Reduction of the emissions of HFC'S, PFC's and SF_6 in the European Union

Final report

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April 1999

Commissioned by the European Commission, DGXI

M717

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FOREWORD

Herewith we present the report on the reduction options of the emissions of HFC's, PFC's and SF_6 in the European Eunion. This report is a Revised Version of the report of October 1998. In this Revised Version, recent comments from industry and DG XI have been taken into account. In this revised report also reference is being made to emission projections given in a recent report for the European Commission (DG III) by March Consulting Group (September 1998).

Main focus of the study is the description of potential reduction measures of HFC's, PFC's and SF_6 in the European Eunion. It aims at giving a framework to deal with emission reduction options in a structured way. Given the relatively small size of the study, only preliminary emission estimates, emission projections and breakdowns could be given. Despite this preliminary character some robust conclusions can already be drawn on some of the reduction options.

The work for this study was mainly carried out in the first half of 1998. In the meantime, more information has become available. We are grateful for the useful comments provided for the update of the report. Other comments concerning the data in this study and the white spots that we inevitably left, are welcome and can be a useful input for follow-up research that is under way at present.

The authors

SUMMARY

Background

Within the activities to develop the Commission' Communication on a Post-Kyoto Climate Strategy analysis is made to identify the least-cost package of specific policies and measures for meeting the Community's proposed quantitative reduction for 6 (groups of) greenhouse gases under the Kyoto Protocol for the period 2008-2012. Work is already in progress for 3 of the 6 gases (CO_2, CH_4 and N_2O). This needs to be complemented by an analysis of the costs of options to reduce emissions of the remaining group of 3 gases (HFC's, PFC's and SF_6, hereafter also indicated as "halogenated gases") to identify cost-effective and effective policies.

Aim of this study

The aim of this work is to make a preliminary assessment of the options and costs of controlling the three gases HFC's, PFC's and SF_6 as well as the barriers for implementing reduction policies for these gases.

This report provides a first estimate of the development of the EU wide use and emissions of HFC's, PFC's and SF_6 in 2005 and 2010 (compared to 1990/1995) with existing (current) national and Community policies, presents existing estimates of the (capital and operating) costs and associated emission reductions (in 2010) of options to control HFC, PFC and SF_6 emissions in the EU 15, and identifies and elaborates on the barriers for implementing the identified emission reduction options.

Emission sources

In this study the following emission sources are distinguished:

Table 1 Emission sources

HFC	PFC	SF_6
• HFC production/ handling • HCFC-22 production • Refrigeration (Industrial, Commercial, Transport, Households, Stationary airco, Heat pumps) • Mobile airco • Foam • Solvents • Aerosols, Fire extinguishing, Other	• Primary aluminium production • Semiconductor manufacturing • Other	• Electricity distribution • Magnesium production • Semiconductor manufacturing • Noise isolating windows • Tyres • Other

Process emissions are responsible for a large part of emissions in countries locating these production processes: HFC-23 emissions during HCFC-22 production, PFC emissions from primary aluminium production, SF_6 emissions from magnesium production
In the future, other emission sources become relatively more important, due to achieved emission reduction in those production processes on the one hand, and increasing demand for certain applications on the other (c.f. stationary and mobile airco, specific applications for SF_6).

Emission data supplied by member states
Within the framework of the setting of the Community targets for the extra greenhouse gases resulting from the Kyoto protocol, emission estimates and projections on halogenated gases have been collected from Member States and discussed during the Expert Group meeting of February 24, 1998.
Table 2 gives emission estimates based on these reported data from member states. *Note that the emission data in this table give a preliminary breakdown based on a number of assumptions. Further improvement of these estimates is necessary.*

Some remarks should be made with regard to these estimates.
First, so far no national data have been collected from Greece, Ireland, Luxembourg, Portugal and Spain. Other countries like Austria, Belgium and Denmark do not (or only partly) give emission projections for the years 2000 and 2010.

Second, comparability of data is insufficient. Most countries, among them Austria, Belgium and Finland report *potential* emissions, referring to emissions that could occur if all halocarbons used were emitted into the atmosphere. Other countries provide *actual* emissions, differing from potential emissions because there may be a time lag between use and emission and emission could be avoided by emission prevention. Countries reporting partly actual emissions are Germany (actual emissions for 1990/1995, potential for 2000/2010) and The Netherlands. There are several methodologies for estimating actual emissions (see for example RIVM 1995, app. 5-1). Within the scope of this study it is not possible to go into more detail concerning these methodologies and resulting emission estimates. Here only ranges in emission projections are presented.

