration systems are carefully analysed it is the norm to find significant opportunities for efficiency improvements. These can usually be achieved by small changes in operating practice (such as better compressor sequencing or temperature control) or improved maintenance (such as ensuring no build up of non-condensable gases in the condenser or reducing excessive frost on evaporators). Very few refrigeration systems have sufficient metering to allow proper energy efficiency analysis to be carried out on a regular basis. For example, compressors are rarely fitted with kWh meters. The overall technical potential for improved operation and maintenance practices is probably in excess of 20%.

5. **Optimum selection of refrigerant.** There are differences between the thermodynamic performance of the various refrigerant fluids. Whilst these could in theory lead to significant differences in efficiency, it should be noted that few fluids would reach the market if their performance was significantly worse than competing options. For a wide range of refrigeration applications one would not expect more than about a 5% difference in efficiency between ammonia or the most appropriate HFC or hydrocarbon. In some applications the best HFC may provide the best thermodynamic potential for efficiency, whereas in other circumstances ammonia or a HC might prove more efficient.

2.2 Foam Blowing

2.2.1 Foam Market Sub-Segments

There are numerous different types of insulating and integral skin foam used in the EU. These are described in reasonable detail in the references quoted at the beginning of this chapter. For the purposes of this HFC study it was important to sub-divide foam usage into appropriate segments for detailed appraisal. The segments chosen were as follows:

- F1 Polyurethane – appliances
- F2 Polyurethane – flexibly-faced laminate
- F3 Polyurethane – discontinuous panel
- F4 Polyurethane – continuous panel
- F5 PU, PIR and Phenolic – block foam
- F6 PIR/Phenolic – flexibly-faced laminate
- F7 Polyurethane – spray, injected and pipe-in-pipe
- F8 Extruded polystyrene
- F9 Polyethylene foam
- F10 Polyurethane – integral skin

2.2.2 Alternative Foam Blowing Agents

Prior to the Montreal Protocol a wide range of foams, including the types listed above were produced using CFC blowing agents, particularly CFC 11 and CFC12. The current EU Regulation on ozone depleting substances (EU 3093/94) has already banned the use of HCFCs in all foams except rigid insulating foam and integral skin foam for safety applications. This has meant that many foam producers in markets such as packaging and cushioning have had to move to non-fluorocarbon blowing agents such as water or CO_2. The phase out of fluorocarbons in these markets was successfully completed by 1995. The relatively high price of HFCs is very likely to prevent them finding any future market outside the 10 segments listed above.

Within the 10 market segments listed many manufacturers are currently using HCFC blowing agents. Foams blown with HCFCs are usually based on one of the following:

- HCFC 141b
- A mixture of HCFC 142b and HCFC 22.

Most PU (polyurethane), PIR (polyisocyanurate) and phenolic foams using HCFCs are based on 141b. This includes segments F1, F2, F3, F4, F5, F6, F7 and F10 described above. XPS (extruded polystyrene) and PE (polyethylene) foams are usually blown with the HCFC 142b/22 mixture, when HCFCs are still used .

The current EU Regulation 3093/94 is likely to be revised during 1998/9. The revision will probably lead to greater pressures on the foam industry to find alternative blowing agents. The foam blowing industry has made efforts to identify and commercialise alternatives to HCFC blowing agents. Some of the alternatives are already commercially available, but others have yet to reach the market.

For PU foams, which represent the largest share of the market, the only commercially available alternative is pentane. Chemical companies are currently trying to commercialise a number of liquid HFCs, notably HFC 245fa and HFC 365mfc. These are not likely to be commercially available until 2001 to 2003. The HC and HFC options each have advantages:

- HCs are proven and are very cheap (about 25% of the cost of HCFC 141b). They have a very low GWP. However, they are highly flammable giving rise to safety problems during production and, perhaps more crucially, reducing the fire resistance of finished products. Significant investment is required in production equipment to safely use HCs. Also, the insulation "efficiency" of pentane foam is about 10 to 20% below that of 141b foam. Notwithstanding the disadvantages, a number of European foam blowers have already converted their plants to HCs.
- The new HFCs are generally non-flammable and can be used with only minor modifications to production machinery. They are expected to have insulation properties similar to that of 141b foam. However, the HFCs are not yet commercially proven and are likely to be expensive (probably at least twice the price of 141b and 8 times the price of HCs). Also, the HFCs have a high GWP. Many PU manufacturers feel that the improved physical properties of an HFC foam (fire resistance, thermal conductivity and rigidity) will make it worth the extra cost. Manufacturers argue that the high GWP of HFCs is of little relevance as much of the blowing agent stays within the foam throughout its life. Providing the blowing agent is recovered and destroyed/re-used at the end of the life of the foam (as required by a draft EU Directive) there will be minimal atmospheric emissions.

Similar options exist for PIR and Phenolic foams. However, these foams are sold at a cost premium over other insulants because of their good fire resistance. Many PIR and phenolic foam manufacturers consider use of HCs unacceptable for this reason.

For XPS foam there are also two main alternatives, both of which are already commercially available i.e. CO_2 and HFC 134a. Again both options have their advantages:

- CO_2 is low cost and has a negligible GWP. However, use of CO_2 is difficult and requires substantial investment at the manufacturing facility. CO_2 has poorer insulation effectiveness than the HCFCs being replaced and this is already being seen to restrict the market acceptance of the products so produced.
- HFC 134a has equivalent insulation effectiveness to HCFC blown XPS and requires less plant conversion investment. However, the fluid is more expensive than CO_2 and has a much higher GWP.

PE foam is successfully being made with HCs although safety in manufacture and storage can still be a problem. This extends to the early usage life of thick sectioned foams and no satisfactory solution for safe transport and installation of such foams has yet been found. Integral skin manufacturers are beginning to use mixtures of HFC 134a/water or CO_2/water.

Table 2.3 Foam Blowing Agent Alternatives

Market Segment	Blowing Agents used prior to Montreal Protocol	Main HCFCs in current use	Non-HCFC Options[1]
PU appliances	CFC 11	HCFC 141b	HFCs, HCs
PU flexible laminate	CFC 11	HCFC 141b	HFCs, HCs
PU discon. panel	CFC 11	HCFC 141b	HFCs, HCs
PU continuous panel	CFC 11	HCFC 141b, HCFC 22/142b	HFCs, HCs
Block foam	CFC 11	HCFC 141b	HFCs, HCs
PIR, Phenolic laminate	CFC 11	HCFC 141b	HFCs
PU spray	CFC 11	HCFC 141b	HFCs
XPS	CFC 12	HCFC 22/142b	HFC 134a, CO_2
Polyethylene	CFC 12	HCFC 22/142b	HCs
PU integral skin	CFC 11	HCFC 141b	HFC 134a, CO_2

Note to Table 2.3 1 Non-HCFC options includes some fluids currently available (e.g. HCs and HFC 134a) and others not yet commercially available.

2.2.3 Alternative Insulation Technologies

Fluorocarbon blown foam competes with a number of other types of insulating foam in end-user markets. Products such as mineral fibre and expanded polystyrene (EPS) hold very significant shares of the insulation market. For example, in the UK building insulation market mineral fibre dominates with 75% of sales volume. In Germany mineral fibre represents 53% of the market and EPS accounts for a further 32%. Fluorocarbon building foams including PU, PIR and XPS have less than a 15% share in the market by volume, although this is a substantially greater proportion by value.

End users often select fluorocarbon foams in favour of cheaper alternatives such as mineral fibre because of superior properties such as fire resistance, structural rigidity, moisture resistance and insulation effectiveness. The market is highly competitive and it is feasible to expect some change in the current demarcation between fluorocarbons and other insulating materials as the new HFC blown products come to the market during the next few years.

2.2.4 Emissions Reduction Opportunities

Emissions reduction opportunities vary according to the type of foam in question and the application to which it is put. It is difficult to generalise on the potential of savings that might be achievable. However, there are measures that could be adopted in each of the phases of production, usage and decommissioning. The table below illustrates some of these but it should be stressed that such measures will not be applicable across all foam types and products. The cost-effectiveness and practicality of some of these measures is discussed in Chapter 5.

Table 2.4. Emissions Reduction Opportunities for Foams

Phase of Life	Possible Leak Reduction Measure	Applicable Foam Types
Manufacture	Capture of vapour at "head"	XPS, PU/PF Flex Board
	Re-capture from scrap/trim	All foam types (esp. Block)
	Better installation practice	All foam types
Use Phase	Lower permeability facings	Flexibly-faced laminates
De-commissioning	Controlled removal procedures	All foam types
	Incineration facilities	All foam types

2.2.5 Energy Efficiency Issues

Thermal insulation materials are manufactured for the prime purpose of saving energy (and, by association, carbon dioxide emissions). This makes the energy efficiency issue of vital importance in considering of the future role of HFC blown foams.

The assessment of energy efficiency is not made easy by the fact that the performance of any insulation material is dependent on the environment into which it is put. The assessment is most relevant when comparisons are being made between alternative insulants for a given application. This comparative work was the subject of a recent study carried out by Caleb Management Services (Caleb, 1997). The report identified some typical examples which were sufficient to show that the ranking of alternative products can vary when measured in terms of their overall global warming impact. If the other physical requirements of insulation products are overlaid as a further part of the selection criteria, the choice can be even more complex. Caleb’s work showed that HFC-blown foams can provide the best environmental option in several key applications, due to improved energy efficiency. This fact makes the on-going availability of HFCs vital to the foam sector if the optimum benefit is to be obtained from insulation - particularly in fixed gap situations.

2.3 General Aerosols

2.3.1 General Aerosol Market Sub-Segments

There are numerous different types of aerosol used in the EU. These are described in reasonable detail in the UNEP Technical Option Committee reports (UNEP, 1994 and UNEP, 1998). For the purposes of this HFC study it was useful to sub-divide aerosol usage into appropriate segments for detailed appraisal. The segments chosen were as follows:

- A1 Personal Care Products (e.g. hair care, deodorants, shaving cream etc.)
- A2 Household Products (e.g. air fresheners, oven cleaners, fabric cleaners etc.)
- A3 Industrial Products (e.g. lubricants, specialist cleaning sprays etc.)
- A4 Other General Aerosols (e.g. food products, novelties)

It should be noted that MDIs are dealt with as a completely separate market segment (see Chapter 2.4). Some aerosol applications cover more than one of the above categories. For example insecticides and paints are used in both the household and industrial markets. Personal care products dominate the aerosol market, representing about 75% of consumption. Household products and industrial products represent about 15% and 5% of the market respectively.

2.3.2 Alternative Aerosol Propellants

Prior to the Montreal Protocol about 70% of aerosols utilised CFC propellants. The remaining 30% mainly used HCs. The consumption of CFCs for aerosols within the EU in 1976 was around 177000 tonnes, split evenly between CFC 11 and CFC 12. This fell to 142000 tonnes in 1986 and then entered a rapid decline as the EU aerosol industry took voluntary actions to use CFC alternatives. Consumption was only 21000 tonnes in 1990. By 1995 the consumption of CFCs for general aerosols fell to zero.

End users can choose between four main alternative types of propellant. These are:

- Hydrocarbons (HCs)
- Dimethyl ether (DME)
- Compressed gases (e.g. CO_2, N_2, compressed air, nitrous oxide)
- HFCs

The HCs used are usually mixtures of propane, butane and iso-butane. The mixture proportions are chosen to provide the appropriate vapour pressure. HCs are effective and cheap propellants. The main disadvantages are flammability and VOC emissions. Manufacturers have managed to redesign the nozzles of aerosols to minimise the impact of flammability. HCs have established a dominant position in the aerosol market.

DME is also a flammable propellant and is currently used in a small number of applications where the solubility and pressure characteristics of DME are particularly suitable. DME is likely to be used in much greater volumes if VOC regulations limit the use of HC propellants. However, DME is a "low strength" VOC so it may not be the total answer to the VOC problem.

Compressed gases are used in a few aerosol applications, but have characteristics that make them less effective than "boiling liquid propellants" in many situations. The main drawback relates to pressure characteristics – with compressed gases the propellant pressure gradually falls as the aerosol can is emptied. This leads to poor performance.

HFCs are currently only used when the flammability issue cannot easily be overcome. The most important markets for HFC aerosols are in the industrial segment for applications such as lubricants, specialist cleaning, mould release sprays and pipe freezing. There are also a few niche HFC markets such as certain food products, artificial snow, silly string and football klaxons. HFC applications represent about 3 to 4% of the total general aerosol market – equivalent to about 6000 tonnes of HFC use, mostly HFC 134a. The price differential between HFCs and HCs is important to manufacturers – currently HFCs are about 4 times the price of HCs. This will limit the future growth of HFC aerosols in an unregulated market. However, if there was any legislation to prevent HC use (e.g. related to VOCs) one could envisage a significant growth of the HFC aerosol market.

Users and Governments are aware of the highly emissive nature of aerosols and are trying to avoid HFC use to limit global warming impact. For example, in the UK there is a voluntary agreement between the aerosol manufacturing industry and the Government. The industry has undertaken not to use HFCs unless there is no safe/practical alternative. HFC manufacturers often discourage potential aerosol end users from using HFCs when they think that another propellants could be just as effective.

2.3.3 Alternative Technologies

A proportion of the pre-Montreal Protocol market for CFC propelled aerosols have moved to alternative technologies. These include techniques such as pumped sprays and powder formulations. However, these alternatives are sometimes less effective than aerosols, hence market penetration has been limited. There has been a steady growth in the total EU aerosol market over the last 10 years, illustrating the fact that alternative technologies are not having a strong market influence.

2.3.4 Emissions Reduction Opportunities

There is no possibility to reduce the emissions from aerosols in use. All of the propellants will be emitted to atmosphere when the aerosol is used. There is a minor opportunity available at aerosol manufacturing plants to ensure that manufacturing emission is minimised. There may also be a minor opportunity for recovery of propellant from unused aerosols.

2.3.5 Energy Efficiency Issues

There are no energy efficiency issues linked with aerosol manufacture and usage.

2.4 Metered Dose Inhalers

2.4.1 MDI Market Sub-Segments

MDIs are used for the delivery of pharmaceutical products in the form of a mist delivered into a patient's lungs. We have subdivided the application of such inhalers into three groups as follows:

MDI 1 Asthma

MDI 2 Chronic obstructive pulmonary diseases (COPD e.g. chronic bronchitis, emphysema)

MDI 3 Other diseases

2.4.2 Alternative MDI Propellants

The MDI industry have been trying to develop alternatives to CFC propelled inhalers for many years. HFCs, in particular HFC 134a, were chosen for development in around 1988. Apart from the necessity for highly sophisticated toxicity tests it has been necessary to spend significant periods of time re-formulating the old products to ensure that the pharmaceutical agent can be delivered to patients with the maximum effectiveness. This process is nearing completion and a number of HFC MDIs are becoming available on the market, with either HFC 134a or HFC 227. Both patients and doctors appear to be somewhat reluctant to switch from the tried and tested CFC products to the newer alternatives. This is likely to slow the process of CFC phase out from this market. It is likely that the whole cycle of product development and testing together with market acceptance will take in the order of 20 years.

Because of such an excessively slow product development cycle it is hard to envisage any significant market penetration of non- HFC propelled MDIs by 2010.

2.4.3 Alternative Technologies

The types of drugs delivered by MDIs can also be delivered by 3 alternative technologies. These include:

- Dry powder inhalers
- Nebulisers
- Oral treatments.

The first two of these alternatives are techniques that involved inhaling the drug into the patient's lungs (similar to MDIs) whereas oral treatments are not inhaled. Non-MDI products of this sort have undergone a significant amount of development but have not yet achieved any significant market penetration. In those countries where anti-HFC policies are particularly strong (e.g. Scandinavia) there has been some acceptance of products such as dry powder inhalers. However, even in these markets MDIs still hold over 30% of the market share.

2.4.4 Emissions Reduction Opportunities

As with general aerosols there are no emissions reduction opportunities in this market segment.

2.4.5 Energy Efficiency Issues

There are no energy efficiency issues linked with MDI manufacture and usage.

2.5 Solvents

2.5.1 Solvent Market Sub-Segments

There are numerous different solvent applications in the EU. These are described in reasonable detail in the references quoted at the beginning of this chapter. For the purposes of this HFC study it was important to sub-divide solvent usage into appropriate segments for detailed appraisal. The segments chosen were as follows:

S1 Precision Cleaning

S2 Electronics Cleaning

S3 Metal Cleaning

S4 Dry Cleaning

2.5.2 Alternative Solvent Fluids

Numerous fluids are used for solvent applications. The main ozone depleting substances used historically were:

- CFC 113
- 1,1,1 trichloroethane

Carbon tetrachloride was also used as a solvent, but only in small quantities. Production and import of these 3 fluids is already banned under the existing EU ozone depletion Regulation. Use of the fluids as a solvent has fallen dramatically since phase out, although a few companies still rely on stockpiles of the old solvents.

One of the alternatives for CFC 113 is HCFC 141b. This is the only HCFC used as a solvent, mainly for precision cleaning. It is also used for some general metal degreasing and a little dry cleaning. The EU use of 141b as a solvent in 1997 was very low, being estimated at about 6000 tonnes.

HFC solvents are an attractive alternative to 2 groups of solvent users:

- those still using CFC 113 and 1,1,1 trichloroethane
- those who converted to HCFC 141b

A variety of organic solvents can be considered in place of CFC 113, 1,1,1 trichloroethane and HCFC 141b. Certain HFC fluids can be used, especially HFC 4310 which is sold under the trade name of Verterel. HFC 365mfc, which is one of the new liquid HFCs being considered for foam blowing, will probably prove to be an effective solvent.

Other possible organic fluids include HFEs (hydrofluoroethers), IPA (isopropyl alcohol), trichlorethylene, HCs and PFCs (perfluorocarbons).

2.5.3 Alternative Cleaning Technologies

Most CFC 113 and 1,1,1 trichloroethane users have moved to NIK technologies. Many of the new techniques are now well proven and could prove attractive to companies considering HFCs. The key NIK technologies are:

a) **Water Based Cleaning.** Aqueous and semi-aqueous methods have already been adopted widely in the solvent sector to replace CFC 113 and 1,1,1 trichloroethane. They can also be applied to many applications of HCFC 141b. Conversion to water based cleaning methods usually involves a substantial modification to the current process with inevitable high costs.

b) **No-Clean Processes.** Many manufacturers, especially in the electronics sector have found it possible to make perfectly good products without the need for traditional cleaning.

2.5.4 Emissions Reduction Opportunities

In some applications there are significant opportunities to reduce the emission of solvent during the cleaning process. In general there are two types of emission from a solvent cleaning system. The first is evaporation from the cleaning bath itself and the second is carry over of liquid solvent on the surface of products being cleaned. By improving the design of the solvent bath enclosure and of vapour recovery condensing systems it is possible to minimise evaporative loss. By allowing an adequate opportunity for liquid solvent to drain from products before they leave the solvent enclosure it is also possible to minimise carry over losses. In applications where alternative technologies or non-HFC fluids are not applicable it is important that every effort is made to minimise operational emissions.

2.5.5 Energy Efficiency Issues

The use of energy is not a highly significant factor in the solvent market although care must be taken in comparing the energy consumption of certain competing technologies. In some cleaning processes it is important to dry the products leaving the cleaning system. In the case of aqueous cleaning methods the energy consumed for drying may be considerably higher than that for organic solvents. If a user is moving away from HFCs to aqueous cleaning purely to minimise direct global warming emissions it is important to check these energy consumption figures at the design stage.

2.6 Fire Fighting

2.6.1 Fire Fighting Market Sub-Segments

There are 2 main sub-divisions of the fire fighting market that was served by halons prior to the Montreal Protocol. These are:

FF 1 Fixed systems

FF 2 Portable extinguishers

2.6.2 Alternative Fire Fighting Fluids

In the fixed systems market there are four main types of extinguishing fluid currently being used or considered. These are:

Halons. Even though halon production/import was banned in 1995, they are still widely used in existing systems because emission levels are low and because there is an effective recycling market. The future of the recycling market could be restricted if the current draft of the replacement to EU Regulation 3093/94 is adopted. This will ban placing on the market and use of halons after the end of 2004 (except for some uses deemed critical by the Parties to the Montreal Protocol).

HFCs, mainly HFC 227 and some HFC 23 and 134a. HFCs are being used where "halon-like" properties are important. The HFC products are expensive (up to 7 times more than the 1986 price for halons). This restricts the applications to about 25% of the number of new systems that would have previously used halons.

PFCs. Certain PFCs are currently being considered in specialist applications that require high concentrations of fire fighting agent (e.g. protection against explosions in armoured vehicles).

HCFCs. These are being used in some parts of the EU in contravention to EU Regulation 3093/94, which does not permit this use. The draft of the new regulation also does not permit use of HCFCs for fire fighting applications.

For portable extinguishers the vast majority of old halon applications have moved away from fluorocarbons. The main application in which halon type products are still important is for aircraft use. A new product, HFC 236, has recently been registered and may take up a small niche market in specialist portable extinguishers.

2.6.3 Alternative Fire Fighting Technologies

NIK technologies are of significant importance in relationship to the replacement of fixed halon systems. About 50% of the market no longer use fixed extinguishing systems. Instead they rely on high sensitivity smoke detection systems to minimise the possibility of serious fires. About 25% of the market have moved to alternative technologies such as inert gases or water based systems. This leaves about 25% of the market interested in HFC type products.

The majority of portable halon extinguishers are being replaced by alternative technologies such as CO_2, foam or water systems.