Another aspect of comparability is whether emission projections refer to the situation with or without control. For example, scenario's for the years 2000 and 2010 for The Netherlands do not include (additional) emission control. On the other hand, Germany reports scenario's with measures.

Third, there are several uncertainties concerning the emission data. It is not clear whether national reported data include all possible emission sources

(for example certain specific applications of PFC and SF_6) and to what extend these gases are used in those applications.
Also projections concerning future emissions and availability of reduction measures probably differ among countries. Besides, different mixes of HFC's with different average GWP values are assumed.

Table 2 Preliminary emission data set for cost calculations, emission projections for 2010, EU-15, Mt CO2-equivalents (business as usual)

<table>
<tr><td colspan="3">Total halogenated gases[1)]
2010: 82 Mt</td></tr>
<tr><td>HFC's[2)]
2010: 65 Mt</td><td>PFC's
2010: 5 Mt</td><td>SF_6
2010: 12 Mt</td></tr>
<tr><td>HCFC-22 production
2010: 10 Mt

Refrigeration
2010: 25 Mt
of which:[3)]
Industrial: 1 Mt
Commercial: 11 Mt
Transport: 3 Mt
Stationary airco: 1 Mt
Mobile airco: 8 Mt
Households: 0.2 Mt

Foam
2010: 25 Mt[5)]

Other
2010: 5 Mt[6)]</td><td>Aluminium production
2010: 5 Mt

Other
2010: pm</td><td>Electricity distribution
2010: 6 Mt

Other[4)]
2010: 6 Mt</td></tr>
</table>

1) Source: Expert Group 1998a. First country comments included (Expert Group 1998b).
2) Conservative (low) estimate of HFC emissions per emission source deducted from the emission ranges in table 2.1, par. 2.2.
3) Own preliminairy estimation of distribution emissions refrigeration, based on emission rates per application and estimations of numbers of installations.
4) Assumption: of which 3 Mt related to noise isolating windows.
5) Emissions might be lower as it could be argued that emissions from the foam bank will not yet have reached this level in the year 2010.
6) This should be considered as a minimum figure.

Abatement options HFC's, PFC's, SF_6

The report gives an inventory of abatement options, cost and emission reduction potentials, for all emission sources distinguished in table 1.

These abatement options are ranked by type of technology, using the following categories:

A. Reduction and prevention of leakage during use (by better installations/materials, preventive maintenance) and during installation, maintenance, refill
B. Recycling/reuse of discarded agents
C. Application of alternative agents
D. Development of modified (components of) installations, using less or no HFC's, PFC's, SF_6
E. Miscellaneous (e.g. incineration)

Table 3 summarises the abatement options, reduction potentials and cost. Note that this table gives typical figures but that in fact (wider) ranges are possible depending on size of equipment and local circumstances. Note that the effects on energy cost and energy-related CO_2-emissions are **not** included in the figures in this table.

Total abatement cost

In table 4 total abatement cost for the EU-15 are summarised. Two variants have been indicated: i) maximum use of alternatives and ii) maximum leakage reduction. Where results for those variants differ - and that is mainly the case within refrigeration - cost and emission reduction of both variants have been indicated (i/ii). Table 0.3 shows that maximum substitution of HFC's by alternatives results in higher reduction and lower cost than in case of maximum leakage control.

If measures above 100 ECU/tonne CO_2-eq. are excluded (for commercial refrigeration and stationary airco), total abatement cost will be 1000/3400 mln ECU and emission reduction 62/58 Mt CO_2-eq.

Table 4 Summary of total abatement cost estimate for 2010, EU-15

	Cost (mln ECU)	Reduction (Mt)
HFC	4200/5500	63/48
PFC	24	4
SF_6	8	7
Total	4200/5500	74/69

This first rough estimate of total abatement cost and emission reduction for the EU-15 in 2010 shows that with maximum application of abatement measures mentioned in this report an emission reduction of about 85% of

total emissions in EU 15 for these three gases together can be reached for about 5000 mln ECU.
Considering the measures included in this report, HFC reduction accounts for 85% of emission reduction and 99% of abatement cost. Also relative cost are largest for HFC emission reduction, with average abatement cost of 60-90 ECU/t CO_2-eq. (or 20 ECU/t CO_2-eq. when measures > 100 ECU/ t CO_2-eq. are excluded). For PFC and SF_6 average abatement cost are about 1 - 6 ECU/t CO_2-eq.

Conclusions

It should be noted that these results have a preliminary character and that further elaboration is necessary. However some conclusions may be drawn at this stage:

- There is a substantial potential for reducing emissions of HFC's, PFC's and SF_6.
- There are a number of low-cost options, including emission reduction at HCFC-22 manufacturing (HFC-23 incineration) and at primary aluminium production (process modifications) and leakage reduction and recycling of SF_6.

Recommendations

Further development of the emission data set and check of by national experts of emissions per application is needed. Differences in data and methodologies between countries should be identified. Furthermore, more data on measures and cost are needed to complete and check the information currently available. A workshop with main stake holders and experts may accelerate the information gathering (and reviewing) process.
This report can be considered as a basis for further elaboration in the directions mentioned above. With a more detailed and consistent emission data set for EU-15 countries and with further completed and differentiated cost data, these first rough cost estimates can be refined.

Table 3 Marginal cost and reduct ion potentials abatement options

Source	**Measure**	**Marginal emission reduction**	**Estimated emissions EU-15 in 2010 (Mt CO_2-eq.)**	**Maximum reduction potential EU-15 (Mt CO_2-eq.)**	**Marg**	
					< 0	
HFC						
HCFC-22 production	Incineration	90%	10	9		
Refrigeration general	Recycling	?	25	?		
Industrial refrigeration	Leakage reduction	67%	1	0.67		
	Alternatives	100%	1	1		
	Process modifications		1			
Commercial refrigeration	Leakage reduction	80%	11	8.8		
	Alternatives	100%	11	11		
	Process modifications	90%	11	9.9		
Transport refrigeration	Leakage reduction	80%	3	2.4		
	Alternatives	100%	3	3		
Stationary airco	Alternatives	100%	1	1		
Household refrigeration	Recollection	100%	0.2	0.2		
Mobile airco	Alternatives	100%	8	8		
Solvents, other	Process optimisations	100%	5	5		
Foam	Alternatives	100%	25	25		

Source	**Measure**	**Marginal emission reduction**	**Estimated emissions EU-15 in 2010 (Mt CO_2-eq.)**	**Maximum reduction potential EU-15 (Mt CO_2-eq.)**	**Marg**	
					< 0	
PFC						
Aluminium production:	Process modifications	85%	5	4.3		
Semiconductor industry	Alternatives, process optimisations	100%	pm			
SF_6						
High (and mid) voltage switches	Leakage reduction modifications	90%	6	5.4		
	Recycling	100%	6	6		
Magnesium production	Leakage red., alte r-natives, process mod.	90%	pm			
Semiconductor industry	Process modifications	100%	3	3		
Tyres	Alternatives	100%	pm			
Windows	Leakage reduction	50%	3	1.5		
	Recycling	75%	3	2.3		
All substances						
Other/new uses	pm					

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Within the activities to develop the Commission' Communication on a Post-Kyoto Climate Strategy analysis is made to identify the least-cost package of specific policies and measures for meeting the Community's proposed quantitative reduction for 6 (groups of) greenhouse gases under the Kyoto Protocol for the period 2008-2012. Work is already in progress for 3 of the 6 gases (CO_2, CH_4 and N_2O). This needs to be complemented by an analysis of the costs of options to reduce emissions of the remaining group of 3 gases (HFC's, PFC's and SF_6, hereafter also indicated as "halogenated gases") to identify cost-effective and effective policies. In addition, the barriers for implementing such policies for the 3 gases need to be elaborated, preferably in dialogue with industry representatives.

1.2 AIM OF THIS STUDY

The aim of this work is to assess the options and costs of controlling the three gases HFC's, PFC's and SF_6 as well as the barriers for implementing reduction policies for these gases. With help of this information the EC will be able to design a cost-effective climate strategy covering all gases.