2.6.4 Emission Reduction Opportunities

Significant reductions have already been made in the emission of fire fighting fluids from fixed systems of the halon type. Fixed systems have no moving parts and are effectively leak free throughout their life. However, emissions can occur through system testing and false alarms as well as during actual fires. Prior to the Montreal Protocol, it used to be common practice to regularly test a halon system by discharging a large proportion of the system charge. This practice is no longer carried out. Current system suppliers use computer modelling techniques as design aids. These have been rigorously validated in full scale type approval tests, removing the need to discharge test every system. End users also rely on quality assurance systems and independent testing in third party approved laboratories. Other loss of fluid through false alarms has also been considerably reduced by improvements in technology, particularly in relation to fire sensing systems. New systems can be expected to have average annual emission rates in the range of 1% to 3% of system charge.

2.6.5 Energy Efficiency Issues

There are no energy efficiency issues linked with use of fire fighting systems.

3. HFC EMISSIONS

3.1 Introduction

A crucial aspect of the analysis in this project is to compare the atmospheric emissions of HFCs under different assumptions and control scenarios. To do this in an effective way a spreadsheet computer model has been developed to evaluate EU emissions on a year by year basis between 1998 and 2020.

A description of the emissions model and details of assumptions made in the use of the model are given in Appendix A. In this Chapter the emissions model results are presented for both the Business-as-Usual Scenario and controlled HFC markets.

3.2 Basis of the Emissions Model

There are numerous points in the lifecycle of HFC using products at which emissions can occur as shown in Figure 3.1. Some initial losses occur during fluid production. A manufacturing company then uses the fluid to make a product; some emissions occur during product manufacture. The finished product then goes through an appropriate lifecycle, which could vary in length from less than 1 year (e.g. an aerosol product), to over 50 years (e.g. building insulating foam). Emissions can occur at any time in this lifecycle. Finally, a product reaches the end of its useful life; emissions to atmosphere can occur on product decommissioning/disposal.

The computer model uses four "emissions factors" to characterise the HFC emissions from each market sub-segment. These are:

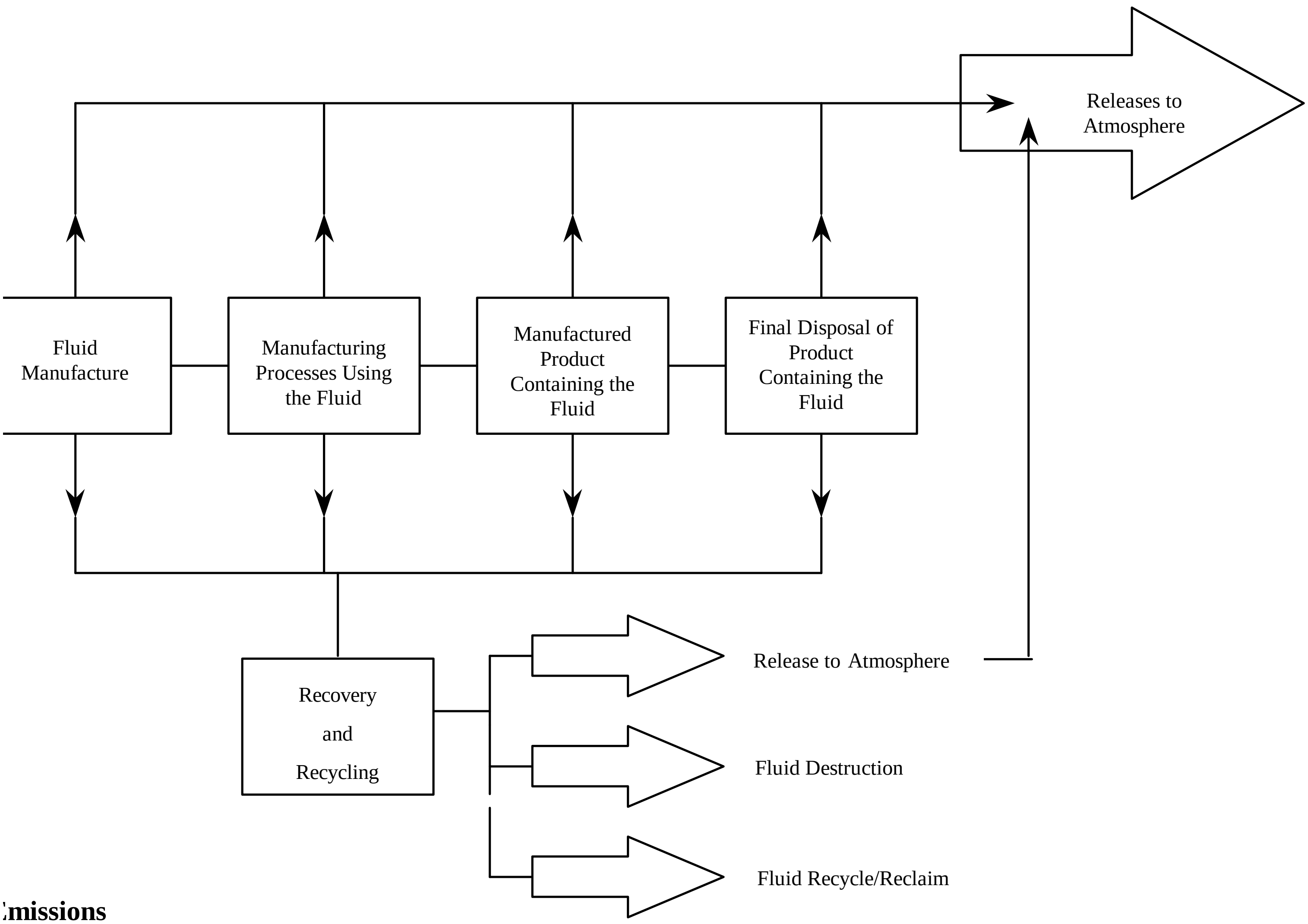
- **Fluid Manufacturing Factor** - losses during fluid production, expressed as a percentage of fluid production.

- **Product Manufacturing Factor** - losses during the manufacture, storage, transport and installation of an end product, expressed as percentage of fluid consumed for manufacturing new products.

- **Product Life Factor** - emissions of fluid from a product during its useful lifetime, expressed as a percentage loss from the installed bank.

- **Disposal Loss Factor** - this defines the proportion of fluid that is emitted at the end of a product's useful life, during the decommissioning process (as opposed to being recovered and then re-used or destroyed). This is expressed as a percentage of the amount of fluid in products being decommissioned.

Figure 3.1 - Simplified Emission Model



:missions

'luid Recovery

For the purposes of this study it is important to be able to re-evaluate emissions for a wide range of control scenario assumptions. This can be achieved by splitting the analysis of end user markets into relatively small sub-segments (as described in Chapter 2). This has allowed us to make individual emission factor assumptions for each sub-segment. The model makes use of estimates of the amount of fluid used in each market sub-segment to manufacture new products and of the rate of product decommissioning/disposal. Annual estimates have been made between 1990 and 2020.

It is important to note that the import and export of products containing HFCs influence EU emissions. All HFCs manufactured in the EU could give rise to some emissions at the chemical plant, whether or not the fluid is subsequently exported. Fluid that is exported in manufactured products cannot lead to EU product life or product disposal emissions. Conversely fluid that is imported in such products has the potential to produce emissions. In the emissions model developed in this study, the fluid manufacturing factor is applied to all fluid to be produced in EU chemical factories. The product manufacturing factor is applied to all equipment manufactured in the EU, irrespective of whether it is for home or export markets. The product life and disposal loss factors are applied to all products used in the EU market irrespective of whether they were manufactured in the EU or elsewhere. Values for the various emissions factors and other parameters used in the emissions model are detailed in Appendix A.

Each Member State of the EU has to provide historical emissions data and future emissions forecasts to the IPCC (Intergovernmental Panel on Climate Change). The IPCC require data to be submitted in two formats for a simplified "worst case" model and for a more sophisticated model. The worst case model is based only on fluid consumption data and makes the very poor assumption that consumption is equal to emissions. The sophisticated model is similar to the one described in this section i.e. it properly takes into account the lifecycle of the fluid. All the modelling carried out in this study is compatible with the IPCC sophisticated model.

3.3 Business-as-Usual Scenario HFC Emissions

The first stage in the analysis of HFC emissions has been to postulate what is likely to happen without further regulations.

It is difficult to define precisely how the market will develop. Many end users are well aware of the high global warming potential of HFCs and already try to minimise their potential levels of emissions. In some countries voluntary agreements have been made between industry sectors and Government; these describe how emissions will be minimised. Certain EU countries have indicated that much tougher policy measures are likely to be implemented and that there will be little or no HFC emission by 2010.

However, it is also necessary to remember that there are very few current regulations that legally prevent end users adopting HFCs. It is possible to envisage circumstances where external influences (such as tough regulations on VOC emissions) could make HFCs very attractive alternatives in some end use markets.

Taking these factors into account a "Business-as-Usual Scenario" has been developed. This is intended to be a realistic best estimate of the level of future emissions against which a variety of emission reduction strategies can be compared. The Business-as-Usual Scenario gives a good indication of the level of HFC emissions that will occur without further intervention from Member State Governments or without co-ordinated policies and measures agreed by the EU as a whole. It is important to recognise that an accurate emissions forecast for the Kyoto Protocol commitment period (i.e. 2008 to 2012) is virtually impossible to make because there are numerous uncertainties regarding the development of the HFC end user markets. However, for the purposes of this study, the Business-as-Usual Scenario provides a very useful "base case".

The modelling for the Business-as-Usual Scenario is based on a "bottom up" assessment of each of the 25 market sub-segments. For each market sub-segment we have obtained data from industry experts to predict the market penetration of HFC products and the level of emissions likely to occur. Modelling assumptions are detailed in Appendix A. For refrigeration and air-conditioning market sub-segments and for foam insulation it is important to remember that the overall global warming impact is the sum of direct HFC emissions and indirect CO_2 emissions (related to energy consumption). In this chapter estimates of the indirect emissions related to these end use markets are also presented.

It must be stressed that the Business-as-Usual Scenario assumes that HFC emissions do not reach the historical levels of CFC and HCFC emissions in the various end use markets. This is a reasonable assumption because many end users and some Member State Governments have already taken significant steps to minimise emissions. However, if the market remains unregulated it must be recognised that emissions levels could get to a much higher level than the Business-as-Usual Scenario if there is no clear incentive to achieve low emissions or if outside forces (e.g. VOC regulations) change the habits of users.

3.3.1 Results of the Business-as-Usual Scenario Modelling

The results of the emissions modelling for the main market segments are presented in Table 3.1 and Figure 3.2. The data in Table 3.1 are the summarised output of the emissions computer model (see Appendix A). The table clearly shows which of the main market segments are likely to make the greatest contribution to 2010 HFC emissions. Refrigeration is the largest contributor to emissions, with foam making the second largest contribution.

For comparative purposes, Table 3.1 also shows the modelling data for 1995. This shows the significance of HFC 23 emissions at that time and the low level of usage and emissions from all users sectors. It is useful to note that the model shows fairly constant EU HFC emissions between 1990 and 1995, hence the choice of Kyoto Protocol "base year" is not critical.

Table 3.1 EU HFC Emissions

Market Segment	HFC Emissions Mtonnes CO_2 equiv.		% of total emissions
	1995	Business-as-Usual Scenario, 2010	
Refrigeration/air-conditioning	4.3	28.2	42.7%
Foam	0	13.6	20.6%
HFC 23 from HCFC 22 manuf.	35.0	9.7	14.7%
General Aerosols	1.3	7.0	10.6%
MDIs	0	4.8	7.3%
Solvents	0	2.0	3.0%
Losses from HFC manufacture	0.1	0.5	0.8%
Fire-fighting	0	0.2	0.3%
TOTAL EU EMISSIONS	**40.7**	**66.0**	100.0%

Figure 3.2 EU HFC Emissions in 2010,
Business-as-Usual Scenario

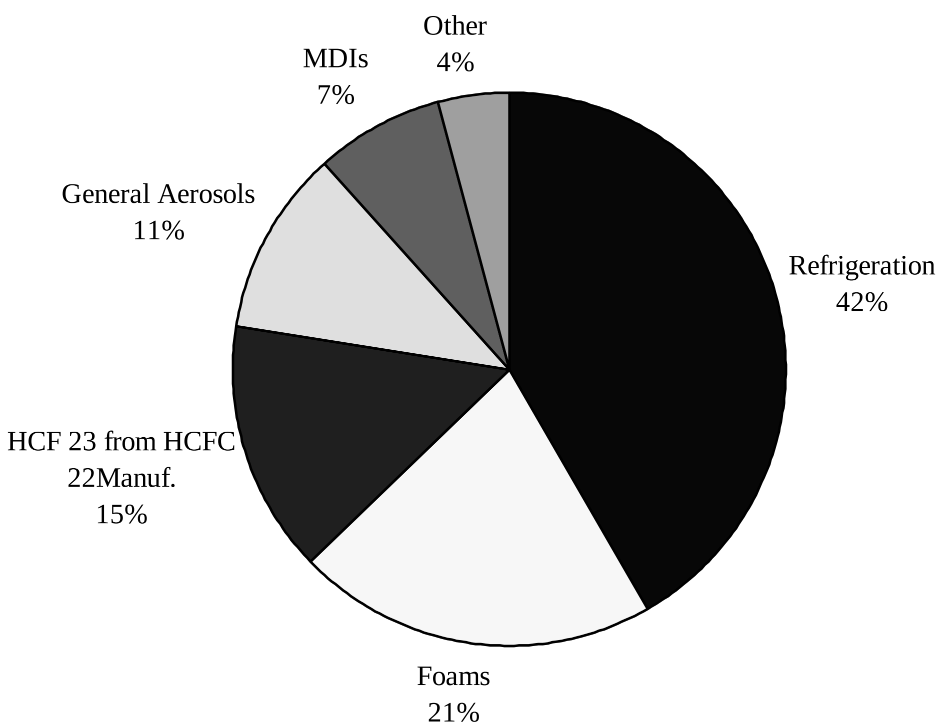


Table 3.2 EU HFC Emissions in 2010,

Business-as-Usual Scenario, Split by Emissions Source

Market Segment	% of market segment emission split by:		
	Product Manufacturing Loss	Product Life Loss	Product Disposal Loss
Refrigeration/air-conditioning	1	87	12
Foam	69	31	0
HFC 23 from HCFC 22 manuf.	100	0	0
General Aerosols	1	96	3
MDIs	1	96	3
Solvents	2	98	0
Losses from HFC Manufacture	100	0	0
Fire-fighting	1	97	2
TOTAL EU EMISSIONS	**32%**	**62%**	**6%**

Figure 3.3 EU HFC Emissions in 2010,
Business-as-Usual Scenario, Split by Emissions Source

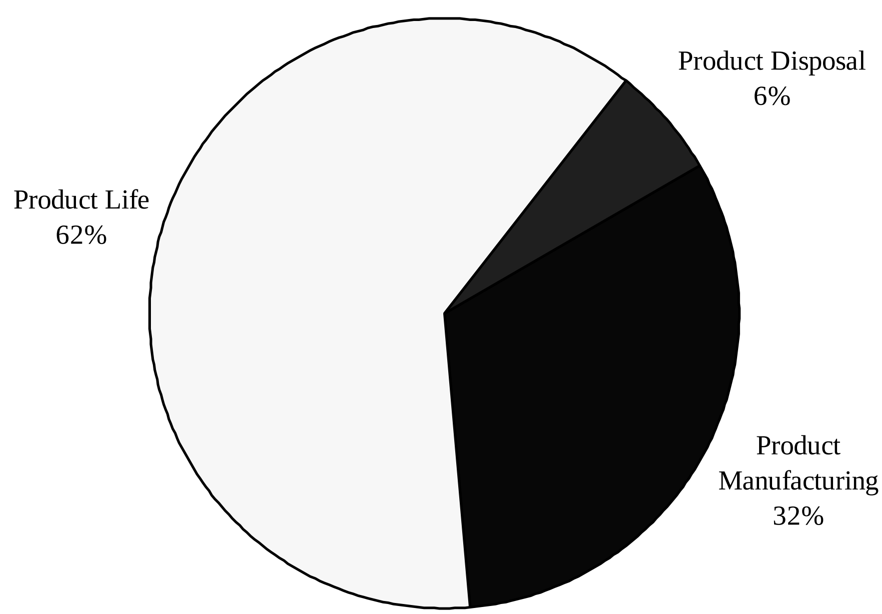


Table 3.2 and Figure 3.3 show a breakdown of emissions under the Business-as-Usual Scenario, split into product manufacturing, product life and product disposal emissions. The table shows that for the majority of market segments it is the product life losses that dominate emissions. In the foam sector manufacturing losses are very important. Care should be taken in interpreting the disposal losses in 2010. In some markets, particularly foams, there will be no disposals until well after that date as the average product life is very long.

It is important to note that the data in Table 3.1 provides an overall total for EU-15. There are some significant variations between EU countries at market sub-segment level. In particular only 7 countries are HCFC 22 producers, hence the 1995 "base level" is high in these producing countries but close to zero in all others. This has an important impact when considering individual Member State targets.

3.3.2 Breakdown of Emissions from Refrigeration Market Segments

The level of emissions from refrigeration and air-conditioning market sub-segments is shown in Table 3.3.

Table 3.3 EU Emissions in 2010, Business-as-Usual Scenario ,

Direct HFC Emissions, Refrigeration and Air-conditioning

Market Segment	HFC Emissions Mtonnes CO_2 equiv.	% of total emissions
Supermarket Refrigeration	9.0	32
Mobile air-conditioning	8.9	32
Industrial Refrigeration	3.4	12
Air-conditioning, DX systems	2.6	9
Small Commercial Distributed	1.8	6
Domestic Refrigeration	0.8	3
Transport Refrigeration	0.7	3
Air-conditioning, chillers	0.7	1
Other Small Hermetic	0.3	1
TOTAL EMISSIONS	**28.2**	**100**

Table 3.3 gives some very useful detail from within the refrigeration and air conditioning market segment. The table shows that three refrigeration market sub-segments dominate the total HFC emission forecast. These are supermarket refrigeration, mobile air-conditioning, and industrial refrigeration. They represent over 75% of emissions under the Business-as-Usual Scenario. This is a highly relevant factor, as it influences the control scenarios being considered in the next section.

Table 3.4 shows how the emissions from each refrigeration sub-segment are split between Product Manufacturing, Product Life and Product Disposal. The table shows that for domestic and other small hermetic refrigeration it is the Disposal loss that is dominant (about 70% of emissions). For all other types of refrigeration the Product Life loss is dominant (86 to 98% of emissions). In all cases Product Manufacturing losses are negligible.

Table 3.4 EU Emissions in 2010, Business-as-Usual Scenario

Split of Emissions Source, Refrigeration and Air-conditioning

Market Segment	**% of market segment emission split by:**		
	Product Manufacturing Loss	**Product Life Loss**	**Product Disposal Loss**
Supermarket Refrigeration	1	93	6
Mobile air-conditioning	1	86	13
Industrial Refrigeration	2	98	0
Air-conditioning, DX systems	2	97	1
Small Commercial Distributed	1	94	5
Domestic Refrigeration	2	26	72
Transport Refrigeration	1	92	7
Air-conditioning, chillers	4	92	4
Other Small Hermetic	3	29	68
TOTAL EU EMISSIONS	**1%**	**87%**	**12%**

Tables 3.3 and 3.4 present details of the direct HFC emissions from refrigeration and air-conditioning equipment. The refrigeration and air-conditioning market segments use significant quantities of electricity, which lead to "indirect" emissions of CO_2 at power stations. Table 3.5 provides an estimate of the indirect CO_2 emissions linked with each of the market sub-segments and compares this to direct emissions. The data shows that indirect CO_2 emissions represent a much larger global warming impact than the direct HFC emissions. Under the Business-as-Usual Scenario the indirect CO_2 impact is 84% of the total equivalent warming impact (TEWI) for refrigeration and air-conditioning. The relative importance of each sub-segment, in terms of levels of emissions, changes when indirect emissions are taken into account. In particular, domestic refrigeration only represents 3% of direct emissions, but it becomes the largest single emitter when indirect CO_2 is included – it is nearly 20% of the total.

The figures in Table 3.5 stress the need to include indirect emissions when evaluating control scenarios.

Table 3.5 EU Emissions in 2010, Business-as-Usual Scenario

Comparison of Direct and Indirect Emissions, Refrigeration and Air-conditioning

Market Segment	Global Warming Emission, Mtonnes CO_2 equiv.			% of GW impact related to energy use
	Direct HFC Emissions	Indirect CO_2 Emissions	Total Global Warming Impact	
Supermarket Refrigeration	9.0	23	32.0	72%
Mobile air-conditioning	8.9	14	22.9	61%
Industrial Refrigeration	3.4	25	28.4	88%
Air-conditioning, DX systems	2.6	10	12.6	79%
Small Commercial Distributed	1.8	12	13.8	87%
Domestic Refrigeration	0.8	30	30.8	97%
Transport Refrigeration	0.7	6	6.7	90%
Air-conditioning, chillers	0.7	12	12.7	94%
Other Small Hermetic	0.3	12	12.3	98%
TOTAL EMISSIONS	**28.2**	**144**	**172.2**	84%

One reason that the indirect emissions are such a high percentage of the Business-as-Usual Scenario is that current programmes and initiatives within the EU are oriented more towards HFC emissions than to improvements in energy efficiency. We have established that refrigeration users are more aware of the direct global warming emissions than they are about energy consumption – even though there is excellent energy reduction potential. This factor should again influence decisions about control scenarios.