Objectives

To reach the overall aim, the project can be split up into 5 separate objectives:

1. Provide an estimate of the development of the EU wide use and emissions of HFC's, PFC's and SF_6 in 2005 and 2010 (compared to 1990/1995) with existing (current) national and Community policies. This will be done by making use of existing estimates by the Member States and emission inventory experts;
2. Collect the best existing estimates of the (capital and operating) costs and associated emission limitations / reductions (in 2010) of options to control HFC, PFC and SF_6 emissions in the EU 15. The degree of reliability of the figures will be indicated; furthermore, it will be ensured that the cost estimates are comparable with cost estimates provided for the other 3 gases in a companion study. The inventory will be carried out by applying the same methodology that is also harnessed for the project "Economic evaluation of the quantitative objectives for climate change", where Ecofys will make similar inventories for methane and nitrous oxide.
3. Rank these options on the basis of their cost-efficiency (cost per ton CO_2 equivalent abated) in EU-wide cost-functions;
4. Identify and elaborate on the barriers for implementing the identified emission limitations / reductions options by means of different instruments (such as negotiated agreements, standards, taxes) or barriers due to a lack of available alternatives to HFC's, PFC's and SF_6. Furthermore, it

will be identified which policies and measures could be meaningfully implemented at the EU level. An overview will be given of the extend to which the concrete policies and measures can contribute to achieve the EU's Climate objective (post-Kyoto);

5. Incorporate comments from member states and stakeholders on draft reports; it is assumed that the Commission will assist in identifying these parties and generating these comments.

1.3 PROJECT APPROACH

Emission data

In this study the following emission sources are distinguished:

HFC	PFC	SF_6
• HFC production/ handling • HCFC-22 production • Refrigeration (Industrial, Commercial, Transport, Households, Stationary airco, Heat pumps) • Mobile airco • Foam • Solvents • Aerosols, Fire extinguishing, Other	• Primary aluminium production • Semiconductor manufacturing • Other	• Electricity distribution • Magnesium production • Semiconductor manufacturing • Noise isolating windows • Tyres • Other

This split up is made with regard to cost calculations of abatement options mentioned in this report.
In chapter 2, national emissions as reported by member states are given (Expert Group 1998, fax 19-2-98).

Categorisation of abatement options HFC's, PFC's, SF_6

The following types of abatement options are distinguished:

A. Reduction and prevention of leakage during use (by better installations/materials, preventive maintenance) and during installation, maintenance, refill
B. Recycling/reuse of discarded agents
C. Application of alternative agents
D. Development of modified (components of) installations, using less or no HFC's, PFC's, SF_6
E. Miscellaneous (e.g. incineration)

This categorisation is followed for all emission sources distinguished in this report. If applicable, for each type of abatement option cost indications are given. Chapter 6 contains an overview of the potential abatement measures per application and cost indications (in ECU/kt CO_2-eq. abated)

Structure of the report
Chapter 2 gives an indication of total emissions in the European Union and the share of most important applications in those emissions. Also some reservations are made concerning existing emission inventories used in this study.
In the following chapters 3 to 5, most important applications of respectively HFC, PFC and SF_6 are described. For each application, currently available information is given on 1) emission trends in the EU 15, 2) current national and international policies, 3) an overview of emission abatement options and a description of measures selected in the abatement database.

Chapter 6 gives an overview of selected abatement options with their marginal cost and relative contribution to the EU GHG emission reduction goals.

Chapter 7 of this report contains suggestions concerning types of policy instruments that can be used to lower (e.g. price- and technology-) barriers to implement the abatement options that are mentioned in this report. Examples of policy instruments are: legislative standards concerning leakage control, bans of certain substances, negotiated agreements, financial instruments (taxes, subsidies, refund systems).

Finally, Chapter 8 gives some first conclusions and recommendations.

2.

EMISSIONS OF HFC, PFC AND SF_6 IN THE EU

2.1 DATA SUPPLIED BY MEMBER STATES

Within the framework of the setting of the Community targets for the extra greenhouse gases resulting from the Kyoto protocol, emission estimates and projections on halogenated gases have been collected from Member States and discussed during the Expert Group meeting of February 24, 1998. Some remarks should be made with regard to these estimates.

First, so far no national data have been collected from Greece, Ireland, Luxembourg, Portugal and Spain. Other countries like Austria, Belgium and Denmark do not (or partly) give emission projections for the years 2000 and 2010.

Second, comparability of data is insufficient. Most countries, among them Austria, Belgium and Finland report *potential* emissions, referring to emissions that could occur if all halocarbons used were emitted into the atmosphere. Other countries provide *actual* emissions, differing from potential emissions because there may be a time lag between use and emission and emission could be avoided by emission prevention. Countries reporting partly actual emissions are Germany (actual emissions for 1990/1995, potential for 2000/2010) and The Netherlands.
There are several methodologies for estimating actual emissions (see for example RIVM 1995, app. 5-1). Within the scope of this study it is not possible to go into more detail concerning these methodologies and resulting emission estimates. Here only ranges in emission projections will be mentioned, if possible.
Another aspect of comparability is whether emission projections refer to control or no control. For example, scenario's for the years 2000 and 2010 for The Netherlands do not include (additional) emission control. On the other hand, Germany reports scenario's with measures.

Third, there are several uncertainties concerning the emission data. It is not clear whether national reported data include all possible emission sources (for example certain specific applications of PFC and SF_6) and to what extend these gases are used in those applications.
Also projections concerning future emissions and availability of reduction measures probably differ among countries. Besides, different mixes of HFC's with different average GWP (Global Warming Potentials) values are assumed.

Below, emission estimates and projections are given for the EU, based on reported data from member states and completed with data from other sources and own estimates. The data set thus obtained forms the starting point for the cost calculations in this study. However, when better emission data become available, cost calculations can be applied to those new figures.

2.2 EMISSIONS IN 1990/1995 AND PROJECTIONS

According to the data provided by the Member States, total emissions of the halogenated gases HFC's, PFC's and SF_6 in the European Union (EU-15) amount to about 60 Mt CO_2-equivalents, this is about 1-2% of total EU-15 emissions of CO_2, CH_4 and N_2O in 1990.
Emissions of halogenated gases of 60 Mt CO_2-equivalents include rough estimates for the countries Greece, Ireland, Portugal and Spain based on the reported data from the other 11 countries (Expert Group 1998, table 2).

Given reported data from 11 member states, largest contribution to total fluorocarbon emissions in 1995 comes from HFC's (64%), then SF_6 (25%) and third PFC's (11%).

In 2010, total reported fluorocarbon emissions are about 82 Mtonne CO_2-equivalent, an increase of about 20-40% compared to emissions of 60 Mtonne in 1995. When breaking down these figures, it appears that the share of HFC's rises to 79% and the shares of SF_6 and PFC's decrease to 15% and 6%.

Tables 2.1 and 2.2 summarize the available emission data. Figures in table 2.1 are based on country reports (Expert Group 1998, table 2).
In addition to the totals as reported by the Member States, a breakdown of total emission data for the major emission sources is given (table 2.2), for current emissions and projected emissions in 2010. To give a rough idea of main emission sources, in this table HFC emissions are divided in emissions from HCFC-22 production, refrigeration, foam and other. PFC emissions are divided in emissions from aluminium production and other sources, SF_6 emissions are divided in emissions from use of SF_6 in electricity distribution and other sources. Data on the individual emission sources are based on several – contradicting – literature sources. Therefore ranges are indicated to illustrate the uncertainty of existing emission estimates and the breakdown of emissions. The following remarks are added to these figures.

HCFC-22 production
HCFC-22 production is estimated to be between 53 kt [Solvay 1997] and 80 kt in 1995 [Expert Group 1997]. Assuming an emission rate without control of 2-4%, total HFC-23 emissions in 1995 amount to about 12 - 37 Mtonne CO_2-equivalent, assuming no abatement. If abatement is assumed, emissions may be lower.
When considering current abatement initiatives, abatement of HFC-23 emissions from HCFC-22 production is already applied in France and Spain. In The Netherlands and UK, emission abatement is planned for in the near future. Therefore, current emissions with control reported by member states will be lower.
The new EU regulation will most likely affect the total HCFC-22 production in 2010. March Consulting Group 1998 (p. 33) gives an HFC emission for HCFC-22 production in 2010 of 9.7 Mt CO_2-eq.

Refrigeration

Demand for (H)(C)FC's in 1993 was estimated as 64.5 kt (HCFC-22: 34 kt, CFC-12: 27 kt, CFC-115 3.5 kt [Elf Atochem 1996]).

Equating use/sales with emissions, and a substitution rate by HFC's of 100% maximum future emissions would amount to 97 Mt CO_2-eq. However, the substitution rate in 1995 is still rather limited.