The indirect emissions are slightly more evenly spread over the 9 segments than the direct emissions. The four highest emitting sub-segments represent about 65% of the total indirect emissions (these are domestic, supermarket refrigeration, industrial refrigeration and mobile air-conditioning). For direct emissions the four highest emitting sub-segments represent almost 90% of the total.

3.3.3 Breakdown of Emissions from Foam Market Segments

Table 3.6 gives a detailed breakdown of HFC emissions from the foam market segments. The table clearly shows the dominance of XPS. It represents 51% of the emissions under the Business-as-Usual Scenario. It should be noted that because of the long lifecycle of most foam products that there are no disposal emissions by 2010 in the majority of foam market sub-segments. If building insulation foam is not recovered at the end of life there will be some extra level of emissions after 2050.

Table 3.7 shows how the emissions from each foam sub-segment are split between Product Manufacturing, Product Life and Product Disposal. The table clearly shows that for foam the product manufacturing losses dominate (69% of total foam emissions). This is quite different from the figures for refrigeration shown in Table 3.4 where manufacturing loss is negligible. Manufacturing loss is especially high for block foam because a substantial proportion of block foam for pipe section is wasted because blocks must be trimmed to form the required shape. For polyethylene foam the manufacturing loss is high because of the relatively open structure of cells in the foam.

It must be remembered that the figures presented are for 2010. No HFC blown foam will have reached the end of its life by this date hence disposal losses are zero. However, disposal losses will begin to rise as products reach the end of life. For appliances and block foam this will begin around 2015. For other foams disposal losses will not start until around 2040, as they are mostly used in long life-cycle building construction applications.

Extrapolating the emissions model to 2020 shows a rise in foam emissions from 13.6 to 22 Mtonnes CO_2 equiv. This is due to an increasing bank size and the start of disposal losses from appliances and block foam. If the model is extrapolated to 2050 the emissions rise to 27 Mtonnes CO_2 equiv. This allows for disposals from all foam segments. These figures are based on annual foam production equal to that in 2010 and no recovery of blowing agent from old foam.

Table 3.6 EU Emissions in 2010, Business-as-Usual Scenario

Direct HFC Emissions, Foam Blowing

Market Segment	HFC Emissions Mtonnes CO_2 equiv.	% of total emissions
XPS	6.9	51
PU spray/pipe-in-pipe	1.8	13
PU Discontinuous Panel	1.1	8
PU, PIR, Phenolic Block	1.1	8
PU Flexibly faced laminate	1.0	7
Polyethylene foam	0.6	4
PU Continuous Panel	0.4	3
PIR, Phenolic f-f laminate	0.4	3
PU Appliances	0.3	2
Integral Skin foam	0.0	0
TOTAL EMISSIONS	**13.6**	**100**

Table 3.7 EU Emissions in 2010, Business-as-Usual Scenario

Split of Emissions Source, Foam Blowing

Market Segment	% of market segment emission split by:		
	Product Manufacturing Loss	Product Life Loss	Product Disposal Loss
XPS	56	44	0
PU spray/pipe-in-pipe	82	18	0
PU Discontinuous Panel	77	23	0
PU, PIR, Phenolic Block	92	8	0
PU Flexibly faced laminate	63	37	0
Polyethylene foam	96	4	0
PU Continuous Panel	61	39	0
PIR, Phenolic f-f laminate	64	36	0
PU Appliances	64	36	0
Integral Skin foam	0	0	0
TOTAL EU EMISSIONS	**69%**	**31%**	**0%**

3.4 HFC Emissions League Table

To analyse the benefits of HFC emission control measures it is necessary to consider each of the 25 market sub-segments. It is most logical to do this taking into account the relative magnitude of HFC emissions that are likely to occur. It is then possible to identify market sub-segments that have the greatest potential for emission reduction. Table 3.8 gives a listing of market sub-segment emissions listed in the form of a "League Table". Figure 3.4 shows the same data presented as a bar chart.

Table 3.8 HFC Emissions League Table,

EU HFC Emissions in 2010, Business-as-Usual Scenario

Market Sub-Segment	HFC Emissions Mtonnes CO_2 equiv.	% of total emissions	Sub-totals	Cumulative Sub-totals
			% of total emissions	
HFC 23 from R22 Manufacture	9.7	14.7%		
Supermarket refrigeration systems	9.0	13.6%		
Mobile air-conditioning	8.9	13.5%		
General Aerosols	7.0	10.6%		
Extruded polystyrene foam	6.9	10.4%	62.8%	62.8%
Metered Dose Inhalers	4.8	7.3%		
Industrial refrigeration systems	3.4	5.2%		
Air-conditioning, distributed	2.6	3.9%		
Solvents	2.0	3.0%		
Small commercial distributed ref.	1.9	2.9%	22.2%	85.0%
PU spray, injected and pipe-in-pipe	1.8	2.7%		
Polyurethane – discontinuous panel	1.1	1.7%		
PU, PIR and Phenolic – block foam	1.1	1.7%		
PU – flexibly-faced laminate foam	1.0	1.5%		
Domestic refrigeration	0.8	1.1%	8.8%	93.8%
Refrigerated transport	0.7	1.1%		
Air-conditioning chillers	0.7	1.1%		
Polyethylene foam	0.6	0.9%		
HFC Manufacturing	0.5	0.8%		
Polyurethane – continuous panel	0.4	0.6%	4.4%	98.2%
PIR/Phen. – flexibly-faced laminate	0.4	0.6%		
Other small hermetic refrigeration	0.3	0.5%		
PU - appliances	0.3	0.5%		
Fire Fighting	0.2	0.3%		
Polyurethane – integral skin foam	0.0	0.0%	1.8%	100.0%
Totals	66.0	100.0%		

Figure 3.4 EU HFC Emissions Forecast for 2010, Business-as-Usual Scenario

The Table 3.8 and Figure 3.4 give a helpful insight into the relative magnitude of emissions. For convenience, Table 3.8 has been sub-divided into five groups. The top group, containing the 5 market sub-segments with the highest emissions, represents 63% of total emissions. The top two groups represent 85% of the total and it is clearly these ten market sub-segments that must receive the majority of attention. Emissions should also be minimised from the other market segments, but it must be recognised that there is little potential to significantly influence total emissions in these low emission markets.

Indirect emissions of CO_2 from HFC end use markets are discussed separately in Chapter 3.7.

3.5 Discussion of HFC Emission Control Mechanisms

To reduce the level of HFC emissions from the Business-as-Usual Scenario presented in the Table 3.8 it will be necessary to introduce controls to modify the way in which the HFC market develops. There is a range of different control mechanisms available, which are discussed in general terms in this section. In Appendix B we give more detail about how these different control mechanisms could be applied to individual end use market segments. It should be noted that several of the control mechanisms described below are already in use within the EU. The main control mechanisms analysed in this study are as follows:

a) **Voluntary agreements.** These could be made with end user representatives or product manufacturers, and would be based upon one or both of the following:

   - voluntary agreement to restrict the use of HFCs in certain end use applications

   - voluntary agreement to make significant efforts to reduce levels of emissions at each stage during the product lifecycle (i.e. product manufacturing, product life and product disposal).

   An advantage of this control mechanism is that voluntary agreements are relatively easy to implement in some market segments. A major disadvantage is that it is more difficult to predict the effectiveness of a voluntary agreement than of a legal requirement. In general terms voluntary agreements are most effective when applied to a market segment with a small number of powerful "influencing organisations". This might include the mobile air-conditioning, supermarket refrigeration and XPS foam segments where a small number of very large companies are responsible for fluid selection. It is far harder to apply voluntary agreements to market segments with a large number of "influencing organisations". For example industrial refrigeration is influenced at site level, hence there are many tens of thousands of users that would need to sign up to a voluntary agreement. Clearly this is difficult to achieve.

b) **Emissions reporting mechanisms.** Emission reporting is another relatively low cost impact technique that will draw attention to HFC usage and hence encourage some end users and product manufacturers to minimise their emissions. This mechanism is unlikely to have a significant impact by itself but could form a crucial part of the successful implementation of other control measures. Emission reporting may be difficult to apply widely from an administrative point of view.

c) **End use emission regulations.** In some end use markets it would be practical to regulate the way in which HFCs are used and emitted. For example, in many refrigeration sub-segments it would be possible to significantly reduce emissions through leakage and on product disposal by some form of emission regulation. A mechanism of this type will be considerably enhanced if it is applied together with end use emission reporting. This mechanism cannot be applied to all market segments. It will not work for intrinsically emissive applications such as aerosols.

d) **Fiscal measures such as product taxation, by fluid.** By increasing the price of HFCs end users and product manufacturers will be encouraged to use alternative fluids where available or to minimise levels of emission through product life and on disposal. Taxation could be applied on a fluid basis where the end use application is not taken into account. This would be a relatively crude technique that could put undue financial pressure on some market segments.

e) **Fiscal measures such as product taxation, by market segment.** A more targeted way of introducing a taxation control mechanism would be to do so on a market segment basis. For example certain markets could be taxed whilst others are not subject to taxation.

For options (d) and (e) it would be necessary to carefully consider both the level and structure of a tax. The level must be set to ensure the tax will provide sufficient market forces for emission reductions to be achieved. Considerations on structure include fiscal neutrality and re-use of sums raised. Ideally a global warming tax should be fiscally neutral – i.e. the overall tax burden within a member state should remain constant. This can be achieved either by lowering other tax levels (e.g. business taxes such as Corporation Tax) or by re-injecting the tax into subsidy schemes to help HFC users reduce emissions levels. This latter mechanism is obviously the more complex but it has the excellent benefit of doubling the financial incentive to reduce emissions.

f) **Emissions trading.** This is a mechanism that was introduced at the Kyoto meeting as a technique to be considered for reducing levels of global warming emissions. A significant advantage is that trading will allow end users to judge the financial benefits of emitting global warming gases. Hence, if use of HFCs is of critical importance to a particular company they may find it most cost effective to trade emissions, which essentially means they will be making an investment to reduce someone else's global warming emissions. However, setting up an emission trading mechanism for HFC usage could be particularly difficult. It will be necessary to allocate some form of emissions permits that would be used for trading purposes. This will be difficult enough for emissions from an established market such as energy, but would be particularly complex in an area of rapid market growth such as the use of HFCs. It would be essential not to allow emissions trading for HFCs to be carried out in isolation from other global warming gases, as there is a risk of increasing CO_2 emissions while HFCs are being addressed.

g) **End use controls, by market segment.** End use restrictions on greenhouse gases in general, and on HFCs in particular, are not mentioned in the Kyoto Protocol. This is quite different from the Montreal Protocol on ozone depleting substances, which explicitly foresees use controls. However, to give a complete picture of all possible control options, this study also analyses end use controls, on a market sub-segment basis. This instrument represents the classical "command and control" policy approach. Such controls are relatively easy to implement but they bear the risk of higher costs for industry compared to market based instruments and less flexibility to reach a certain emission reduction target. Also, unilateral enforcement of a ban often requires extensive efforts by public authorities to avoid fraud (e.g. smuggling of substances for banned uses).

3.6 HFC Emissions in a Regulated Market

In Appendix B we provide details of a range of control scenarios that can be envisaged for each of the market sub-segments. These have been chosen to represent the best technical opportunities for emission reduction. In this section we summarise the analysis given in Appendix B. A total of 90 control scenarios have been analysed for the 25 market sub-segments in Table 3.8

Some of the control scenarios proposed in Appendix B are described as "low impact". This means that in the emissions modelling we have made assumptions such as partial uptake of a zero GWP alternative fluid or a small improvement in leakage rates. Other scenarios are "high impact" which are based on assumptions such as significant uptake of a zero GWP alternative fluid or a large improvement in leakage rates. The assumptions are fully described in Appendix B.

The emission reduction potential is summarised in Table 3.9 for Direct HFC emissions. (Note, indirect emission reduction is discussed separately in Chapter 3.7). Table 3.9 both show 3 "composite" scenarios, built up from a selection of the 90 scenarios analysed in Appendix B. These are:

- **Scenario 1, Business-as-Usual.** This is the unregulated Business-as-Usual Scenario presented earlier in this chapter. It is the basis for comparing the emission reduction potential of the other 2 scenarios.

- **Scenario 2, Low Impact Measures.** This scenario represents the likely level of emissions if the low impact measures are undertaken.

- **Scenario 3, High Impact Measures.** This scenario represents the likely level of emissions if the high impact measures are undertaken.

From Table 3.9 it can be seen that the overall emission reduction potential, from the 2010 HFC Business-as-Usual Scenario is as follows:

- for Scenario 2, Low Impact measures there is an emission reduction potential of 41%, from 66.0 to 38.6 Mtonnes CO_2 equiv.

- for Scenario 3, High Impact measures there is an emission reduction potential of 66%, from 66.0 to 22.4 Mtonnes CO_2 equiv.

It is important to relate this potential for emission reduction with the level of HFC emissions in 1995 (which is the "base year" for Kyoto targets being used by most EU countries). 1995 EU HFC emissions are estimated to have been 40.7 Mtonnes CO_2 equiv. Hence with Low Impact measures a 5% emission reduction would be achieved, compared to this 1995 figure. This just falls short of the overall Kyoto reduction target for the EU of 8%. With High Impact measures the emission reduction is 45%, well in excess of the Kyoto target.

Table 3.9 Direct HFC Emissions Reduction Potential

(see Appendix B for detailed discussion of scenarios and assumptions)

Market Sub-Segment	2010 Direct HFC Emissions, Mtonnes CO_2 equiv.		
	Scenario 1, Business-as-Usual	**Scenario 2, Low Impact Measures**	**Scenario 3, High Impact Measures**
HFC 23 from R22 Manufacture	9.7	1.1	0.5
Supermarket refrigeration systems	9.0	5.7	3.5
Mobile air-conditioning	8.9	7.1	5.6
General Aerosols	7.0	3.9	2.0
Extruded polystyrene foam	6.9	4.0	1.0
Metered Dose Inhalers	4.8	3.4	2.4
Industrial refrigeration systems	3.3	2.3	1.2
Air-conditioning, distributed	2.6	1.9	1.3
Solvents	2.0	1.6	0.4
Small commercial distributed ref.	1.9	1.2	0.8
PU spray, injected and pipe-in-pipe	1.8	1.4	0.8
Polyurethane – discontinuous panel	1.1	0.6	0.2
PU, PIR and Phenolic – block foam	1.1	0.8	0.6
PU – flexibly-faced laminate foam	1.0	0.5	0.2
Domestic refrigeration	0.8	0.4	0.2
Refrigerated transport	0.7	0.6	0.4
Polyethylene foam	0.6	0.3	0.1
Air-conditioning chillers	0.7	0.4	0.2
HFC Manufacturing	0.5	0.4	0.3
Polyurethane – continuous panel	0.4	0.2	0.1
PIR/Phen. – flexibly-faced laminate	0.4	0.2	0.1
Other small hermetic refrigeration	0.3	0.2	0.1
PU - appliances	0.3	0.2	0.2
Fire Fighting	0.2	0.2	0.2
Polyurethane – integral skin foam	0.0	0.0	0.0
Totals	66.0	38.6	22.4

The data in Table 3.9 illustrates the extent of the technical potential to reduce HFC emissions. The costs of achieving these savings are discussed in Chapter 5.There is potential for emission reduction in most of the 25 market segments. It is interesting to note that policies to achieve maximum emission reduction by 2010 are not necessarily the same as policies to achieve the maximum long term emission reduction. This is because many of the longer term technical opportunities only achieve maximum benefit when the whole bank has been replaced. This can take many years in certain market sub-segments.

3.7 Indirect Global Warming Emissions

As already discussed, it is important not to consider HFC emissions in isolation from other global warming emissions. Energy related CO_2 emissions are an important part of the total global warming impact for certain market sub-segments. Table 3.5 shows the total global warming impact for refrigeration and air-conditioning market sub-segments. Domestic refrigeration moves up from being a relatively minor HFC emitter to being the largest overall emitter.

A number of the 90 emission reduction scenarios presented in Appendix B relate to energy efficiency improvements. In Table 3.10 we give a summary of the emission reduction potential for refrigeration and air-conditioning market sub-segments, taking both direct and indirect emissions into account. It can be seen that the overall emission reduction potential for Total Global Warming emissions is as follows:

- for Scenario 2, Low Impact measures there is an emission reduction of 17% from 172 to 143 Mtonnes CO_2 equiv.

- for Scenario 3, High Impact measures there is an emission reduction of 30% from 172 to 121 Mtonnes CO_2 equiv.

Table 3.10 Total Global Warming Emissions Reduction Potential

Refrigeration and Air-conditioning Market sub-segments

(Direct HFC emissions plus Indirect CO_2 Emissions)

Market Sub-Segment	2010 Total Global Warming Emissions, Mtonnes CO_2 equiv.		
	Scenario 1, Business-as-Usual	Scenario 2, Low Impact Measures	Scenario 3, High Impact Measures
Domestic refrigeration	30.8	25.9	21.2
Supermarket refrigeration systems	29.6	22.4	18.3
Industrial refrigeration systems	28.4	24.4	21.3
Mobile air-conditioning	26.9	22.4	18.2
Small commercial distributed ref.	13.9	12.1	10.8
Air-conditioning chillers	12.4	10.8	9.7
Other small hermetic refrigeration	12.3	10.7	9.1
Air-conditioning, distributed	11.2	9.1	7.8
Refrigerated transport	6.8	5.6	4.9
Totals	172.3	143.4	121.3

4. HFC AND HCFC MANUFACTURE

In this Chapter we review the manufacture of HFCs and HCFCs in the EU. Estimates of the current and future requirements for each HFC fluid are given. These figures are related to current and planned production capacity. HCFC 22 manufacture is also reviewed as it leads to a significant level of HFC emissions (HFC 23 is a by-product of HCFC 22 manufacture).

4.1 HFC Requirements

In Chapter 3 and Appendix A we have described the emissions modelling technique used to predict HFC emissions on a year by year basis for the 25 market sub-segments analysed. The model includes:

- assessments of the split between the HFCs used in each market sub-segment
- estimates of the annual quantities of HFCs used for the manufacture of products
- estimates of the annual quantities of HFCs used for the servicing of the bank.

From these figures we have been able to estimate the quantity of each of the HFCs that will be consumed within the EU on an annual basis. The results are summarised in Table 4.1 for the Business-as-Usual Scenario. Table 4.2 shows the assessments that have been made regarding the split of refrigerants used.

Table 4.1 EU HFC Consumption Forecasts, Business-as-Usual Scenario

HFC	Estimate of Annual EU Consumption, metric tonnes		
	1998	2005	2010
245fa/365mfc	0	38000	49000
134a	25000	37000	41000
125	3500	4500	4000
143a	2500	2500	2000
227	500	1500	1500
32	1000	2500	2000
152a	2000	2000	2000
23	20	10	10
Total	**34500**	**88000**	**101500**

Table 4.2 Split of HFC Usage in Market Sub-Segments

Market Sub-Segment	HFCs Used*
R1 Domestic Refrigeration	134a
R2 Other Small Hermetic Refrigeration Units	90% 134a, 5% 404a, 3% 407c, 2% 507
R3 Small Commercial Distributed Systems	60% 134a, 20% 404a, 15% 407c, 3% 413a, 2% 507
R4 Supermarket Distributed Systems	25% 134a, 50% 404a, 15% 407c, 5% 507, 5% 410a
R5 Industrial Systems	35% 134a, 20% 404a, 25% 407c, 10% 507, 10% 410a
R6 Air-conditioning Distributed Systems	25% 134a, 40% 407c, 35% 410a
R7 Air-conditioning Chillers	40% 134a, 40% 407c, 20% 410a
R8 Refrigerated Transport	30% 134a, 50% 404a, 10% 413a, 10% 507
R9 Mobile a/c	134a
F1 PU Appliances	245fa/365mfc
F2 PU Flexibly faced laminate	245fa/365mfc
F3 PU Discontinuous Panel	245fa/365mfc
F4 PU Continuous Panel	245fa/365mfc
F5 PU, PIR, Phenolic block	245fa/365mfc
F6 PIR, Phenolic flexibly faced laminate	245fa/365mfc
F7 PU Spray/injected/pipe-in-pipe	245fa/365mfc
F8 Extruded polystyrene (XPS)	90% 134a, 10% 152a
F9 Polyethylene Foam	134a
F10 Integral Skin Foam	245fa/365mfc
General Aerosols	90% 134a, 10% 152a
MDIs	75% 134a, 25% 227
Solvents	365mfc
Fire fighting	85% 227, 10% 134a,5% 23

* see Appendix C for the constituents of HFC blends 404a, 407c, 410a, 413a, 507

The data for HFCs 245fa and 365mfc have been aggregated as it is quite unclear at this time how much market share each of these fluids will take. Table 4.1 shows a clear dominance of HFCs 245fa/365mfc and HFC 134a. These will account for over 90% of EU consumption in 2010 under the Business-as-Usual Scenario. It is expected that HFCs 245fa/365mfc will be used almost exclusively for foam blowing. HFC 134a will be used in several markets including refrigeration, foam blowing, MDIs and general aerosols. HFCs 125, 143a and 32 are of importance to the refrigeration industry where they will be used as blend constituents. HFC 227 will be used mainly in MDIs and for fire fighting systems. HFC 152a is used in some aerosol and XPS applications and as an ingredient in a number of HCFC blends. HFC 23 will only be used for a small number of fire fighting applications and some specialist low temperature refrigeration.

It must be noted that the data in Table 4.1 is for the Business-as-Usual Scenario. Assuming that the EU and/or Member States take up some of the control measures described in this report it is evident that EU consumption will be lower than shown in the table. Table 3.9 shows emission reductions from the Business-as-Usual Scenario with low impact and high impact control measures. There is a 40% emission reduction with low impact measures and a 65% reduction with high impact measures. Although reductions in consumption and emissions are not necessarily equal, these figures give an indication of the possible reductions in forecast consumption that could occur by 2010.