March Consulting Group 1998 (p. 33) gives an HFC emission for refrigeration in 1995 of 4.3 Mt CO_2-eq.

Assuming the 2010 use/sales level of refrigerants equal to 1993 and a substitution rate by HFC's of 100%, maximum future emissions would amount to 97 Mt CO_2-eq. However, emissions from refrigeration are likely to be significantly lower as a results of the ongoing shift in the sector to other substances and more efficient technology with lower refrigerant charge. On the other hand, projections of future emission growth depend on assumptions regarding the increasing use of applications like (mobile) airco. Therefore, a preliminary range is given of 0-100 Mt Mt CO_2-eq.

March Consulting Group 1998 (p. 33) gives an HFC emission for refrigeration in 2010 of 28.2 Mt CO_2-eq.

Foam

In this report it is assumed that in 1995 no substitution of CFC's and HCFC's by HFC's has taken place yet.

Industry assumes for the demand of HFC for rigid foam a range of 0 to 40 kt in 2020 [Elf Atochem 1996]. Taking into account a GWP of 800 and 0% recovery, maximum emissions could be calculated as 32 Mt CO_2-equivalents (in 2020). March Consulting Group 1998 (p. 33) gives an HFC emission for foam in 2010 of 13.6 Mt CO_2-eq.

Other HFC emission sources

Industry gives the following HFC emission estimates for the year 2020. Estimates for 2010 are not given. Therefore in this report we use these 2020 emissions for the year 2010.

Aerosol emission estimates for 2020 vary between 5-10 kt HFC or 7-13 Mt CO_2-eq. [Elf Atochem 1996]), and 18-27 kt HFC or 25-38 Mt CO_2-eq., [Expert Group 1997].

Solvent emissions in 2020 vary between 1-3 kt HFC, which is 1-4 Mt CO_2-eq., depending on GWP value assumed: a GWP of 1500 [Elf Atochem 1996] or 4000 [Expert Group 1997].

Emissions from fire extinguishers are estimated to be 1 Mt in 2020 [Elf Atochem 1996].

Adding these figures, total Other HFC emission estimates for the year 2020 vary between 9 - 43 Mt CO_2-equivalent.

March Consulting Group 1998 (p. 33) gives a total of Other HFC emissions of 14 Mt CO_2-eq.: HFC emissions from aerosols in 2010 of 11.8 Mt CO_2-eq.

(general aerosols 7 and MDIs 4.8 Mt CO_2-eq.), solvents 2.0 Mt CO_2-eq. and fire extinguishers 0.2 Mt CO_2-eq.

Aluminium production

Based on average emission factors given by the European Aluminium Association [EAA, 1997] the emissions from primary aluminium production (without control) can be estimated as about 9 Mt CO_2-eq. in 1995 and 7 Mt CO_2-eq. in 2010.

Electricity distribution

Using estimates based on Olivier [1998], SF_6 emissions in 1995 are about 5 Mt CO_2-eq. Assuming improved leakage prevention due to new switches that will be installed after the year 2000, emissions will decrease.

Table 0.1 Emissions 1995 and 2010 in EU-15, in Mt CO_2-equivalents, Member State estimates

Total halogenated gases[1)] 1995: 58 Mt 2010: 82 Mt		
HFC's[1)] 1995: 37 Mt 2010: 65 Mt	**PFC's**[1)] 1995: 7 Mt 2010: 5 Mt	**SF_6**[1)] 1995: 14 Mt 2010: 12 Mt

1) Source: Expert Group 1998a. First country comments included (Expert Group 1998b).

Table 0.2 Emissions 1995 and 2010 in EU-15, in Mt CO2-equivalents, estimates based on other sources.

HFC's	**PFC's**	**SF_6**
HCFC-22 production 1995: 12-37 Mt 2010: 10 Mt	*Aluminium production* 1995: 9 Mt 2010: 7 Mt	*Electricity distribution* 1995: 5 Mt 2010: 5 Mt
Refrigeration 1995: 4.3 Mt[1)] 2010: 0-100 Mt[2)]	*Other* 1995: ? 2010: ?	*Other* 1995: ? 2010: ?
Foam 1995: 0 Mt 2010: 0-32 Mt		
Other 1995: ? Mt 2010: 9 – 43 Mt		

1) Source: March Consulting Group 1998, p. 33.

2) Subject to (amongst others) (H)CFC substitution rate. March Consulting Group 1998 (p.33) gives HFC emissions of 28,2 Mt (business-as-usual scenario 2010).

3) Subject to (amongst others) (H)CFC substitution rate. March Consulting Group 1998 (p.33) gives HFC emissions of 13.6 Mt
4) March Consulting Group 1998 (p.33) gives HFC emissions of 14 Mt.

3.

HFC'S

3.1 INTRODUCTION

According to the data reported by Member States, HFC emissions in 1995 contributed for about 64% to total HFC-, PFC- and SF_6 emissions (in CO_2-eq.) in EU-15. Large contributor in 1995 in the EU-15 was HCFC-22 production (HFC-23 emissions as by-product).
Other emission sources distinguished in this study are: HFC production and handling, Refrigeration, Mobile airco, Solvents, Foam, and "Other" (Aerosols, Fire extinguishing).

Emissions related with production and handling of fluorocarbons are not further elaborated upon in this report, as few data production and emissions in the EU are available (Olivier [1998] assumes an emission factor of 0.5% of total production).

Within the category 'Refrigeration', the following applications are specified: Industrial, Commercial, Transport, Stationary air-conditioning, Household refrigeration and Heat pumps.
The distinction between these applications is necessary as there is a large variation in emission trends, abatement options, implementation rates and costs among the specific applications.

3.2

EMISSIONS HFC-23 DURING PRODUCTION OF HCFC-22

3.2.1 Emissions

In 1995 there where the following HCFC-22 producing countries: France, Italy, Germany, Greece, Netherlands, Spain and UK. Annual emission of HFC-23 as by product of the HCFC production amount to about 2% to 4% of HCFC-22 production [Expert Group 1997, App. A.7.3].
HFC-23 has a Global warming potential of 11700 which is relatively high compared to other HFC's whose Global Warming Potentials mainly vary between 1000-3000 and do not exceed 6800.

Current and potential applications of HCFC-22 are:
Aerosol propellants: as alternative aerosol propellant instead of CFC-11
Foam blowing: as alternative in polyurethane foams to replace CFC-11, as alternative in phenolic insulation board to replace CFC-11 and CFC-113, and as alternative in blowing polyolefin foams, polystyrene, extruded boardstock and billet to replace CFC-12.
Refrigeration: alternative for CFC-11, CFC-12 and R-502 in most cooling systems, air-conditioning, heat pumps, also used in blends (R-401A/B, R-402A/B) to replace CFC's in various cooling systems [RIVM 1995].
Feedstock: as raw material in the production of other chemicals and products.

In some countries HCFC producers have already taken measures to reduce HCFC emissions or are planning to do so. For example, France, Germany and Spain already reduced their emissions by incineration of flue gasses [Elf Atochem 1996]. Similar initiatives are developed in the Netherlands, UK and Italy [Du Pont 1998].

3.2.2 Current national or EU policies

According to the Montreal Protocol, HCFC's have to be phased out by the year 2030.
New EU regulation on ozone depleting substances is due to be adopted later this year (Common position adopted 22 February 5748/99). Under this regulation, most HCFC uses will be phased out between 2000 and 2004, with the last phase-out date 1 January 2010. HCFC production for non-feedstock applications will also be phased out starting with a 65% cut by 1 January 2008 compared to the 1997 level. This will most likely affect the total HCFC-22 production even if feedstock uses is exempted from the bans in the regulation.

In the USA, additional restrictions have been formulated (use of HCFC is not allowed when alternatives are available).

3.2.3 Measures

HFC-23 emissions related to HCFC-22 production can be prevented or reduced in two ways: i) during production, and ii) restricting the use of HCFC-22. Restriction of the use of HCFC-22 is discussed in the next paragraphs regarding other applications of HFC's. This paragraph concerns HCFC-22 production related emissions.

Table 0.1 gives an overview of reduction measures at the production stage.

Table 0.1 Reduction measures emissions HCFC-22 production.

Name of measure	Reduction	Remarks	Data source
B. Recycling			
Recycling of HFC-23 from flue gases of HCFC-22 production	?	research for cost-effective way	RIVM 1996, p.32
E. Miscellaneous			
Incineration	50-90%	In NL: 50-90% reduction in 1998-2003. In GER: incin-eration; small part recycled. In UK: project aiming at more than 90% reduc-tion.	Expert Group 1997; UBA-FW 97-072, p. 125; Du Pont, 1998

The reduction measure included in the calculations in this report is incinera-tion.