4.2 HFC Production Capacity

The figures in Table 4.1 can be compared to current and projected EU production capacity to identify potential shortfalls in future supplies.

Currently there is no capacity anywhere in the world for producing commercial quantities of HFC 245fa or HFC 365mfc. Clearly the data in Table 4.1 shows that considerable quantities of these fluids are required in the EU under the Business-as-Usual Scenario. It will be very difficult for chemical companies to make investment decisions about these gases as there are numerous risk factors regarding the development of the HFC blown foam markets. One of those factors will be the EU response to the Kyoto Protocol. It will be very important that a rapid and clear response is made if chemical companies are to make investment decisions early enough to ensure that HCFC phase out deadlines can be met. It may be of commercial advantage to EU companies if these HFCs are produced in the EU. Uncertainty regarding response to the Kyoto Protocol could force investments to be made outside the EU.

Current HFC 134a capacity is in excess of 1998 requirements, but there is likely to be a shortfall by 2005. However the shortfall might not be significant and could be offset by emission reduction initiatives.

Current HFC 125 capacity is well below requirements and there is a need for imports, mainly from the US. There is a current excess of HFC 143a capacity, which should be sufficient to meet future EU demands, but may not provide any scope for exports. Most HFC 227 is imported from the US.

HFC 32 capacity is well below requirements. Our modelling shows a relatively modest requirement for HFC 32 in 2005 (Business-as-Usual Scenario, 2500 tonnes). It is interesting to note that this is significantly lower than some industry forecasts. The Business-as-Usual Scenario assumes significant improvements in leakage levels together with some market penetration from HCs and ammonia in traditional HCFC 22 markets.

4.3 HCFC 22 Manufacture

During the production of HCFC 22 there is an emission of HFC 23 as a by-product. Between 3 and 5% of HCFC 22 output is produced as HFC 23.

Historically, the majority of HFC 23 emissions were vented to atmosphere. There was a small requirement for HFC 23 as a feedstock in halon manufacture and for use as a refrigerant in specialised applications. Hence, some manufacturers have always recovered the HFC 23 stream for these purposes. However, for many manufacturers there was no cost effective requirement for HFC 23 and the by-product was vented.

HFC 23 is a particularly powerful global warming gas with a GWP of 12100. During the last few years HCFC 22 producers have become increasingly aware of the impact of HFC 23 by product emissions and some have taken steps to capture and destroy the HFC 23 stream.

In the period 1990 to 1995 the emission of HFC 23 from HCFC 22 manufacturing plants dominated the total EU emissions of HFCs. In 1990 it presented 100% of HFC emissions. By 1995 this had fallen to 85% of emissions, partly due to emission reduction initiatives by HCFC 22 producers and also because of the increasing market size for HFCs in other applications. The 2010 Business-as-Usual Scenario shows HFC 23 emissions to be the largest single emission market sub-segment, representing 15% of total HFC emissions.

These relatively high levels of emissions in 1990 and 1995, the base years for the Kyoto Protocol, will actually help the EU achieve their overall emission reduction target. They provide a "starting point" well above a zero emission level, even though end use markets were using little or no HFCs.

Currently there are three distinct markets, which are:

- the EU "consumption" market, mainly for refrigeration, foams and solvents
- export markets for similar products
- the "feedstock" market, where HCFC 22 is used as a raw material for fluoropolymer production.

The EU consumption and export markets are subject to restrictions in EU regulations related to ozone depleting substances. Assuming that the 1998 draft proposals for a new regulation on ozone depleting substances come into force, there will be a substantial cut in the EU consumption market by 2010 and some reduction in exports. The feedstock market is outside the scope of both the Montreal Protocol and EU regulations. The fluoropolymer market is currently growing at a fairly significant rate hence the requirement for HCFC 22 as a feedstock will grow during the next few years. These changes in the structure of the HCFC 22 market have been taken into account in our emissions modelling. We estimate a peak market of around 180 to 190 ktonnes in the period 1999 to 2002, falling to around 130 ktonnes in 2010 and 100 ktonnes in 2020.

There is excellent potential to reduce the emission of HFC 23 from HCFC 22 plants. It is possible to capture the gas stream and pass it to an incinerator facility in which up to 99% of the emission can be destroyed. There are a total of 11 HCFC 22 manufacturing plants in Europe. It is believed that 6 plants will have some level of HFC recovery by around 2000, although it is unlikely that the average recovery rate is as high as 99%. We are not aware of any current plans to add recovery equipment to the other 5 plants.

5. ECONOMIC IMPLICATIONS OF CONTROL SCENARIOS

The purpose of this Chapter is to establish the most cost effective options for reducing the total impact of HFC usage on global warming. It is clear from the analysis in Chapter 3 and Appendix B that there is good technical potential to reduce levels of emissions from the Business-as-Usual Scenario. However, this technical potential does not take into account the costs of achieving savings. It is important to compare the cost effectiveness of each measure if a logical and acceptable emissions reduction strategy is to be proposed.

It is vital that the costs involved are compared between the 25 HFC using market sub-segments to ensure that the lowest cost opportunities are selected. It is equally important to compare the costs of achieving HFC emission reductions with the costs of reducing emissions of other global warming gases. The Kyoto Protocol is based on a "basket" approach where it is necessary for countries to reduce their overall global warming impact. The most cost effective opportunities should be targeted first, irrespective of which gases are involved.

5.1 Methodology for Assessment of Cost Effectiveness

In order to make economic comparisons we have defined a parameter called "Cost Effectiveness" that represents the cost of achieving emissions reductions. The units of Cost Effectiveness are ECU per tonne CO_2 equivalent. The precise definition of Cost Effectiveness used in this study is:

- the incremental net costs required to achieve emission reductions from the Business-as-Usual Scenario divided by the total emissions reductions achieved.

The selection of an appropriate "time window" for the cost and emissions calculations is crucial. We believe that the best approach is to consider cumulative costs and cumulative emissions in the period 2000 – 2012. This would ensure that all investments made from the start of a co-ordinated EU emissions reduction policy (assumed to be 1/1/2000) until the end of the Kyoto Protocol commitment period are included in the assessment. It is not appropriate to base Cost Effectiveness on emissions in a single year (e.g. 2010) as this gives no recognition of the environmental benefits of early investments.

It is appropriate to apply a "discount factor" to investments made after 2000. This is in accordance with normal accounting practices. It also gives recognition to the fact that investments made late in the time window will only contribute a relatively small cumulative emission reduction. A discount rate of 8% has been used.

To gain information on costs and savings for each control scenario, contact has been made with trade associations, manufacturers, end-users and research associations in each market sector. The following general assumptions have been made to allow a comparison of alternative options for reducing HFC emissions.

Emissions Calculations

1. The emissions reductions used are those achieved throughout the entire period 2000 to 2012.

2. Emissions reductions take into account direct HFC emissions and indirect CO_2 emissions as appropriate.

Cost Calculations

There are 3 components to the costs incurred in reducing HFC emissions. These are:

3. **"One-off" development and capital investment costs.** This includes the extra development funding required to bring the solution to market. It also includes capital investments to install new equipment or to modify a production facility.

4. **"On-going" product manufacturing costs.** These will occur when an alternative product is more expensive to produce than the original.

5. **On-going product usage costs or savings.** The additional costs incurred by the end user in using an alternative technology. In many cases this element may be a saving e.g. reduced refrigerant leakage requires less top up fluid; improved energy efficiency reduces energy purchases.

6. All costs are taken before tax since it is reasoned that any tax saving or burden will be shared across the EU.

7. All capital investment costs are discounted at a rate of 8% from a base year of 2000.

8. In some of the scenarios proposed the cumulative emission reduction in the period 2000 – 2012 are negative. This implies that the control scenario gives higher emissions than the Business-as-Usual Scenario. In this situation we define the Cost Effectiveness as "none".

9. In some of the scenarios proposed the net costs are negative. This implies that the end user savings in the 12 year time window exceed the development and manufacturing costs. In this situation the Cost Effectiveness is also negative.

5.2 Results of Cost Effectiveness Calculations

Details of the assumptions and data used in each market sub-segment are included in Appendix B. In this Chapter we summarise the results and provide a commentary on the key findings.

Table 5.1 gives Cost Effectiveness data for the most important market sub-segments. The codes used for each measure correspond to codes used in Appendix B. Low impact measures are referred to as "LI" and high impact measures as "HI".

Table 5.1 Cost Effectiveness of HFC Emission Reduction Control Scenarios

Market Sub-Segment/ Control Scenario (note: LI = low impact, HI = high impact)	Emission Reduction, Mtonnes CO_2 equiv.		Cost Effectiveness
	2010	2000 - 2012	ECU/tonne CO_2
HFC 23 from HCFC 22 Manufacture			
HFC23/1. LI Product Manufacturing Emission	-8.6	-83	1
HFC23/2. HI Product Manufacturing Emission	-9.2	-114	2
Supermarket Refrigeration			
R4/1. LI Alternative fluids + leakage reduction	-3.2	-53	7
R4/2. HI Alternative fluids + leakage reduction	-5.2	-66	9
R4/3. LI Energy efficiency improvements	-2.0	-18	-77
R4/4. HI Energy efficiency improvements	-4.0	-39	-77
Mobile Air-conditioning			
R9/1. Alternative fluid from 2007	-1.6	-8.6	122
R9/2. Alternative fluid from 2004	+2.2	+37.2	none
R9/3. LI Leakage reduction	-1.7	-17.6	14
R9/4. HI Leakage reduction	-3.3	-34.0	15
R9/5. LI Energy efficiency improvements	-0.5	-5.2	-140
R9/6. HI Energy efficiency improvements	-1.1	-9.6	-111
General Aerosols			
GA/1. LI Alternative fluids + NIK technologies	-3.1	-22.3	16
GA/2. HI Alternative fluids + NIK technologies	-5.0	-44.6	29
Extruded Polystyrene			
F8/1. LI Alternative fluids + NIK insulants	-2.9	-18.8	11
F8/2. HI Alternative fluids + NIK insulants	-5.9	-37.4	10
F8/3. LI Product manufacturing emission reductions	-1.3	-10.2	5
F8/4. HI Product manufacturing emission reductions	-2.8	-19.9	5

Table 5.1 Continued from Previous Page

Market Sub-Segment/ Control Scenario (note: LI = low impact, HI = high impact)	Emission Reduction, Mtonnes CO_2 equiv.		Cost Effectiveness
	2010	2000 - 2012	ECU/tonne CO_2
Metered Dose Inhalers			
MDI/1. LI NIK technologies	-1.4	-13.7	109
MDI/2. HI NIK technologies	-2.4	-23.4	115
Industrial Refrigeration			
R5/1. LI Alternative fluids + leakage reduction	-1.1	-8.4	23
R5/2. HI Alternative fluids + leakage reduction	-2.2	-13.9	31
R5/3. LI Energy efficiency improvements	-2.0	-7.0	-43
R5/4. HI Energy efficiency improvements	-5.0	-39	-77
Air-conditioning, Distributed DX			
R6/1. LI Alternative fluids + leakage reduction	-0.7	-4.1	26
R6/2. HI Alternative fluids + leakage reduction	-1.3	-7.5	23
R6/3. LI Energy efficiency improvements	-1.0	-7.0	-70
R6/4. HI Energy efficiency improvements	-2.0	-14.0	-79
Solvents			
S/1. LI Alt. fluids + NIK technologies + leak red.	-0.4	-4.0	37
S/2. HI Alt. fluids + NIK technologies + leak red.	-1.6	-15.7	78
Small Commercial Refrigeration			
R3/1. LI Alternative fluids + leakage reduction	-0.7	-4.8	18
R3/2. HI Alternative fluids + leakage reduction	-1.1	-7.4	19
R3/3. LI Energy efficiency improvements	-1.0	-8.0	-94
R3/4. HI Energy efficiency improvements	-2.0	-20.0	-85

Table 5.1 Continued from Previous Page

Market Sub-Segment/ Control Scenario (note: LI = low impact, HI = high impact)	Emission Reduction, Mtonnes CO_2 equiv.		Cost Effectiveness ECU/tonne CO_2
	2010	2000 - 2012	
Domestic Refrigeration			
R1/1. LI Alternative fluids	-0.1	-1.1	190
R1/2. HI Alternative fluids	-0.2	-1.7	400
R1/3. LI Alt. fluids + disposal emission reduction	-0.4	-3.0	95
R1/4. HI Alt. fluids + disposal emission reduction	-0.6	-4.6	170
R1/5. LI Energy efficiency improvements	-5.0	-22.0	-109
R1/6. HI Energy efficiency improvements	-10.0	-50.0	-117

Table 5.1 gives a clear indication about which measures are likely to prove the most cost effective. The actual figures quoted for Cost Effectiveness should be treated as "order of magnitude estimates".

The control measures fall into 4 main groups, in terms of Cost Effectiveness:

- some measures can be considered **"low cost"**, with a Cost Effectiveness between 0 and 10 ECU/tonne CO_2 equiv. These should clearly be given the highest priority in a direct emission reduction strategy.
- some measures can be considered **"medium cost"**, with a Cost Effectiveness between 10 and 50 ECU/tonne CO_2 equiv. These measures may also prove important if the highest possible impact is to be achieved.
- the remaining options can be considered **"high cost"**, with a Cost Effectiveness between 50 and 400 ECU/tonne CO_2 equiv. It is unlikely that these options are worth including in an emissions reduction strategy.
- some measures have a **negative Cost Effectiveness**. This means that the on-going savings for the user are greater than the costs and there is a beneficial return on the investments made. All such measures relate to improved energy efficiency and savings of indirect CO_2 emissions. None of the direct HFC emission reduction scenarios has benefits that exceed the costs. This shows that if the EU is to adopt the most economically beneficial options that all opportunities to reduce global warming emissions should be compared on an equal basis. It is worth noting that in some situations the "beneficiary" of energy cost savings is not the organisation

responsible for the initial investment (e.g. a building developer invests in insulation but it is the building user that pays for the energy). In these circumstances it is common to find inefficient systems being installed. Control mechanisms must take this into account.

The dividing lines between low and medium cost (10 ECU/tonne CO_2 equiv.) and between medium and high cost (50 ECU/tonne CO_2 equiv.) are quite arbitrary. They can only be properly judged if the Cost Effectiveness of HFC emission reduction options are compared to similar data for the other 5 global warming gases covered by the Kyoto Protocol.

A review of the detailed emission reduction and costs data in Appendix B gives some interesting and sometimes surprising insights into the advantages and disadvantages of emission reduction opportunities. In the following sections of this Chapter we summarise some of the key issues. Market segments are dealt with in the same order as that in the emissions league table (Table 3.8). As well as discussing Cost Effectiveness we also make comments on the most appropriate control mechanisms for each market segment.

5.3 Market Segment Discussion

5.3.1 HFC 23 from HCFC 22 Manufacture

Modelling of future HCFC 22 production is based on the assumption that the proposed revisions to the EU Regulations on ozone depleting substances (EC 3093/94) are implemented.

Historical emissions rates from this sector were in the range 3 to 5% of HCFC 22 output if no attempts were made to recover the HFC 23 by-product. Recovery/incineration equipment can be installed which can capture virtually all these emissions, reducing the overall emissions rate by up to 99%. The majority of HCFC 22 plants in the EU will have recovery equipment in place by 2010 under the Business-as-Usual Scenario. However, there are about 5 plants for which there are no current plans for installation of good recovery systems.

There are no development costs as the technology already exists, but there are significant installation and running costs. There are also small quantities of extra indirect emissions due to increased energy use, although these are very small in comparison to HFC emissions saved. It takes around 2 years to fully install and commission the equipment.

From Table 5.1 and Table B4 we can see that the Cost Effectiveness is very good, being between 1 and 2 ECU/tonne CO_2 equiv. This is easily the most cost effective measure out of all the direct HFC emission reduction scenarios analysed. As well as having good Cost Effectiveness, the best of the scenarios (HFC 23/2, high impact emission reduction) also has the potential to make the largest single contribution to emission reduction of all the measures analysed in this study. The emission reduction in

2010 would be 9.2 Mtonnes CO_2 equiv., which is 14% of the Business-as-Usual Scenario HFC direct emissions total of 66.0 Mtonnes CO_2 equiv.

Table B4 compares a low impact and high impact scenario. The Cost Effectiveness for the high impact scenario is very low, hence it is recommended that this scenario be selected. This is based on recovery system collects and destroys 99% of the HFC 23 produced. The low impact scenario was based on a 97.5% recovery rate.

To maximise the emission reduction potential all HCFC 22 plants should achieve a minimum level of recovery (i.e. 99%). This means that some existing recovery systems may need to be upgraded.

Given the small number of companies involved (there are 7 EU HCFC 22 producers) this measure could be progressed by voluntary agreement. All the producers have significant interests in the future of HFCs. It should be noted that the cost data in Table B4 assumes that all existing HCFC 22 plants will be retrofitted with recovery systems. Given the substantial drop in HFCF 22 production likely because of new EU ozone regulations (a 30% fall from 1999 levels by 2010), it is possible that some plants will close. HFC emission rates might be used as one of the criteria when deciding which plants to close.

5.3.2 Supermarket Refrigeration Systems

Tables 5.1 and B8 show there is good potential to achieve low cost emission reductions in the supermarket sector. Under the Business-as-Usual Scenario we recognise that supermarkets will be adopting a range of technologies to reduce historical levels of refrigerant emissions. These include refrigerant charge reduction and refrigerant leakage reduction through improved system design and maintenance, together with some use of ammonia and HCs in place of HFCs. Scenarios R4/1 and R4/2 extend this Business-as-Usual Scenario policy to higher levels of leak prevention and greater market penetration from alternatives fluids. The low impact scenario achieves a 2010 emission reduction of 3.2 Mtonnes CO_2 equiv. with a Cost Effectiveness of 7 ECU/tonne CO_2 equiv. The high impact scenario achieves a 2010 emission reduction of 5.2 Mtonnes CO_2 equiv. with a Cost Effectiveness of 9 ECU/tonne CO_2 equiv.

There are also significant energy efficiency opportunities where the savings should outweigh the costs.

Supermarkets have the potential to be the second largest HFC emitter in 2010 and both the low and high impact control scenarios have good Cost Effectiveness. There are a relatively small number of major supermarket companies within the EU (the 100 largest probably represent over 80% of turnover) so a voluntary agreement methodology is worth considering first. Alternatively a fiscal measure could be used to encourage better leakage prevention technology or more use of alternative fluids.

5.3.3 Mobile Air Conditioning

Our interviews with the car industry indicated that manufacturers are treating the Kyoto Protocol very seriously. They expect to be continually in the spotlight over the next decade as cars are responsible for a large proportion of greenhouse gas emissions. Hence we expect that the Business-as-Usual Scenario will result in a dramatic improvement in the performance of mobile air-conditioning systems both in terms of leakage rates and energy efficiency. Savings in other control scenarios must be viewed in the knowledge that the Business-as-Usual Scenario is likely to achieve a significant proportion of the savings realistically attainable.

The scenarios presented in Appendix B.3 give interesting and slightly surprising results. We have analysed 2 scenarios in which CO_2 refrigerant replaces HFCs in all new vehicles. In the first scenario the industry is allowed to develop the new CO_2 systems at a "normal" rate and only introduce the technology when it performs better than HFC systems in terms of total global warming emissions. This has been assumed to be in 2007. A key aspect of this scenario is that we expect car manufacturers to continue making investments in the refinement of HFC systems, both in terms of leakage reduction and energy efficiency. The total investment required is quite high and the net savings are relatively modest because the energy efficiency of the CO_2 system will be lower than the best HFC systems in the time window up to 2012. The Cost Effectiveness of this first scenario is 122 ECU/tonne CO_2 equiv., which is not very attractive.

In the second CO_2 scenario we postulate regulations that push the car industry to stop using HFCs by 2004. If such legislation were imposed we have assumed that the industry would not make further investments to refine their HFC designs. Also it is likely that CO_2 technology would have to be introduced before good levels of energy efficiency are achieved. In these circumstances our modelling shows that higher levels of global warming emissions would be achieved in the period 2000 – 2012 than under the Business-as-Usual Scenario. This example clearly shows the potential dangers of pushing technologies too fast.

By far the most cost effective scenarios for direct HFC emission reduction from the mobile air-conditioning segment relate to faster improvements in system leakage rates and product disposal losses. We postulate extra investments being made to achieve the Business-as-Usual Scenario improvements in leakage more quickly. The low and high impact scenarios both had a Cost Effectiveness of around 15 ECU/tonne CO_2 equiv. The high impact scenario gives savings of 3.3 Mtonnes CO_2 equiv. in 2010.

There are also significant energy efficiency opportunities where the savings should outweigh the costs.

Once again the small number of manufacturers in this market segment makes voluntary agreements an attractive control mechanism. Alternatively, emission regulations can be considered. Fiscal measures are unlikely to be effective unless they were introduced at a very high level of taxation.

5.3.4 General Aerosols

The vast majority of the aerosol market has moved from CFC propellants to HCs. Although HCs are flammable they have proved feasible alternatives in a wide range of markets including most personal care and domestic products. The low cost of HCs has been an important factor in encouraging manufacturers to develop technical solutions that suit these mass markets.

The only markets in which manufacturers have moved from CFCs to HFCs are those where flammability is considered to be of particular importance. There are four major applications where these concerns currently result in significant usage of alternatives:

- Freezing sprays for electronics testing
- Freezing sprays for pipework isolation
- Air dusters (usually used on electronic products such as computers)
- Leisure products such as silly string, artificial snow etc.

We have received somewhat inconsistent views about the potential for these aerosol markets to use alternative propellants or NIK technologies. It is the opinion of some industry experts that non-HFC technical solutions exist for most applications. Other experts have indicated much more limited potential to reduce reliance on HFCs. The costs of some NIK solutions could be very high as they will incur many "hidden" costs:

- The use of HFC propelled freezer sprays for industrial plumbing avoids costly drain downs of systems or installation of many more shut off valves.
- HFC air dusters are widely used in cleaning "live" computers - some computers cannot be shut down - and a back up would therefore be required.
- Currently, the only alternative to HFCs for certain leisure products such as silly string is to ban production which would kill a profitable industry.

The potential to use alternative technologies and propellants in these markets is not totally clear. Given the relative importance of the market segment in terms of HFC emissions (it represents 11% of 2010 Business-as-Usual Scenario emissions) it may be necessary to carry out further more detailed research. We have analysed 2 scenarios in which 40% or 70% of HFC usage is replaced with alternative fluids such as compressed gas or by NIK delivery systems. These achieve 2010 emission reductions of 3.1 and 5 Mtonnes CO_2 equiv. respectively. The Cost Effectiveness of the low impact scenario is 16 ECU/tonne CO_2 equiv. whilst the high impact scenario only achieves 29 ECU/tonne CO_2 equiv.

These opportunities are not as cost effective as some of the best ones discussed above, but they still achieve a good level of emission reduction at the lower end of the "medium cost band". They are worthy of further consideration. A fiscal measure could help push some manufacturers towards alternative options, whilst allowing those in critical areas to continue using HFCs.

5.3.5 Extruded Polystyrene

The various foam market segments are probably the most difficult to analyse from a global warming perspective because of the crucial interaction between direct and indirect global warming and the sensitivity to application specific parameters such as annual running hours, energy source and dimensional constraints. These issues are discussed in more detail in Section 2.2.5 and Appendix D.

In the Business-as-Usual Scenario, the XPS market sub-segment has significantly higher global warming emissions than other foam types. Table 3.6 shows that XPS might represent 51% of foam related HFC emissions. This stresses the importance of addressing this market sub-segment. An important reason for this high level of emission is the emissive nature of the manufacturing process. In the Business-as-Usual Scenario we have assumed a 25% product manufacturing emission in 2010, which is a significant improvement on the current average of about 33%.

To simplify the cost analysis for XPS we have split the market into 2 parts:

- for about 85% of the market for new XPS there are no particular thickness constraints. Hence we have compared HFC and CO_2 blown XPS at a constant level of indirect emission. This implies that CO_2 blown XPS will be thicker, and hence more expensive, than HFC blown XPS. With this analysis technique it is possible to identify the cost of making direct HFC emission reductions, knowing that indirect emissions are unaffected.

- 15% of the XPS market is for refrigerated trucks. These have severe space constraints and it is not appropriate to analyse increased thickness for the CO_2 alternative. Hence we have compared the direct savings with the extra indirect emissions.

The control scenarios described in Appendix B.5 are based on use of alternative fluids and NIK insulants or on reduced manufacturing emissions:

- **Alternative fluids.** The low impact scenario for alternative fluids/NIK insulants assumes 50% of HFC blown XPS is replaced by alternatives by 2007. The high impact scenario assumes no HFC blown XPS is produced after 2007. These control scenarios give 2010 emission reductions of 2.9 and 5.9 Mtonnes CO_2 equiv. respectively. The Cost Effectiveness for both these scenarios is close to 10 ECU/tonne CO_2 equiv. It should be noted, however, that based on currently available technology the high impact scenario may be impossible to achieve; it is understood that not all XPS products can be manufactured using CO_2.

- **Emission Reduction.** The low impact scenario for reduced product manufacturing emissions assumes the emission rate falls from 25% to 20%, whilst the high impact scenario achieves 15%. These control scenarios give 2010 emission reductions of 1.3 and 2.8 Mtonnes CO_2 equiv. respectively. The Cost Effectiveness for both these scenarios is close to 5 ECU/tonne CO_2 equiv.

A detailed analysis of the direct and indirect emissions from constant thickness HFC or CO_2 blown XPS for refrigerated trucks shows that the total global warming emissions are lower with CO_2 blown foam at utilisation rates below 5000 hours/year.

In summary the analysis shows that there is cost effective potential to reduce overall global warming emissions in the XPS markets by using CO_2 blown XPS or other NIK insulants. This might be best achieved through a voluntary agreement as there are very few XPS producers in the EU (2 large companies and a few smaller ones).

However, it should be stressed that the analysis described above simplifies a highly complex situation. Further research work may be necessary to identify the best options.

5.3.6 Metered Dose Inhalers

MDIs are still being manufactured using CFC propellants under essential use exemptions within the Montreal Protocol and EU Regulations on Ozone Depleting Substances. From the perspective of ozone depletion it is essential that non-CFC alternatives are adopted as soon as possible as the current rate of MDI related CFC emissions from the EU is highly significant. The main alternatives are HFC propelled MDIs, DPIs (dry powder inhalers), nebulisers and oral treatments (e.g. tablets). The pharmaceutical industry indicates that HFC MDIs are by far the most suitable short term alternative on the grounds of both medical effectiveness and cost. HFC MDIs have the potential to achieve the most rapid reduction in CFC usage of all the possible alternatives.

Whilst HFC MDIs are leading the way in most EU countries there are some countries who are trying to limit the use of HFCs by promoting DPIs. In Sweden DPIs hold a substantial market share. However, because of a very significant cost penalty this is only being achieved with Government intervention.

There are a very small number of drug companies manufacturing metered dose inhalers and therefore specific information cannot be given without breaching confidentiality. There appears to be a consensus on the following points:

- Any new propellant requires at least 10 years of medical trials before it can be generally released. It is therefore unlikely that a new MDI propellant will emerge by 2012.

- DPIs are inherently more complicated and hence more expensive than MDIs - they are currently four times more expensive but this should drop by half when volumes rise. Nevertheless, all the major manufacturers expect to have DPIs available within the next four years.

- There is no expectation that tablet treatments will significantly reduce the market volume for inhaled treatments due to the expected growth in the overall market.

On the basis that DPIs could achieve some success as MDI alternatives we have proposed 2 control scenarios where DPIs achieve significant market penetration. In the low impact scenario a 30% market penetration is achieved by 2006 and in the high impact scenario a 50% market penetration is achieved earlier, by 2004. The 2010 emission reduction potential is between 1.4 and 2.4 Mtonnes CO_2 equiv. The Cost Effectiveness of both scenarios is quite poor at around 110 ECU/tonne CO_2 equiv. because of the high unit cost of DPIs compared to MDIs.

Because of the high costs involved it would only be possible to move from MDIs to DPIs with strong intervention. Patients or Member State Health Services would have to pay substantially more for their treatments unless some form of Government subsidy is provided. Hence voluntary agreements are unlikely to be effective. A fiscal measure that brought MDI and DPI costs in line might be the most effective control mechanism.

It is important that the impact on CFC phase out is taken into account when setting a strategy for MDIs. Doctors and patients often hesitate to move between CFC and HFC MDIs because they are risk averse and conservative. This is not altogether surprising, as there is a significant health risk for asthma sufferers if they get their medication wrong. Patients could perceive a move from MDIs to DPIs as even more risky. Hence regulations to limit use of HFC MDIs could slow the move away from CFCs.

Bearing in mind the high costs and possible impact on CFCs, policies in this segment need very careful consideration and further research.

5.3.7 Industrial Refrigeration Systems

Industrial refrigeration users appear relatively slow to respond to environmental issues compared to some other user sectors such as supermarkets. This is illustrated by the relatively high current use of HCFCs in new industrial systems, even though users are usually aware of HCFC phase out plans. Hence the Business-as-Usual Scenario does not assume as much change in current practices as the Business-as-Usual Scenario for supermarkets. However, we still allow for some refrigerant charge reduction and refrigerant leakage reduction through improved system design and maintenance, together with a growing use of ammonia in place of HFCs. Scenarios R5/1 and R5/2 (see Table B28) extend this Business-as-Usual Scenario policy to higher levels of leak prevention and greater ammonia market penetration. The low impact scenario achieves a 2010 emission reduction of 1.1 Mtonnes CO_2 equiv. with a Cost Effectiveness of 23 ECU/tonne CO_2 equiv. The high impact scenario achieves a 2010 emission reduction of 2.2 Mtonnes CO_2 equiv. with a Cost Effectiveness of 31 ECU/tonne CO_2 equiv.

There are also significant energy efficiency opportunities where the savings should outweigh the costs.

Industrial refrigeration is a difficult market segment to influence because of the large number of independent sites owning equipment and because of the wide variety of different applications. The first of these issues makes it difficult to target the key "influencers" whilst the second issue makes it difficult to benchmark a particular system in terms of emissions and efficiency. The most effective control mechanism for industrial refrigeration might be end user emission regulation, covering both direct and indirect emissions.

5.3.8 Solvents

Currently there is no use of HFCs for solvent applications as no suitable HFC is available. One or more of the new "liquid HFCs" being developed for the foam blowing market is expected to have good solvent properties (e.g. HFC 365mfc). These new

HFC solvents are likely to be strong contenders for the market currently served by HCFC 141b. Assuming that the current proposals for a new EU Regulation on Ozone Depleting Substances becomes law, HCFCs will be phased out of solvent applications from 1/1/2003, except for certain aerospace industry requirements.

Under the Business-as-Usual Scenario we have assumed that only 40% of current HCFC users move to HFC solvents. With further investment there is potential to reduce this HFC usage further. This will be achieved mainly by encouraging users to move from HCFCs to other alternatives such as organic solvents or aqueous systems. There is also some further potential to improve product life emissions from HFC systems. A low impact scenario assumes a 20% reduction in HFC use from the Business-as-Usual Scenario, whilst a high impact scenario is based on a 75% reduction. The emission reductions achieved in 2010 are 0.4 and 1.6 Mtonnes CO_2 equiv. respectively. The Cost Effectiveness is 37 ECU/tonne CO_2 equiv. for the low impact scenario and 78 ECU/tonne CO_2 equiv. for high impact.

5.3.9 Small Commercial Distributed Refrigeration

This market sub-segment includes a wide range of small sized refrigeration equipment used in locations where untrained staff and members of the public may enter. Typical applications include pub cellar coolers, small cold stores in retail shops and milk cooling equipment on farms. This category of equipment is described as "distributed". Components in the refrigeration plant such as evaporators and condensers are in separate locations; refrigerant is distributed around the system in pipes that are fabricated on site during installation. This is different from "small hermetic systems" which are completely built in the factory. Distributed systems are intrinsically more prone to leakage than factory built systems. For this reason use of a non-flammable refrigerant is usually the preferred option. This limits the extent to which HC refrigerants can penetrate this market.

The Business-as-Usual Scenario assumes a 30% market penetration by HCs in 2010. It also assumes a leakage reduction from 15% in 1998 to 10% in 2010 and a 15% energy efficiency improvement.

Scenarios R3/1 and R3/2 (see Table B36) extend this Business-as-Usual Scenario policy to higher levels of leak prevention and greater HC market penetration. The low impact scenario achieves a 2010 emission reduction of 0.7 Mtonnes CO_2 equiv. with a Cost Effectiveness of 18 ECU/tonne CO_2 equiv. The high impact scenario achieves a 2010 emission reduction of 1.1 Mtonnes CO_2 equiv. with a Cost Effectiveness of 19 ECU/tonne CO_2 equiv.

There are also significant energy efficiency opportunities where the savings should outweigh the costs.

As with industrial refrigeration there are a large number of independent end users, hence voluntary agreements would have limited potential (although could be possible with owners of large chains such as pubs and restaurants. To achiever wider impact fiscal measures may be the most effective control, to encourage leakage prevention and increase the opportunities for HCs.

5.3.10 Polyurethane Insulation

There are a number of market sub-segments that produce different types of PU foam. The most important of these from an emissions perspective are spray/injected foam, flexibly faced laminate and discontinuous/continuous rigid faced panels. Under the Business-as-Usual Scenario the 2010 emissions for these 4 market sub-segments total 4.3 Mtonnes CO_2 equiv. which is about 30% of all foam related emissions.

The technical opportunities for reducing emissions include use of HC blowing agents, use of NIK insulants or reductions in product manufacturing and product life losses. As with XPS insulation, the analysis of global warming impact is highly complex and is very application specific. HC blown foam has the disadvantage of a lower insulation capability compared to HFC blown foam, hence it is important to balance the direct emission savings with any increase in indirect emissions.

We have used a similar analytical approach to XPS foam: where thickness is unconstrained we have estimated the extra thickness of HC blown foam to provide equal indirect emissions for a given thickness of HFC blown foam. In this way we can relate the direct emission reductions to the costs of the thicker foam.

It is important to point out a significant distinction between the use of alternative fluids in the XPS and PU markets. The key HFC alternative in the XPS market is CO_2. The primary disadvantage of using CO_2 in place of HFCs is a reduction in insulation value. Changes to other foam properties can be considered as secondary. For PU foam the key alternatives are HCs (usually pentane or cyclo-pentane). These are highly flammable fluids that, if used inappropriately, impose fire risks on both foam producers and foam users. Hence, there are 2 primary disadvantages of HC blown foam i.e. reduced insulation value and increased fire risk. It is worth noting that there are a few cases reported in which foam blowing plants using HCs have burned down. Hence any policy measures related to PU foam must take these flammability issues into account.

The analysis for flexibly faced PU laminate and discontinuous PU panels gives broadly similar results. In both market sub-segments the Business-as-Usual Scenario emissions are 1.0 Mtonnes CO_2 equiv. in 2010. This level of emissions can be reduced in 2 distinct ways:

- HFC blown foam can be substituted by HC blown foam and NIK insulants. Emission reduction potential in 2010 for each market is between 0.5 and 1 Mtonnes CO_2 equiv. for the low and high impact scenarios (50% and 100% substitution respectively). The Cost Effectiveness in all cases is around 60 ECU/tonne CO_2 equiv. This is a relatively high figure that makes these scenarios quite unattractive.

- Another option is to continue using HFCs and to concentrate on reducing product manufacturing and product life emissions. Emission reduction potential in 2010 for each market is between 0.2 and 0.4 Mtonnes CO_2 equiv. for low and high impact scenarios. The Cost Effectiveness ranges between 20 and 30 ECU/tonne CO_2 equiv., making this approach more financially attractive.

In the continuous PU panel market sub-segment the saving potential in moving to HCs is less than half of the above figures and the Cost Effectiveness is around 110 ECU/tonne CO_2 equiv. The Cost Effectiveness of reduced manufacturing and life emissions is 50ECU/tonne CO_2 equiv. These high costs are due to the relatively low levels of emission already being achieved.

For PU spray and injected foam the high flammability of HCs makes it hard to use these alternatives at all. NIK alternatives such as blown fibre can be considered in a limited range of applications, but there is no current technology available to replace the majority of this type of PU.

PU is also used in domestic appliances and for block foam. HFC consumption and emissions are quite low in both market sub-segments. Domestic refrigerators are often space constrained, hence maximising insulation value is important, particularly as most refrigerators suffer heat losses continuously all year. Refrigerator efficiency is discussed in more detail in Section 5.3.12.

5.3.11 Other Foam

The other foam sub-segments not discussed in the above sections include PIR and phenolic foam laminate/block foam, polyethylene foam and integral skin foam.

PIR foams and phenolic foams are more expensive than PU equivalents and are sold on the basis of improved fire resistance. Use of HCs as alternative blowing agents compromises this fire resistance, hence this is not a viable alternative for these markets. Currently there are no other technologies available that offer the combination of properties offered by PIR and phenolic foam. The main emission reduction opportunity for these market sub-segments is product manufacturing and life emission reductions. The Cost Effectiveness of such emission reductions is around 25 ECU/tonne CO_2 equiv. for laminate foams.

Polyethylene foam can be made with HCs. The Cost Effectiveness is very good because of the reduction in blowing agent costs – there should be a net saving through the adoption of this alternative. Whilst some manufacturers have already done this, others are reluctant to make the transition because of the fire risks.

All integral skin foam is expected to use non-HFC alternatives under the Business-as-Usual Scenario.

5.3.12 Domestic Refrigeration

Domestic refrigerators are an interesting market sub-segment because they illustrate the danger of making investments in an illogical and often uneconomic way. Table B42 shows that under the Business-as-Usual Scenario direct HFC emissions from domestic refrigerators will be 0.8 Mtonnes CO_2 equiv. This is 1% of total HFC emissions. Indirect emissions related to electricity use are nearly 40 times higher than this figure, at 30 Mtonnes CO_2 equiv.

A control scenario that moves all domestic refrigerator production to HCs by 2006 will give an emission saving in 2010 of only 0.2 Mtonnes CO_2 equiv. The Cost Effectiveness of this measure is estimated to be 400 ECU/tonne CO_2 equiv. This very poor Cost Effectiveness can only be understood by reviewing the emissions in some detail. There are 2 key issues:

- domestic refrigerators are intrinsically very low leakage, so although the market is very large (implying high costs), the emission reduction potential is low

- 72% of HFC emissions are related to product disposal losses (see table 3.4). Because the majority of domestic refrigerators currently being built are based on HFCs we can expect significant HFC emissions in the time window 2000 – 2012, even if all new refrigerators are built with HCs.

Hence an control option related to use of HCs has little impact and very poor economics in the time window considered. The impact can be improved if the control scenario combines use of HCs in new refrigerators with an initiative to recover more HFCs from old refrigerators. The savings treble and the Cost Effectiveness falls to 170 ECU/tonne CO_2 equiv. However, this is still quite unattractive financially.

The most important opportunity for domestic refrigerators is energy efficiency. Table B43 shows that the potential for global warming emission reduction through improved efficiency is 50 times higher than through use of HCs. What is even more important is that the user should benefit in financial terms – the value of the electricity savings should easily outweigh the investment costs. If a high impact energy efficiency scenario is adopted for all domestic refrigerators there is the potential to save 10 Mtonnes CO_2 equiv. and to save 9 billion ECUs in electricity costs in the period 2000 – 2012.

5.3.13 Other Refrigeration

The commentary in the sections above has included details for the refrigeration market sub-segments with the highest potential for emission reduction. Four sub-segments have not yet been referred to. These are DX air-conditioning, water chiller air-conditioning, refrigerated transport and small hermetic systems.

Small hermetic systems have similar potential to domestic refrigeration i.e. the potential for direct HFC savings are very limited but the potential for energy related savings are high.

The other 3 sub-segments have emission reduction potential similar to small commercial refrigeration and industrial refrigeration. There is reasonable potential to achieve direct HFC emission reductions with a Cost Effectiveness in the range 20 to 30 ECU/tonne CO_2 equiv. There is good potential to achieve energy efficiency improvements at no net cost to the user.

5.3.14 Fire Fighting

This market sub-segment has already made enormous improvements in emission rates compared to those from pre-Montreal Protocol halon systems. There is little technical potential to reduce HFC emissions any further. HFC systems are more expensive than alternatives and are therefore only used when the improved fire extinguishing properties are particularly important.

The Business-as-Usual Scenario predictions show a low level of 2010 emissions: 0.2 Mtonnes CO_2 equiv., 0.3% of 2010 total. Hence no specific emission reduction measures are proposed, but it is recommended that emission reporting mechanisms are used to ensure that industry predictions are achieved.

5.3.15 HFC Manufacturing Emissions

The Business-as-Usual Scenario predictions show a low level of 2010 emissions: 0.5 Mtonnes CO_2 equiv., 0.8% of 2010 total. Assuming that the cost effective control measures described in previous paragraphs are implemented the total size of the HFC market will fall and manufacturing emissions will reduce. With low impact measures the emissions will fall to about 0.4 Mtonnes CO_2 equiv. and with high impact measures to 0.3 Mtonnes CO_2 equiv. No further emission reduction technologies are suggested as HFC producers already need to meet stringent emission targets under other environmental legislation. It is recommended that emission reporting mechanisms are used to ensure that predicted low levels of emissions are achieved.

5.4 International Competitiveness

During the course of the study care has been taken to assess the possible impact of the control options proposed on the competitiveness of the EU in exports of finished products. This has been achieved by examining how quality, volumes (efficiencies of scale), performance and unit cost will be affected by each control option suggested.

If all OECD countries ratify the Kyoto Protocol, all the major players in international export markets will face a requirement to reduce global warming emissions in their domestic markets. This means that providing EU policies follow rational economic principles there should be no damage to our export competitiveness. Indeed, there could be useful advantages for our exporters if we are able to develop particularly cost effective ways of reducing global warming emissions. Such products and technologies could be in great demand throughout the world. However, if some OECD countries do not ratify the Kyoto Protocol there could be competitiveness problems.

We have reviewed the various control scenarios proposed in Appendix B and have identified a number of areas that have the potential of a significant negative impact on the competitiveness of EU industry. These are listed in Table 5.2.

Table 5.2 Controls with Potential for Negative Impact on EU Exports

Market Segment	Control Options with negative impact on trade
Mobile air-conditioning	Rapid and inappropriate introduction of alternate refrigerants such as CO_2.
Domestic Refrigerators	Wide spread adoption of HC technology, making exports difficult to countries not allowing HCs on the grounds of safety or VOC emissions (e.g. USA).
General Aerosols	Banning of HFC products with no low cost alternative.
Solvents	Wide-spread use of aqueous solvents in markets not suited to the technology.
MDIs	Wide-spread uptake of DPIs through subsidy, leading to lack of competitiveness for MDIs in export markets.

It is useful to note that all of the examples listed in Table 5.2 are scenarios with high costs associated with them. The Cost Effectiveness of these controls are all above 50 ECU/tonne CO_2 equiv. Some are well above 100 ECU/tonne CO_2 equiv.

Our overall conclusion on export competitiveness is that:

- if measures with very poor economic performance are "forced" into the EU domestic market there is a significant risk of loss of export potential
- if measures with particularly good economic performance are developed more rapidly in the EU than in the rest of the world (through positive policies within the domestic market) there is a good chance of developing new export markets.

These points once again stress the need of adopting a structured policy that adopts the most cost effective measures across the whole basket of global warming gases.

5.5 Monitoring HFC Use and Emissions

Good monitoring of the use and emissions of HFCs over the coming years will be an essential part of an emissions reduction process.

All the emissions forecasts presented in Chapter 3 of this report are based upon complex assessments of the use of HFCs in each end user market. Inevitably this forecasting methodology has required numerous assumptions to be made. It is essential that the future use and emissions of HFCs from each Member State is monitored on a regular basis to enable the forecasts for the period 2008 to 2012 to be refined and improved.

In the unregulated market described in Chapter 3.3, the Business-as-Usual Scenario has been prepared as a best estimate of future HFC emissions. This gives an emission forecast for 2010 of 65 Mtonnes CO_2 equiv. However, without any regulations it is feasible to envisage circumstances in which emissions reach a much higher level. In practice it is important that growth of this sort does not occur. This must be monitored carefully over the next few years.

If the market is regulated using some of the control options described in this report it will remain important to continue monitoring use and emissions to judge the effectiveness of the control measures. Whether the market is regulated or not, this monitoring process is important. We strongly advise that the market segmentation approach that has been used in this report be reflected in any future monitoring mechanism. This is the best way in which the patterns of emission growth or reduction can be analysed. This will allow Member States to continually update and improve the control mechanisms being adopted. A "top down" emission reporting mechanism, based on HFC production data, will not provide enough detail to monitor the effectiveness of emission reduction strategies.

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APPENDIX A EMISSIONS MODELLING

The general basis of the emissions model was described in Chapter 3.2. This Appendix gives details of the modelling parameters used.

The computer model used has been adapted from a model originally developed on behalf of the UK Government for preparation of emission inventories for HFCs, PFCs and SF_6 (DOE, 1996).

A.1 Computer Model Parameters

The spreadsheet model carries out identical calculations for each of 23 market sub-segments. Calculations are also carried out for emissions from HFC manufacture and HFC emissions from HCFC 22 manufacture.

Table A1 shows the calculations carried out for a typical market sub-segment. Analysis is done on an annual basis between 1990 and 2010. In all cases there was no use of HFCs prior to 1990, hence the "initial bank" is always zero. A description of each row in the computer model is given in Table A2.

In each market sub-segment an assumption is made about the type of HFC fluid used. In some cases this is a single fluid (e.g. HFC 134a for R1 domestic refrigeration). In other segments a combination of fluids that is believed to best represent future practice has been assumed (e.g.35% 134a, 45% 404a, 5% 413a, 10% 407c and 5% 507 for R4 supermarkets).

The data for fluids used in each sub-segment are consolidated into a figure that represents the annual requirement for each of the HFC fluids. For mixtures like 404a, the appropriate quantity of each component in the mixture is calculated. These annual figures give a useful prediction for the amount of manufacturing capacity required under each scenario. They also form the basis of estimates of fluid manufacturing emissions.

HCFC 22 manufacture is also included in the spreadsheet model as it is a source of HFC 23 emissions.

Table A2 Modelling Parameters

Row	Name	Type[1]	Description
1	Used for manufacture (tnes)	D	Annual tonnage for manufacture of new products
2	Net proportion exported	D	Proportion of new products exported (negative if there is a net import)
3	Size of bank (tonnes)	C	Calculation of bank size in year X (see note 2 below)
4	Decommissioning (tonnes)	D	Annual tonnage of fluid in decommissioned equipment
5	PMfactor	D	Product Manufacturing Factor: proportion of fluid emitted during product manufacture
6	PLfactor	D	Product Life Factor: proportion of bank emitted annually
7	Dfactor	D	Disposal Factor: proportion of decommissioned fluid emitted
8	PM emissions (tonnes)	C	Product Manufacturing Emissions: [Row1]*[Row5]
9	PL emissions (tonnes)	C	Product Life Emissions: [Row3]*[Row6]
10	Disposal emissions (tonnes)	C	[Row4]*[Row7]
11	Total Tonnes emitted	C	[Row 8]+[Row9]+[Row10]
12	GWP of fluid/s	D	Average 100 year GWP of fluids in group
13	ktonnes CO_2 equiv. emitted	C	[Row11]*[Row12]/1000

Notes to Table A2:

1 D is a data field. C is a calculated field.

2 The bank calculation for year X involves values in year X and X-1. Two alternative calculations are required. For applications like refrigeration, annual PL losses are replaced, hence PL emissions do not affect the bank. For applications like foam there is no "servicing" hence PL emissions are lost from the bank.

Serviced Banks:
Bank in year X = [Row3]=[Row3,X-1]-[Row4,X-1]+([Row1]-[Row8])*(1-[Row2])
Unserviced Banks:
Bank in year X = [Row3]=[Row3,X-1]-[Row4,X-1]+([Row1]-[Row8])*(1-[Row2])-[Row9,X-1]

A.2 Market Segment Emissions Factors and Other Assumptions

A.2.1 Refrigeration and Air-conditioning

Table A3 shows emission factors and typical length of equipment life for the 9 refrigeration/air-conditioning market sub-segments. It should be noted that the data in the table is for the year 2010. The emissions model utilises annual values for each parameter between 1990 and 2020 – these may be different from the values in table A3.

Table A3 Emission and Consumption Parameters 2010,

Refrigeration and Air-conditioning

Market Sub-Segment	Business-as-Usual Scenario				Typical Plant Life Years
	PM %	PL %	PD %	New tonnes	
R1 Domestic Refrigeration	1	1	20	1200	13
R2 Other Small Hermetic	1	1	20	300	9
R3 Small Commercial Distrib.	2	8	5	500	13
R4 Supermarket Refrigeration	2	8	5	1500	13
R5 Industrial Refrigeration	2	6	5	1400	25
R6 Air-conditioning, Distrib.	2	8	5	1200	12
R7 Air-conditioning, chillers	1	2	3	1000	25
R8 Transport Refrigeration	1	5	5	350	8
R9 Mobile air-conditioning	1	8	25	6000	12
Total, Refrigeration/AC				**13500**	

Key to Table A3:

PM Product Manufacturing factor, % emission of fluid used to manufacture new equipment

PL Product Life factor, % of refrigerant bank emitted annually

PD Product Disposal factor, % emission of fluid in old plant being decommissioned

New, metric tonnage of HFC fluids used to manufacture new refrigeration/air-conditioning systems in 2010 (NOT EMISSIONS!)

Some important points to note about Table A3 are:

a) Product Manufacturing Factors

Refrigerant emissions during the manufacture of equipment are negligible in comparison to the emissions that occur during the life and on the decommissioning of equipment. Manufacturing emissions are in the order of 100 times smaller than product life emissions for most equipment categories.

b) Product Life Factors

Leakage from existing systems represents the major part of direct greenhouse gas emissions from refrigeration equipment. The average annual leakage rate is sub-sector specific and is highly sensitive to the quality of equipment and maintenance. Because of the increasing price of alternative refrigerants and the attention that has been given to leakage in the last few years, it is reasonable to expect that historical rates of leakage will be improved in years to come under the Business-as-Usual Scenario.

c) Disposal Loss Factors

As with leakage, disposal loss factors are sub-sector specific and one can expect significant differences between historical recovery rates and future practice. Before the beginning of the Montreal Protocol process refrigerant was vented from many old systems when they were decommissioned. Refrigerant would have only been recovered from relatively large systems. This practice is now illegal and it is possible to remove a significant proportion of refrigerant from old systems on decommissioning. The recovered refrigerant can then be recycled or sent for destruction.

d) Growth of the HFC Bank for Refrigeration and Air-conditioning

A key aspect in the development of the refrigeration HFC emission model relates to the assumptions on annual consumption for new equipment and the growth of the HFC refrigerant bank. In 1998 only a small proportion of existing refrigeration systems have HFC refrigerants. The majority still contains CFCs or HCFCs. In the period to 2010 there will be an increasingly large HFC bank as older equipment is replaced or converted. In some market segments, such as R1, domestic refrigeration and R9, mobile air-conditioning the HFC bank in 2010 can be considered "mature" as it represents the final size of the bank. This is because HFC usage began several years ago (1993 for R9, 1995 for R1) and the lifecycle of the products is relatively short. In other markets, such as R5, industrial and R7 air-conditioning chillers the life cycle is long (25 – 30 years) and HCFCs are still being used in new systems in 1998. This means that by 2010 only a proportion of HCFC equipment will have been replaced and the HFC bank cannot be considered fully mature.

The growth of the HFC refrigerant bank is influenced by 3 main parameters:

- the rate of replacement/conversion of older CFC and HCFC systems. Both unregulated scenarios assume that replacement rates will only be influenced by normal plant lifecycles and by the EU Regulation on ozone depleting substances.

- the proportion of systems using HFCs as opposed to alternatives such as ammonia and HCs. The Business-as-Usual Scenario assumes a significant market growth for alternatives in some market sub-segments.

- the average refrigerant charge put into new systems. The Business-as-Usual Scenario follows recent trends towards low charge systems in some markets.

Table A3 reflects these consumption issues with the figures in the column labelled "New".

A.2.2 Foam Blowing

Table A4 shows emission factors and typical length of product life for the 10 foam market sub-segments. It should be noted that the data in the table is for the year 2010. The emissions model utilises annual values for each parameter between 1990 and 2020 – these may be different from the values in table A4.

Some important points to note about Table A4 are:

a) Product Manufacturing Factors

A significant proportion of blowing agent can be lost during the manufacture of insulating foams. This is particularly true of open cell foams where the blowing agent is lost during manufacture and little is recovered. In the case of closed cell foams a much smaller proportion is lost.

b) Product Life Factors

For open cell foams, all the blowing agent is lost during manufacture, hence there is no further emission during the life of the foam. For closed cell foam there is a gradual loss over the life of the foam. Although this is not strictly linear which time, it is assumed to be so for the sake of modelling simplicity.

Table A4 Emission and Consumption Parameters 2010,

Foam Blowing

Market Sub-Segment	Business-as-Usual Scenario				Typical Plant Life Years
	PM %	PL %	PD %	New tonnes	
F1 PU Appliances	3	0.25	60	7500	12
F2 PU Flexibly faced laminate	10	1	0	8000	50
F3 PU Discontinuous Panel	10	0.5	25	10000	50
F4 PU Continuous Panel	5	0.5	20	6000	50
F5 PU, PIR, Phenolic Block	40	1	25	3000	15
F6 PIR, Phenolic f-f laminate	10	1	20	3000	50
F7 PU spray/pipe-in-pipe	20	1	35	9000	25
F8 XPS	25	4	0	12000	50
F9 Polyethylene foam	90	5	0	500	15
F10 Integral Skin foam	95	2.5	0	0	15
Total, Foam Blowing				**58500**	

Key to Table A4:

PM Product Manufacturing factor, % emission of fluid used to manufacture new equipment

PL Product Life factor, % of refrigerant bank emitted annually

PD Product Disposal factor, % emission of fluid in old plant being decommissioned

New, metric tonnage of HFC fluids used to manufacture new foam products in 2010 (NOT EMISSIONS!)

c) Disposal Loss Factors

At present there are few facilities in the EU for recovering blowing agent from closed cell foam at the end of its useful life. Presently most of these foams are placed in landfill and it can be expected that all the blowing agent will be lost, albeit not immediately. Some incineration takes place in those member states equipped to do so. Recovery technologies exist, but they are very expensive to operate. HFC foams will not start reaching the market in any significant quantities until around 2002. As most foam products typically have lives in the region of 25-50 years there would be no end of life emissions in the forecasts for 2010. Hence, the uptake of recovery technologies is irrelevant at this stage although it will have to be taken into account in years to come.

d) Growth of the HFC Bank for Foams

A key aspect in the development of the foams HFC emission model relates to the assumptions on annual consumption for new foam and the growth of the HFC foam bank. In 1998 consumption of HFCs for foam manufacture is at a very low level and the foam bank is of a negligible size. Consumption of HFCs is expected to rise considerably on the period 2000 – 2004. The foam bank will not be "mature" until well into the next century because of the long lifecycle of foam products.

The growth of the HFC foam bank will be influenced by 2 main parameters:

- the price of HFC blowing agents compared to alternative fluids and non-foam insulants. If the price of HFC blowing agents is high, alternative products will be more attractive to end users.

- the importance to end users of properties such as thermal resistance, fire resistance, structural rigidity etc. If these properties are of paramount importance end users may stick to HFC products irrespective of price.

Table A4 reflects these consumption issues with the figures in the column labelled "New".

A.2.3 General Aerosols

The assumptions required for the general aerosol part of the emissions model are far simpler than those required for refrigeration and foams. All propellant used for the manufacture of general aerosols will be emitted to atmosphere, usually within 1 – 2 years of the date of manufacture.

The emissions are split into a manufacturing emission and a product life emission. Minimising the manufacturing emission will help reduce the total consumption of propellant. In large-scale aerosol manufacturing plants manufacturing emissions are at a low level, typically being less than 2%. In smaller operations the loss rate may be higher, at about 5%. By the nature of aerosol use it is impossible to reduce the product life emission below 100% unless the aerosol remains unused. If an unused aerosol is disposed of there is a potential for fluid recovery, although this does not often take place.

The key aspect of modelling future HFC emissions from general aerosols is to predict the size of the HFC propellant market. In 1986, prior to the Montreal Protocol, EU consumption of CFC aerosol propellants was 142 ktonnes (split fairly evenly between CFC 11 and CFC 12). In 1976 the consumption was even higher, at 177 ktonnes. In 1997 CFC and HCFC consumption for general aerosols was zero and HFC consumption was only about 5 ktonnes (mostly of HFC 134a).

As described in Chapter 2.3 a very large proportion of the historical halocarbon propellant market has moved to alternative fluids or technologies. How might the use of HFC propellants for general aerosols develop in an unregulated market place? For the Business-as-Usual Scenario we have assumed that the current level of market penetration for HFCs will remain constant. The relatively high price of HFCs compared to alternative propellant will tend to limit the potential for further growth. Also, in some EU countries the aerosols industries have made voluntary agreements to avoid using HFCs unless there is no safe or practical alternative.

A.2.4 Metered Dose Inhalers

MDIs are a form of aerosol, hence many of the comments made in section A.2.3 above apply. MDIs are a totally emissive application except for the possibility of a small proportion of propellant that could be recovered from out of date products.

As with general aerosols the key to emissions modelling is to estimate the size of the MDI market. The MDI industry have provided a maximum estimate of HFC consumption in 2010 as being 8000 tonnes. We have allowed for a 25% lower market growth rate for the Business-as-Usual Scenario, with an EU usage of 5000 tonnes/year.

A significant proportion of the MDIs manufactured in the EU are exported. These will suffer from a low level of manufacturing emission, but the product life emission will all take place outside the EU. Current exports are 36%. These are expected to grow to between 40 and 50% of EU production by 2010.

A.2.5 Solvents

As with general aerosols and MDIs the assumptions for the solvents emissions model are much simpler than for refrigeration or foams. It is reasonable to assume that the quantity of solvent purchased by an end user in any given year will be completely emitted.

Prior to the Montreal Protocol large quantities of ozone depleting solvents were used. Under the current EU regulation 3093/94 the use of CFCs and 1,1,1 trichloroethane have fallen to very low levels because of the production bans on these substances. The vast majority of users of these substances have converted to NIK cleaning technologies. Currently there is a small EU usage of some 6000 tonnes/year of HCFC 141b in solvent applications. This HCFC solvent has been adopted as a convenient replacement for certain CFC 113 and 1,1,1 trichloroethane cleaning applications. It is only these applications that are likely to consider HFC solvents, as all other users have already found satisfactory alternative fluids or technologies. The high price of HFC solvents compared to HCFC 141b will encourage many current users to find some alternative cleaning technique. In the Business-as-Usual Scenario we have assumed that only 40% of current users adopt HFCs.

A.2.6 Fire Fighting

The key factors that will influence emissions from HFC fire fighting systems are the rate of growth of the HFC market and the annual rate of emission from the HFC bank.

The fire industry expects that HFCs will take a 25% share of the old halon market. This leads to an EU HFC bank of some 3 to 5 ktonnes by 2010. Annual emission rates will fall significantly from current levels because of improved technology (e.g. less likelihood of false alarms triggering a release). The industry expects emission levels from "best practice" new systems to be in the range of 1 to 3% of the bank/year. An emission rate of 2% is used in the Business-as-Usual Scenario. There is technical potential for further reductions to around 1%. Lower figures are impossible to achieve because some fluid is emitted in actual fires.

APPENDIX B ASSESSMENT OF CONTROL SCENARIOS

In this Appendix we present a review of the control mechanisms and control scenarios that can be applied to the 25 market sub-segments described in Chapters 2 and 3.

Control Mechanisms

A qualitative analysis of the control mechanisms described in Chapter 3.5 is presented taking into account the characteristics of each market sub-segment and of each type of control mechanism. For each control we specify the effectiveness in one of four categories. These are:

- **Good** - the control mechanism should have a significant influence on emissions.
- **Reasonable** - the control mechanism will influence emissions but not as effectively in as a "good" mechanism.
- **Possible** - the control may be applicable, but further research may be required to prove this.
- **Less Effective** - the control mechanism is unlikely to have any significant impact in a cost effective manner and/or will be administratively difficult to implement.

In most cases we envisage the control mechanisms being aimed at the user of the products and equipment containing HFCs. However, in some situations where the control is inappropriate for the user it may still be possible to apply it to the manufacturers of the products or equipment. This has been indicated in the Effectiveness and Comments columns of the tables that follow.

Option (d), listed in Chapter 3.5 (Fiscal measures such as product taxation, by fluid) is not included in the analysis of each market sub-segment, as this is a "blanket" option that would be applied to fluids rather than markets.

Emission Reduction Potential and Costs

For each market sub-segment we list the key technical opportunities to reduce emissions (based on the discussion in Chapter 2) and propose possible control scenarios. These are analysed from an emissions and cost perspective. The calculations for each control scenario are based on the emissions spreadsheet model described in Appendix A. The analysis has been carried out on an annual basis between 1998 and 2020. Data is presented for 3 different dates; annual emissions are quoted for 2010 and 2020 together with the cumulative emissions between 2000 and 2012. This cumulative figure is used in the cost calculations to evaluate the cost per tonne CO_2 saved (see Chapter 5 for the basis of the cost calculations.

A number of the control scenarios are described as "low" or "high" impact. This is because many of the technical opportunities will have varying levels of emission reduction potential, depending on the level of market penetration and/or the amount of money invested. The modelling assumptions for these low and high impact scenarios are described in the text.

The Control Option Cost Effectiveness Tables

For each sector the results of the analysis of the control options considered are presented in a standardised Control Option Cost Effectiveness table. This table presents all the monetary expenditure and emissions savings that will be incurred over the full period 2000 to 2012.

This time period is chosen as it includes the Kyoto Protocol commitment period of 2008 to 2012. The period up to 2008 is included to ensure that as soon as any investments are made we are including the environmental benefits in the overall assessment of cost effectiveness. It should be noted an assessment of cost effectiveness based on a "snapshot" of savings in a particular year is likely to give a misleading result.

The data presented in the cost effectiveness tables is as follows:

1. Development and Capital Cost: This is the fixed cost required to research and develop the new technology option plus the cost of installing new equipment or converting existing equipment. In the case of manufactured products such as mobile air-conditioning units it includes the cost of modifying the manufacturing equipment required to produce the product.

2. Product Manufacturing Cost Increase: The extra variable cost of actually producing the total number of units required in the period 2000 - 2012.

3. Product Use Cost Increase: The additional cost (or saving) incurred through use of the new product throughout the period 2000 - 2012.

4. Emission Saving: These savings are presented as the total cumulative direct and/or indirect emissions over the entire period 2000 to 2012 when compared to the Business-as-Usual Scenario.

5. Cost Effectiveness: The cost effectiveness of the control option is expressed in ECU per tonne of CO_2 equivalent. This is the ratio of the net costs (items 1+2+3, above) to the emission saving (item 4). In some instances there will be an increase in emissions due to choice of a poor control option, or a net cost saving due to a reduction in the cost of using the product (usually as a result of an energy saving). In these cases, to avoid confusion through the use of minus signs, where the control option results in an increase in emissions the cost effectiveness is expressed as “none”. Where the control option actually results in a monetary saving rather than expenditure, the cost effectiveness is expressed as “free”.

B.1 HFC 23 from HCFC 22 Manufacture

This market segment is potentially the largest HFC emitter of the 25 segments analysed. The manufacture of HCFC 22 leads to production of HFC 23 as a by-product. HCFC 22 output levels for EU consumption and for export should fall by 2010 because of proposed EU Regulations on ozone depleting substances. However, market growth in the use of HCFC 22 as a chemical feedstock for fluoropolymers will offset this drop to some extent.

Table B1 Control Mechanisms for HFC 23 from HCFC 22 Manufacture

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Good	There are a very small number of producers who all have interests in the future of HFCs, hence a voluntary agreement seems appropriate.
ii) Emission reporting mechanisms	Good	Could keep a good track of emissions via manufacturers.
iii) End use emission regulations	Good	Chemical companies have to meet tight emission regulations under processes such as Integrated Pollution Control.
iv) Fiscal measures, by market segment	Less Effective	HCFC 22 raw materials are important to the economy. Risk of relocation of manufacture outside EU.
v) Emissions trading	Less Effective	All manufacturers face similar cost situation which negates benefits of trading.
vi) End use controls	Less Effective	Impossible to prevent manufacture of HCFC 22 as it is a vital feedstock chemical.
Importance of energy efficiency	Negligible	Fuel related CO_2 emissions are very low.

Table B2 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	9.7	7.3	163

Key Technical Opportunities for Emission Reduction:

- Product manufacturing emission reductions using HFC 23 collection and incineration

Table B3 Emission Reduction Potential, HFC 23 from HCFC 22 Manufacture

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
HFC 23/1	Product manufacturing emission reductions, low impact	-8.6	-6.5	-83
HFC 23/2	Product manufacturing emission reductions, high impact	-9.2	-6.9	-114

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: The base scenario assumes that in 2010 the only HCFC 22 plants that have HFC recovery/destruction systems are those that currently have the equipment and those that have definite plans for installing them. It is assumed that the other EU HCFC 22 plants emit HFC 23 at a rate equivalent to 3 to 4% of HCFC 22 manufacturing rates.

HFC 23/1: All plants have HFC recovery/destruction systems installed by 2006 with 97.5% of all HFC 23 produced being destroyed.

HFC 23/2: All plants have HFC recovery/destruction systems installed by 2004 with 99% of all HFC 23 produced being destroyed. This high impact scenario may require significant modifications to existing recovery systems.

Table B4 Control Option Cost Effectiveness, 2000 to 2012

HFC 23 from HCFC 22

Control Option	Cumulative Costs and Emissions, 2000 - 2010				Cost Effectiveness
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
HFC 23/1	70	30	0	83	1
HFC 23/2	160	50	0	114	2

B.2 Supermarket Refrigeration

This market segment is potentially the second largest HFC emitter of the 25 segments analysed. Most supermarket users moved away from CFC and HCFC refrigerants relatively early in the phase out cycle. Many large supermarket companies have adopted HFCs as their standard refrigerant in new supermarkets and major plant refurbishment. Many of these companies are carrying out trials with alternative refrigerants, in particular ammonia or HCs although market penetration is currently low. Significant changes are being made to refrigeration system designs to utilise less refrigerant charge and to reduce leakage levels. Emission of energy related CO_2 from supermarket refrigeration is significant, hence control policies should take energy into account.

Table B5 Control Mechanisms for Supermarket Refrigeration

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Good (large companies) Reasonable (smaller companies)	Small number of large supermarket owners in EU hence a relatively easy agreement to set up. Large number of smaller owners would be more difficult to control in this way.
ii) Emission reporting mechanisms	Good	For large chains this would be a very useful mechanism.
iii) End use emission regulations	Good	Historical levels of leakage are high. Excellent potential for cost effective reductions.
iv) Fiscal measures, by market segment	Good	Supermarket companies are very cost conscious. This mechanism would leave the choice of refrigerant type open, but help to ensure low levels of leakage if HFCs chosen. It would also encourage HFC designs with low refrigerant charge, which in turn would reduce emissions.
v) Emissions trading	Possible	Could be applied to large chains
vi) End use controls	Less Effective	An HFC ban would restrict design options to small integral systems or to secondary refrigerant systems. These are not necessarily the most appropriate in all types of supermarket.
Importance of energy efficiency	High	72% of total global warming impact is energy related.

Table B6 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	9.0	6.2	144
Indirect CO_2	23	18	325

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (ammonia or HCs)
- Product life emission reductions
- Product disposal emission reductions
- Improved energy efficiency

Table B7 Emission Reduction Potential, Supermarket Refrigeration

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
R4/1	Use of alternative fluids and Product life and Product disposal emission reductions, low impact	-3.3	-2.7	-53
R4/2	Use of alternative fluids and Product life and Product disposal emission reductions, high impact	-5.2	-4.4	-66
R4/3	Improved energy efficiency, low impact	-2.0	-1.0	-18
R4/4	Improved energy efficiency, high impact	-4.0	-3.0	-39

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: The base scenario assumes that use of HFCs for new supermarkets peaks by 1998 and falls significantly over the following 5 years. This is mainly due to reductions in refrigerant charge and also because of a move towards HCs and ammonia in some stores. Leakage rates are assumed to fall from 23% in 1998 to 10% by 2010. Energy efficiency in 2010 is 15% better than in 1998.

R4/1: In this scenario use of HFCs for new supermarkets in 2010 falls to about 80% of the Business-as-Usual Scenario, due to further market penetration by HCs and ammonia. Leakage rates fall to 7%.

R4/2: In this scenario use of HFCs for new supermarkets in 2010 falls to about 60% of the Business-as-Usual Scenario, due to further market penetration by HCs and ammonia. Leakage rates fall to 5%.

R4/3: The energy efficiency improvements of the Business-as-Usual Scenario are implemented at a faster rate, resulting in significant savings by 2010. Energy efficiency in 2010 is 22% better than in 1998.

R4/4: The energy efficiency improvements of the Business-as-Usual Scenario are implemented at an even faster rate and further energy saving technologies are introduced. Energy efficiency in 2010 is 30% better than in 1998.

Table B8 Control Option Cost Effectiveness, 2000 to 2012

Supermarket Refrigeration

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
R4/1	400	0	-50	53	7
R4/2	700	0	-80	66	9
R4/3	600	0	-2000	18	-77
R4/4	1000	0	-4000	39	-77

B.3 Mobile Air-conditioning

This market segment is potentially the third largest HFC emitter of the 25 segments analysed. HFC 134a is used in all new car air-conditioning systems. The market for mobile air-conditioning is growing significantly. From table 3.4 we can see that 86% of emissions are due to product life leakage and 13% of emissions are on disposal. There is good potential to reduce leakage levels by investment in equipment design. Car manufacturers are considering the use of CO_2 or HCs alternative refrigerants – CO_2 is currently favoured by many. Successful development of alternative fluids would help the implementation of a control mechanism. This development cycle needs careful monitoring as it is in its relatively early stages. Emission of energy related CO_2 from mobile air-conditioning is significant, hence control policies must take energy into account.

Table B9 Control Mechanisms for Mobile Air-conditioning

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Good	Small number of car manufacturers in EU hence a relatively easy agreement to set up.
ii) Emission reporting mechanisms	Less Effective (user) Reasonable (manufacturer)	Impossible to apply at user level. Would be useful to get manufacturers and service providers to report on use for new vehicles and for servicing. Also, car breakers could report on disposal emissions.
iii) End use emission regulations	Good	Could regulate designs so car manufacturers would have to meet certain emissions targets. Would also need regulation regarding servicing standards and disposal of old systems
iv) Fiscal measures, by market segment	Less Effective	The cost of refrigerant is relatively low compared to other costs for new systems and for servicing, hence a tax would need to be at a very high level. (Refrigerant cost is only about 1% of system cost)
v) Emissions trading	Less Effective (user) Possible (manufacturer)	Very difficult to apply at user level. May be possible to consider a mechanism linked to manufacturers, but this would have to be based on the assumption that HFC 134a systems are the only feasible option.
vi) End use controls	Less Effective	An HFC ban for mobile air-conditioning could have a useful long term impact. However, it is only feasible when/if an alternative refrigerant has been proved reliable and energy efficient.
Importance of energy efficiency	High	68% of total global warming impact is energy related.

Table B10 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	**2020**	**2000 - 2012**
Direct HFC	8.9	4.1	114.5
Indirect CO_2	14.0	17.9	129.8

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (CO_2 or HCs)
- Product life emission reductions
- Product disposal emission reductions
- Improved energy efficiency

Table B11 Emission Reduction Potential, Mobile Air-conditioning

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	**2020**	**2000 - 2012**
R9/1	Use of CO_2 for new cars from 2007	-1.6	-2.7	-8.6
R9/2	Use of CO_2 for new cars from 2004	+2.2	-2.8	+37.2
R9/3	Product life and Product disposal emission reductions, low impact	-1.8	0	-17.6
R9/4	Product life and Product disposal emission reductions, high impact	-3.3	0	-34.0
R9/5	Improved energy efficiency, low impact	-0.5	0	-5.2
R9/6	Improved energy efficiency, high impact	-1.1	0	-9.6

Notes to Table B11. The + figures for R9/2 implies there is an emission increase up to 2012 if the measure is adopted. The 0 figures for R9/3-6 in 2020 imply that the Business-as-Usual Scenario is achieving optimal levels of leakage and efficiency. However there is a net benefit up to 2012 because of earlier uptake.

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: The base scenario assumes that the car industry will be continually in the spotlight over the next decade as it is responsible for a significant proportion of all greenhouse gas emissions. The industry is already committed to large investment programmes that will reduce global warming impact. A steady and continual improvement in the performance of mobile air-conditioning systems both in terms of leakage rates and energy efficiency is predicted. It is assumed that by 2010 optimum rates for leakage (4% p.a.) and system efficiency (80% of current energy use) will be achieved in newly manufactured vehicles. The refrigerant is assumed to be HFC 134a throughout. The refrigerant charge required falls from 1100grammes in 1998 to 600 grammes per unit by 2007. Car usage and ownership grows steadily and car air-conditioning rises rapidly to 60% penetration. Overall car engine efficiency improves steadily throughout.

R9/1: CO_2 systems replace all HFC systems once their TEWI is lower. This is assumed to be in 2007. The energy efficiency of CO_2 systems in 2007 is taken to be equivalent to 1998 HFC systems. CO_2 systems improve in energy efficiency steadily after 2007, but this always remains higher than HFC systems due to the inherent efficiency of HFC systems. Between 1998 and 2007 HFC systems achieve improved leakage and energy efficiency equivalent to that assumed in the Business-as-Usual Scenario. This is an important assumption as a car built with HFC air-conditioning in 2006 will still be in use until around 2018.

R9/2: The car industry is forced to phase out HFC systems by 2004. This results in a rapid development programme for CO_2 systems. These systems will initially have a higher TEWI than HFC systems under the Business-as-Usual Scenario, due to poorer energy efficiency. In the intervening years, 2000 - 2004 HFC system performance is assumed to remain at the best available current standard, since all investment initiatives are in CO_2 system development. There is therefore no further improvement in HFC leakage and efficiency rates. After 2004, CO_2 systems gradually improve their energy efficiency but this always remains higher than HFC systems due to the inherent efficiency of HFC systems.

R9/3: The optimal leakage reductions attainable in the Business-as-Usual Scenario are achieved 3 years earlier due to increased development expenditure.

R9/4: The optimal leakage reductions attainable in the Business-as-Usual Scenario are achieved 5 years earlier due to increased development expenditure.

R9/5: The optimal energy efficiency improvements attainable in the Business-as-Usual Scenario are achieved 3 years earlier due to increased development expenditure.

R9/6: The optimal energy efficiency improvements attainable in the Business-as-Usual Scenario are achieved 5 years earlier due to increased development expenditure.

Table B12 Control Option Cost Effectiveness, 2000 to 2012

Mobile Air-conditioning

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
R9/1	300	370	380	8.6	122
R9/2	300	570	1800	-37.2	none
R9/3	150	95	0	17.6	14
R9/4	375	140	0	34.0	15
R9/5	300	95	-1125	5.2	-140
R9/6	450	135	-1650	9.6	-111

B.4 General Aerosols

This market segment is potentially the fourth largest HFC emitter of the 25 segments analysed. Use of halocarbons for aerosols has fallen enormously since 1986. The majority of the market has moved to HC propellants and a few users have moved to DME. A very small proportion of current output is based on HFCs - mostly 134a. HFCs are mainly used in applications where a non-flammable propellant is required.

Table B13 Control Mechanisms for General Aerosols

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective (user) Good (manufacturer)	Manufacturers could be encouraged to avoid HFCs especially in large volume applications.
ii) Emission reporting mechanisms	Less Effective (user) Reasonable (manufacturer)	Could keep a good track of usage and emissions via manufacturers.
iii) End use emission regulations	Less Effective	Very difficult to apply except for a small number of unused aerosols which could be returned for propellant recovery.
iv) Fiscal measures, by market segment	Good (low price products) Less effective (industrial products)	The propellant forms a significant proportion of the cost of some aerosols, so this could incentivise manufacturers to find alternative propellants or it may reduce the market size for "trivial" products. Many specialised industrial products are quite expensive, hence this mechanism would have less impact.
v) Emissions trading	Less Effective	Too many user groups and diverse applications to set up reasonable allocation of emissions permits. High transaction costs.
vi) End use controls	Reasonable	This mechanism would have a significant impact and be easy to implement. However it would create significant difficulties for users with no safe/practical alternative. Hence, it would be necessary to sub-divide general aerosol applications into 2 groups so that certain applications could avoid the use ban.
Importance of energy efficiency	None	

Table B14 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	**2020**	**2000 - 2012**
Direct HFC	7.0	7.0	89.2

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (DME or HCs)
- Use Alternative NIK technologies

Table B15 Emission Reduction Potential, General Aerosols

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	**2020**	**2000 - 2012**
GA/1	Use of alternative fluids and NIK technologies, low impact	-3.1	-3.1	-22.3
GA/2	Use of alternative fluids and NIK technologies, high impact	-5.0	-5.0	-44.6

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: The base scenario assumes growth in the use of HFC 134a for specialised applications, stabilising at a consumption of 5,400 tonnes by 2003.

This industrial sector is characterised by an extremely diverse range of opinions as to the extent to which HFC usage can be reduced. At one extreme, in some countries there is a belief that all applications of HFCs can be phased out, whilst at the other extreme, some believe that there is no further scope for reduction of HFC usage. Here a middle ground has been taken which assumes that no uses will be banned but that Government will work closely with industry to actively seek safe ways of reducing usage levels. This is an area where further research is required.

GA/1: By 2007, 40% of HFC usage has been replaced by alternative fluids such as HCs and compressed gas or by NIK delivery systems.

GA/2: By 2006, 70% of HFC usage has been replaced by alternative fluids such as HCs and compressed gas or by NIK delivery systems. HFC usage is continued in certain markets where flammability is a critical issue and where NIK systems are not satisfactory in performance.

Table B16 Control Option Cost Effectiveness, 2000 to 2012

General Aerosols

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
GA/1	200	50	10	22.3	16
GA/2	750	150	400	44.6	29

B.5 Extruded Polystyrene

This market segment is potentially the fifth largest HFC emitter of the 25 segments analysed. Table 3.7 shows that 49% of emissions take place at the manufacturing facility, with the remainder being losses from the bank of installed XPS foam. The main options available for emission reduction are use of an alternative blowing agent, use of non-foam insulating materials or reduction of emissions during XPS manufacture.

Table B17 Control Mechanisms for Extruded Polystyrene

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Good	There are a very small number of XPS manufacturers in the EU, so a voluntary agreement would be easy to set up.
ii) Emission reporting mechanisms	Good	Could keep a good track of usage and emissions via manufacturers.
iii) End use emission regulations	Less Effective	Impossible to influence emissions once foam is manufactured. It may be possible to reduce the permeability of foam facing materials, although this would be difficult for XPS applications.
iv) Fiscal measures, by market segment	Good	The foam blowing agent forms a significant proportion of the cost of foam, so this could incentivise manufacturers to use alternatives. However, it would be necessary to confirm that an HFC use ban did not lead to an increase in CO_2 emissions because of inferior insulating properties of alternatives.
v) Emissions trading	Possible	Could link to a building energy reduction initiative.
vi) End use controls	Less Effective	Although this mechanism is easy to implement it could lead to an increase in CO_2 emissions because of inferior insulating properties of alternatives.
Importance of energy efficiency	High	The insulating properties of XPS lead to significant reduction in CO_2 emissions.

Table B18 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	6.9	9.8	59

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (CO_2)
- Product life emission reductions
- Improved energy efficiency
- Use of NIK insulation materials
- Product manufacturing emission reductions

Table B19 Emission Reduction Potential, Extruded Polystyrene

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
F8/1	Use of alternative fluids + Use of NIK insulation materials, low impact	-2.9	-4.5	-18.8
F8/2	Use of alternative fluids + Use of NIK insulation materials, high impact	-5.9	-9.1	-37.4
F8/3	Product manufacturing + Product life emission reductions, low impact	-1.3	-1.6	-10.2
F8/4	Product manufacturing + Product life emission reductions, high impact	-2.8	-3.6	-19.9

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: In 2010 12000 tonnes of HFC 134a are used to blow XPS. Product manufacturing emissions are 25%.

F8/1: By 2007, 50% of HFC blown XPS has been replaced by CO_2 blown XPS or by NIK insulants. Product manufacturing emissions are 25%.

F8/2: By 2007, 100% of HFC blown XPS has been replaced by CO_2 blown XPS or by NIK insulants.

F8/3: By 2004, product manufacturing emissions are reduced to 20%.

F8/3: By 2004, product manufacturing emissions are reduced to 15%.

Table B20 Control Option Cost Effectiveness, 2000 to 2012

Extruded Polystyrene

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
F8/1	30	170	0	18.8	11
F8/2	50	330	0	37.2	10
F8/3	50	0	0	10.2	5
F8/4	100	0	0	19.9	5

B.6 Metered Dose Inhalers

This market segment is potentially the sixth largest HFC emitter of the 25 segments analysed. HFC 134a and HFC 227 are being used by pharmaceutical manufacturers as aerosol propellants, in place of CFC12. Large sums of money have been spent during the last 10 years to prove the safety and effectiveness of MDIs using these new propellants. CFC 12 MDIs still retains a significant market share, but the new HFC based products are expected to replace CFC 12 products during the next 3 to 5 years. No other propellants are currently under serious development, hence there is no medium term alternative to HFCs. Alternative technologies such as dry powder inhalers and nebulisers exist but are not suitable for many patients. This is the only market segment investigated in this study in which there is no good option to reduce emission levels. The best possibility would seem to be the slow process of encouraging doctors and patients to try alternative treatments. This would increase the market share held by alternative technologies, but it is likely that MDIs will remain the most popular treatment because of medical effectiveness and practical convenience.

Table B21 Control Mechanisms for Metered Dose Inhalers

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective	Costs of alternatives too high.
ii) Emission reporting mechanisms	Good	Could keep a good track of usage and emissions via manufacturers.
iii) End use emission regulations	Less Effective	Impossible to apply except for a small number of unused aerosols which could be returned for propellant recovery.
iv) Fiscal measures, by market segment	Less Effective	Public may find extra costs of pharmaceuticals difficult to accept.
v) Emissions trading	Possible	Pharmaceutical manufacturers could be encouraged to invest in other ways of reducing global warming through this option.
vi) End use controls	Less Effective	It is unlikely that an HFC ban could be applied in this vital end use sector.
Importance of energy efficiency	None	

Table B22 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	4.8	4.9	50.9

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids – none likely to be available by 2010
- Use of alternative NIK technologies

Table B23 Emission Reduction Potential, Metered Dose Inhalers

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
MDI/1	Use of alternative NIK technologies, low impact	-1.4	-1.5	-13.7
MDI/2	Use of alternative NIK technologies, high impact	-2.4	-2.5	-23.4

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: HFCs will replace CFCs for all MDIs. No new propellant will emerge by 2012. HFC 134a will be used in most applications but for certain drugs it is not effective in administering medicine and there is likely to be substantial use of HFC 227 (at least 25%). All the major manufacturers expect to have DPIs available within the next four years, hence there are no additional development costs incurred for these systems. DPIs are inherently more complicated and hence more expensive than MDIs - they are currently four times more expensive and will not gain large market share in the base model (except in a few countries where financial incentives are given to promote DPIs). Tablet treatments will not reduce sales volumes of MDIs as this will be offset by market growth.

MDI/1: By 2006, with large subsidies, DPIs will capture 30% of market share.

MDI/2: By heavy subsidies for the increased costs of DPIs, plus accelerated development expenditure, market penetration of 50% is achieved by 2004.

It is worth noting that under the above scenarios the degree of market share achieved will have little impact on the Cost Effectiveness figure. This is because the manufacturing cost increase and emissions savings are both directly proportional to the market penetration. Hence, if the market penetration achieved is only, say, 20% the Cost Effectiveness would still be around 109 ECU/tonne CO_2. A broadly similar argument applies to higher levels of market penetration.

Table B24 Control Option Cost Effectiveness, 2000 to 2012

Metered Dose Inhalers

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
MDI/1	0	1500	0	13.7	109
MDI/2	200	2500	0	23.4	115

B.7 Industrial Refrigeration Systems

This market segment is potentially the seventh largest HFC emitter of the 25 segments analysed. This is a complex end user market with a large number of end users, many of which have unusual or even unique refrigeration requirements. HFCs are taking some of the industrial markets previously held by CFCs and HCFCs. Ammonia has always had a reasonable penetration in the industrial market – this is now increasing slightly although there is potential for further growth. Other refrigerants such as HCs and water could also have a role to play in minimising HFC emissions. Whilst leakage from industrial ammonia systems has always been quite low, leakage from halocarbon systems has been high. There is good potential for achieving low emissions levels with HFC systems. Emission of energy related CO_2 from industrial refrigeration is significant, hence control policies should take energy into account.

Table B25 Control Mechanisms for Industrial Refrigeration Systems

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective	Too many independent users. Even in large multi-site companies there is little centralised decision making regarding refrigeration.
ii) Emission reporting mechanisms	Reasonable	Usage tends to be quite small – may be difficult to administer.
iii) End use emission regulations	Good	Historical levels of leakage are high. Excellent potential for cost effective reductions.
iv) Fiscal measures, by market segment	Reasonable	This mechanism could be used to encourage more users to adopt ammonia systems or other alternatives. It would also encourage HFC designs with low refrigerant charge, which in turn would reduce emissions.
v) Emissions trading	Good	Large differences in emission abatement costs related to various applications could make trading an effective option.
vi) End use controls	Less Effective	This mechanism would leave users with restricted design options. There are many situations where HFCs are the most effective/practical refrigerant to use.
Importance of energy efficiency	High	89% of total global warming impact is energy related.

Table B26 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	3.4	5.4	38.1
Indirect CO_2	25	25	340

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (ammonia or HCs)
- Product life emission reductions
- Product disposal emission reductions
- Improved energy efficiency

Table B27 Emission Reduction Potential, Industrial Refrigeration

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
R5/1	Use of alternative fluids + Product life + Product disposal emission reductions, low impact	-1.1	-2.2	-8.4
R5/2	Use of alternative fluids + Product life + Product disposal emission reductions, high impact	-2.2	-3.8	-13.9
R5/3	Improved energy efficiency, low impact	-2.0	-2.0	-7.0
R5/4	Improved energy efficiency, high impact	-5.0	-5.0	-39

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: The HFC bank grows steadily, replacing CFCs and HCFCs. HFCs used for new equipment at the peak rate of 2500 tonnes/year in 2001, falling to 1400 tonnes/year from 2004 (due to greater use of ammonia). Leakage rate in 2010 is assumed to be 6%. HFC bank is 21000 tonnes in 2010 and 35000 tonnes in 2020. Energy efficiency is assumed to improve 10% by 2010.

R5/1: Greater use of ammonia and better leakage prevention. Leakage rate in 2010 is assumed to be 5%. HFC bank is 18000 tonnes in 2010 and 28000 tonnes in 2020.

R5/2: Higher impact than R5/1. Leakage rate in 2010 is assumed to be 3%. HFC bank is 16000 tonnes in 2010 and 23000 tonnes in 2020.

R5/3: Improved energy efficiency – 20% better than 1998 by 2010.

R5/4: Improved energy efficiency – 30% better than 1998 by 2010. Faster implementation than R5/3.

Table B28 Control Option Cost Effectiveness, 2000 to 2012

Industrial Refrigeration

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
R5/1	200	0	-10	8.4	23
R5/2	450	0	-20	13.9	31
R5/3	500	0	-800	7.0	-43
R5/4	1000	0	-4000	39	-77

B.8 Air-conditioning, Distributed DX

This market segment is potentially the eighth largest HFC emitter of the 25 segments analysed. It includes all air-conditioning systems where refrigerant is circulated into the occupied space to carry out cooling (unlike "secondary" air-conditioning systems where chilled water is circulated). DX air-conditioning systems range from small "cassette" units and split systems of a few kW to large unitary systems of well over 100kW. Historically virtually all DX air-conditioning units used HCFC 22 as refrigerant. Currently (1998) a large proportion of new systems still use HCFC 22, although the proposed new EU Regulations on ozone depleting substances would ban the use of HCFCs in new systems from the beginning of 2001. HFC systems will probably keep a relatively high market share in the DX air-conditioning market because of the difficulties of overcoming safety problems with HCs or ammonia.

Table B29 Control Mechanisms for Air-conditioning, Distributed DX

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective (user) Reasonable (manufacturer)	Too many independent users. Could get manufacturers to improve/change designs.
ii) Emission reporting mechanisms	Less Effective	Too many small users, hence difficult to administer.
iii) End use emission regulations	Good	Could lead to significant reduction in leakage and disposal emissions.
iv) Fiscal measures, by market segment	Good	Could encourage improved leakage reduction.
v) Emissions trading	Less Effective	Too many users to set up reasonable allocation of emissions permits. Transaction costs too high.
vi) End use controls	Less Effective	Would leave end users with limited choices and potential safety problems.
Importance of energy efficiency	High	79% of total global warming impact is energy related.

Table B30 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	2.6	3.3	19.4
Indirect CO_2	10	10	130

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (HCs)
- Product life emission reductions
- Product disposal emission reductions
- Improved energy efficiency

Table B31 Emission Reduction Potential, Air-conditioning, Distributed DX

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
R6/1	Use of alternative fluids + Product life + Product disposal emission reductions, low impact	-0.7	-0.9	-4.1
R6/2	Use of alternative fluids + Product life + Product disposal emission reductions, high impact	-1.3	-1.8	-7.5
R6/3	Improved energy efficiency, low impact	-1.0	-1.0	-7
R6/4	Improved energy efficiency, high impact	-2.0	-2.0	-14

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: Use of HFCs in new equipment and for HCFC 22 retrofills peaks between 2005 and 2008 at 2000 tonnes. By 2010 this falls to 1200 tonnes/year. Leakage rates fall from 15% in 1998 to 10% by 2010.

R6/1: Slightly more use of alternative fluids. Only 1100 tonnes/year in 2010 for new equipment. Leakage rate in 2010 falls to 8%.

R6/2: More use of alternative fluids. Only 900 tonnes/year in 2010 for new equipment. Leakage rate in 2010 falls to 6%.

R6/3: Same market size and leakage rates as Business-as-Usual Scenario. Energy efficiency improved by 10% from Business-as-Usual Scenario.

R6/4: Same market size and leakage rates as Business-as-Usual Scenario. Energy efficiency improved by 20% from Business-as-Usual Scenario.

Table B32 Control Option Cost Effectiveness, 2000 to 2012

Air-conditioning, Distributed DX

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
F6/1	25	100	-20	4.1	26
F6/2	30	180	-35	7.5	23
F6/3	50	200	-750	7.0	-70
F6/4	100	300	-1500	14.0	-79

B.9 Solvents

This market segment is potentially the ninth largest HFC emitter of the 25 segments analysed. Most halocarbon solvent users have moved to NIK alternatives. A few users still require HCFC 141b and they may turn to HFC solvents when HCFC end use controls come into force.

Table B33 Control Mechanisms for Solvents

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective	Too many independent users.
ii) Emission reporting mechanisms	Less Effective	Users and usage tend to be quite small – may be difficult to administer.
iii) End use emission regulations	Reasonable	There is good potential to reduce emissions by better process design/control and better solvent recovery.
iv) Fiscal measures, by market segment	Good	This mechanism would encourage some users towards alternative solvents/technologies or to reduce HFC usage/emissions.
v) Emissions trading	Less Effective	Too many diverse applications to set up reasonable allocation of emissions permits.
vi) End use controls	Reasonable	This mechanism would have a significant impact but it would cause significant difficulties for certain users without a good alternative Hence, it may be necessary to sub-divide solvent applications into 2 groups so that certain applications could avoid the use ban.
Importance of energy efficiency	None	

Table B34 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	2.0	2.5	20.2

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (organic solvents etc.)
- Product life emission reductions
- Use NIK cleaning systems

Table B35 Emission Reduction Potential, Solvents

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
S/1	Use of alternative fluids + Use NIK cleaning systems + Product life emission reductions, low impact	-0.4	-0.5	-4.0
S/2	Use of alternative fluids + Use NIK cleaning systems + Product life emission reductions, high impact	-1.6	-2.0	-15.7

Assumptions Made in Emissions Modelling

Business As Usual: The base scenario assumes that the use of HFCs rises rapidly to 2,500 tonnes by 2004 and then continues to grow slowly at around 2% p.a. A variety of HFCs are used in this sector - the average GWP is taken to be 810. It is assumed that without intervention, industry will not look for alternatives to HFCs.

S/1: The total additional costs to industry of developing processes to use a new solvent include the accreditation of procedures, which can be a costly exercise. However, process improvements can usually be made at the same time thus giving some cost benefit. Accreditation for military and aerospace activities is also a time consuming exercise that can take many years. By increasing expenditure moderately on process improvement and system overhaul, an extra 20% saving per year is achievable.

S/2: By increasing expenditure much further on process improvement and system overhaul, a maximum of 75 % solvent usage reduction per year is achievable. This will be achievable with some additional drying costs where aqueous solutions are used. This will then slow the process down and incur extra drying costs and therefore some increased CO_2 emissions, although these are only around 1% of the HFC emissions.

Table B36 Control Option Cost Effectiveness, 2000 to 2012

Solvents

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
S1	150	0	0	4.0	37
S2	1200	0	20	15.7	78

B.10 Small Commercial Distributed Refrigeration

This market segment is potentially the tenth largest HFC emitter of the 25 segments analysed. It includes a large number of small users mostly in food/drink retailing, hotels and in the dairy industry. Use of alternative refrigerants such as HCs is possible although safety problems are difficult to solve in this category of refrigerant usage. Leakage reduction has significant potential.

Table B37 Control Mechanisms for Small Commercial Distributed Refrigeration

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective (user) Reasonable (manufacturer)	Too many independent users. Could get manufacturers to improve/change designs.
ii) Emission reporting mechanisms	Less Effective	Too many small users, hence difficult to administer.
iii) End use emission regulations	Good	Could lead to significant reduction in leakage and disposal emissions.
iv) Fiscal measures, by market segment	Good	Could encourage improved leakage reduction.
v) Emissions trading	Less Effective	Too many users to set up reasonable allocation of emissions permits. Transaction costs too high.
vi) End use controls	Less Effective	Would leave end users with limited choices and potential safety problems.
Importance of energy efficiency	High	89% of total global warming impact is energy related.

Table B38 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	1.9	1.6	19.2
Indirect CO_2	12.0	12.0	164

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (HCs)
- Product life emission reductions
- Product disposal emission reductions
- Improved energy efficiency

Table B39 Emission Reduction Potential,
Small Commercial Distributed Refrigeration

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
R3/1	Use of alternative fluids + Product life + Product disposal emission reductions, low impact	-0.7	-0.7	-4.8
R3/2	Use of alternative fluids + Product life + Product disposal emission reductions, high impact	-1.1	-1.2	-7.4
R3/3	Improved energy efficiency, low impact	-1.0	-1.0	-8.0
R3/4	Improved energy efficiency, high impact	-2.0	-2.0	-20.0

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: Use of HFCs in new equipment peaks in 1999 at 700 tonnes. By 2002 this falls to 500 tonnes/year due to market penetration of alternative fluids. Leakage rates fall from 15% in 1998 to 10% by 2010. Energy efficiency in 2010 is 15% better than in 1998.

R3/1: More use of alternative fluids. Only 400 tonnes/year for new equipment. Leakage rate in 2010 falls to 7%.

R3/2: More use of alternative fluids. Only 250 tonnes/year for new equipment. Leakage rate in 2010 falls to 5%.

R3/3: Same market size and leakage rates as Business-as-Usual Scenario. Energy efficiency improved by 22% from 1998 values.

R3/4: Same market size and leakage rates as Business-as-Usual Scenario. Energy efficiency improved by 30% from 1998 values.

Table B40 Control Option Cost Effectiveness, 2000 to 2012

Small Commercial Distributed Refrigeration

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
R3/1	20	75	-8	4.8	18
R3/2	25	130	-15	7.4	19
R3/3	50	100	-900	8.0	-94
R3/4	100	200	-2000	20	-85

B.11 Domestic Refrigeration

This market segment is only the 16th largest HFC emitter of the 25 segments analysed. However, it becomes the largest overall emitter when indirect CO_2 is taken into account. The segment includes domestic refrigerators, freezers and fridge/freezers. Prior to the Montreal Protocol all equipment in this segment used CFC 12. A significant proportion of the new equipment market has switched to HFC 134a. However HCs are becoming increasingly popular refrigerants, with very significant market penetration in Northern Europe. There is little potential to reduce product life leakage rates as they are already at a very low level. There is some potential to reduce product disposal emissions. Historical levels of energy efficiency are quite poor and there is excellent potential to improve efficiency.

Table B41 Control Mechanisms for Domestic Refrigeration

Control Mechanism	Effectiveness	Comments
i) Voluntary agreements	Less Effective (user) Good (manufacturer)	Too many independent users. Could get manufacturers to improve/change designs. Focus must be on energy efficiency.
ii) Emission reporting mechanisms	Less Effective	Too many small users, hence difficult to administer.
iii) End use emission regulations	Good	Could lead to significant reduction in disposal emissions and energy related emissions.
iv) Fiscal measures, by market segment	Less Effective	The refrigerant represents a very small proportion of equipment cost.
v) Emissions trading	Good	If applied to manufacturers.
vi) End use controls	Less Effective	Could reduce direct HFC emissions to zero, but this will only have a tiny impact on total EU emissions.
Importance of energy efficiency	High	98% of total global warming impact is energy related.

Table B42 Forecast of Emissions (Business-as-Usual Scenario)

Type of emission	Mtonnes CO_2 equiv.		
	2010	2020	2000 - 2012
Direct HFC	0.8	0.5	7.6
Indirect CO_2	30.0	30.0	420

Key Technical Opportunities for Emission Reduction:

- Use of alternative fluids (HCs)
- Product disposal emission reductions
- Improved energy efficiency

Table B43 Emission Reduction Potential,
Domestic Refrigeration

Scenario Number	Scenario Description	Emission Reduction Potential Mtonnes CO_2 equiv.		
		2010	2020	2000 - 2012
R1/1	Use of alternative fluids, low impact	-0.05	-0.2	-1.1
R1/2	Use of alternative fluids, high impact	-0.15	-0.5	-1.7
R1/3	Use of alternative fluids + Product disposal emission reductions, low impact	-0.3	-0.3	-3.0
R1/4	Use of alternative fluids + Product disposal emission reductions, high impact	-0.5	-0.5	-4.6
R1/5	Improved energy efficiency, low impact	-5.0	-5.0	-22
R1/6	Improved energy efficiency, high impact	-10.0	-10.0	-50

Assumptions Made in Emissions Modelling

Business-as-Usual Scenario: Peak use of HFCs for domestic refrigerators in 1997 at 2700 tonnes. Falls to 1200 tonnes by 2001 due to market penetration by HCs. Disposal leakage rate falls from 50% in 1998 to 20% by 2005. Energy efficiency in 2010 is 25% better than in 1998.

R1/1: Further market penetration of HCs. Annual HFC usage for new units falls to 800 tonnes by 2004. Disposal leakage as Business-as-Usual Scenario.

R1/2: Total market penetration of HCs. Annual HFC usage for new units falls to zero tonnes by 2006. Disposal leakage as Business-as-Usual Scenario.

R1/3: As R1/1, except disposal leakage rate falls to 10% by 2004.

R1/4: As R1/2, except disposal leakage rate falls to 5% by 2004.

R1/5: Same market size and leakage rates as Business-as-Usual Scenario. Energy efficiency improved by 35% from 1998 values.

R1/6: Same market size and leakage rates as Business-as-Usual Scenario. Energy efficiency improved by 45% from 1998 values.

Table B44 Control Option Cost Effectiveness, 2000 to 2012

Domestic Refrigeration

Control Option	**Cumulative Costs and Emissions, 2000 - 2010**				**Cost Effectiveness**
	Development and Capital Cost MECU	Product Manufacturing Cost Increase MECU	Product Use Cost Increase MECU	Cumulative Emissions Saving Mtonnes CO_2	ECU/tonne CO_2
R1/1	10	200	0	1.1	190
R1/2	25	650	0	1.7	400
R1/3	20	265	0	3.0	95
R1/4	35	750	0	4.6	170
R1/5	100	1500	-4000	22	-109
R1/6	150	3000	-9000	50	-117

X C FLUID PROPERTIES

Number	Chemical Formula	Usage Categories See Note 1	Flammability Category See Note 2	Toxicity Category See Note 3	ODP	100
1	$CC1_3F$	U1, U2, U3, U4	F1	T1	1.0	
2	$CC1_2F_2$	U1, U2, U4	F1	T1	1.0	
3	$CC1F_3$	U1	F1	T1	1.0	
13	$CC1_2FCC1F_2$	U1,U3	F1	T1	0.8	
14	$CC1F_2CC1F_2$	U1	F1	T1	1.0	
15	CF_3CC1F_2	U1	F1	T1	0.6	
22	$CHC1F_2$	U1, U2, U3	F1	T1	0.055	
123	$CHC1_2CF_3$	U1	F1	T2	0.020	
124	$CHC1FCF_3$	U1	F1	T1	0.022	
141b	$CC1_2FCH_3$	U2	F2	T1	0.110	
142b	$CC1F_2CH_3$	U1, U2	F2	T1	0.065	
3	CHF_3	U1	F1	T1	0.0	
2	CH_2F_2	U1	F2	T1	0.0	
25	CF_3CHF_2	U1	F1	T1	0.0	
34a	CF_3CH_2F	U1, U2, U4	F1	T1	0.0	
43a	CF_3CH_3	U1	F2	T1	0.0	
52a	CHF_2CH_3	U1,U2	F1	T1	0.0	
27ae	CF_3CHFCF_3	U4	F1	T1	0.0	
45fa		U2	F1	T1	0.0	
65mfc		U2	F1	T1	0.0	

es: U1 Refrigeration
U2 Foam Blowing
U3 Solvent
U4 Aerosol Propellant
U5 Other

Flammability Categories: F1 Non-flammable
F2 Slightly flammable
F3 Highly flammable

Toxicity Categories: T1 Very low tox
T2 Slightly toxi
T3 Highly toxic

Number	Chemical Formula	Usage Categories See Note 1	Flammability Category See Note 2	Toxicity Category See Note 3	ODP	100
	CF_4	U5	F1	T1	0.0	
	C_2F_6	U5	F1	T1	0.0	
	C_3F_8	U1, U5	F1	T1	0.0	
	C_4F_{10}	U5	F1	T1	0.0	
ethane)	CH_4	-	F3	T1	0.0	
ethane)	CH_3CH_3	-	F3	T1	0.0	
ropane)	$CH_3CH_2CH_3$	U1	F3	T1	0.0	
utane)	C_4H_{10}	U1	F3	T1	0.0	
iso-butane)	$CH(CH_3)_3$	U1	F3	T1	0.0	
	C5H12	U2	F3	T1	0.0	
ane	C_5H_{12}	U2	F3	T1	0.0	
(Ethylene)	$CH_2=CH_2$	U1	F3	T1	0.0	
(Propylene)	C_3H_6	U1	F3	T1	0.0	
luids						
monia	NH_3	U1	F2	T3	0.0	
er	H_2O	U1, U3	F1	T1	0.0	
	CO_2	U1, U2, U3, U4	F1	T1	0.0	
	SO_2	U1	F2	T3	0.0	
.1	$CBrClF_2$	U5	F1	T1	3.0	
1 (R13B1)	$CBrF_3$	U1, U5	F1	T1	10.0	
	SF_6	U5	F1	T1	0.0	
	NF_3	U5	F1	T1	0.0	

es: U1 Refrigeration
U2 Foam Blowing
U3 Solvent
U4 Aerosol Propellant
U5 Other

Flammability Categories: F1 Non-flammable
F2 Slightly flammable
F3 Highly flammable

Toxicity Categories: T1 Very low tox
T2 Slightly toxi
T3 Highly toxic

umber	Constituents of Blend	% Proportions	Usage Categories See Note 1	Flammability Category See Note 2	Toxicity Category See Note 3	ODP	10(
pes							
	12/152a	73.8-26.2	U1	F1	T1	0.7	
	12/22	25-75	U1	F1	T1	0.26	
	115/22	51.2-48.8	U1	F1	T1	0.28	
	13/23	59.9-40.1	U1	F1	T1	0.6	
ls							
	22/152a/124	53-13-34	U1	F1	T1	0.04	
	22/152a/124	61-11-28	U1	F1	T1	0.04	
	22/152a/124	33-15-52	U1	F1	T1	0.03	
	22/125/290	38-60-02	U1	F1	T1	0.02	
	22/125/290	60-38-02	U1	F1	T1	0.03	
	22/218/290	75-20-05	U1	F1	T1	0.04	
	22/218/290	56-39-05	U1	F1	T1	0.03	
	22/142b/600a	55-41-4	U1	F1	T1	0.06	
	22/143a/125	47-46-07	U1	F1	T1	0.02	
	22/124/142b	60-25-15	U1	F1	T1	0.05	
	22/124/142b	65-25-10	U1	F1	T1	0.05	
	22/152a/1270		U1	F1	T1	0.05	
pes							
	125/143a	50-50	U1	F1	T1	0	
	23/116		U1	F1	T1	0	

es: U1 Refrigeration
U2 Foam Blowing
U3 Solvent
U4 Aerosol Propellant
U5 Other

Flammability Categories: F1 Non-flammable
F2 Slightly flammable
F3 Highly flammable

Toxicity Categories: T1 Very low tox
T2 Slightly toxi
T3 Highly toxic

umber	Constituents of Blend	% Proportions	Usage Categories See Note 1	Flammability Category See Note 2	Toxicity Category See Note 3	ODP	10(
	125/143a/134a	44/52/4	U1	F1	T1	0	
	32/125/134a	20/40/40	U1	F1	T1	0	
	32/125/134a	10-70-20	U1	F1	T1	0	
	32/125/134a	23-25-52	U1	F1	T1	0	
	32/125	50-50	U1	F1	T1	0	
	32/125	45-55	U1	F1	T1	0	
	134a/218/600a		U1	F1	T1	0	
59			U1	F1	T1	0	
89	125/218/290		U1	F1	T1	0	
0	290/600a		U1	F3	T1	0	
0	170/290		U1	F3	T1	0	

es: U1 Refrigeration
U2 Foam Blowing
U3 Solvent
U4 Aerosol Propellant
U5 Other

Flammability Categories: F1 Non-flammable
F2 Slightly flammable
F3 Highly flammable

Toxicity Categories: T1 Very low tox
T2 Slightly toxi
T3 Highly toxic