Ad. E Incineration

Incineration of flue gasses reduces emissions about up to 90%. Estimation of annual investment and operational cost: Dfl. 10,000/ton HFC-23 [Du Pont 1998], which is equivalent to about 0.40 ECU/t CO_2-eq.

3.3

INDUSTRIAL REFRIGERATION

3.3.1 Emissions

Industrial refrigeration includes three applications:
a. process refrigeration: integrated part of the production process
b. industry refrigeration: freezing of products
c. storage refrigeration: conservation of products

Most large installations use ammonia as refrigerant. Installations in the Food and Beverages sector use partly fluorinated, partly other refrigerants. Smaller installations for a large part contain chemical cooling agents, including HCFC-22 [Novem/Ecofys 1997b; Prospect 1997].

Industrial refrigeration systems can be classified according to refrigerant content:

- small installations (3-30 kg)
- medium size (30-300)
- large installations (>300kg)

3.3.2 Current national or EU policies

Relevant is the phasing out of CFC's and HCFC's conform the Montreal Protocol, inducing the retrofit or replacement of installations containing CFC-12 or HCFC-22.
In the current EU regulation (3093/94), HCFC's are banned from 1 January 2000, in equipment produced after 31 December 1999, in public and distribution cold stores and warehouses, and for equipment of 150 kW and over, shaft input.
In the new EU regulation (Common position 5748/99), the use of HCFC's is banned:

- from 1 January 2001, in all refrigeration and air-conditioning equipment produced after 31 December 2000
- with the exception of fixed air-conditioning equipment, with a cooling capacity of less than 100 kW, where the use of hydrochlofluorocarbons shall be prohibited from 1 January 2003 in equipment produced after 31 December 2002
- and for reversible air-conditioning/heat pump systems where the use of hydrochlofluorocarbons shall be prohibited from 1 January 2004 in all equipment produced after 31 December 2003.

Some countries (like Denmark, Germany, Netherlands, Iceland, Sweden, Switserland and Austria) have faster phasing out schemes than the Montreal Protocol [Novem/Ecofys 1997b, p. 18]. This induced the search for alternatives, both HFC's and other refrigerants.

In The Netherlands, technical requirements for refrigeration equipment and maintenance are included in a directive on leakage control refrigerators, the so called RLK 1994. This directive applies for refrigeration equipment, air-conditioning and heat pumps with a capacity of more than 500 Watt [Staatscourant 243, p 12-16, 16-12-1994].
In addition, persons and companies handling refrigeration systems and refrigerants should hold an official certificate, assigned by STEK, a foundation especially set up for this purpose [Novem/Ecofys 1997b, p.18].

In the UK, Air Conditioning and Refrigeration Industry made a declaration of intent with respect to among others system handling and professional standards, leakage reduction and improvement of information [Expert Group 1997, App. A.7.2].

3.3.3

Measures

Table 0.2 summarises reduction options for industrial refrigeration.

Table 0.2 Reduction measures industrial refrigeration

Name of measure	Marginal reduction	Remarks	Data source
A. Leakage			
Reduction of leakage	Average reduction of leakage from 15% to 5%	Improved maintenance, technical and material improvements	Novem/Ecofys 1997b, p.25
C. Alternatives			
Ammonia as cooling agent (smaller installations)	100%	current trend: "down scaling": use of ammonia for smaller installations	Novem/Ecofys 1997b, p.23/24
Water as refrigerant	100%		Novem/Ecofys 1997b, p.24;
Hydrocarbons	100%		Prospect 1997, p. 20
D. Process modifications			
Installation of indirect and compact systems	90-95%	Reduction by use of harmless transport mediums, such as ice crystals, brine, CO_2	Novem/Ecofys 1997b, p. 26;

Due to large differences in size of installations for industrial refrigeration, this study distinguishes between i) large installations (> 300 kg) and ii) small and medium installations (3-300 kg).

It is assumed that large installations all use ammonia as refrigerant.
For small and medium installations, the following abatement options are relevant:

A. Leakage reduction
C. Alternatives
D. Process modifications

Ad A. Leakage
Due to regulation with respect to leakage in The Netherlands (STEK, RLK), the annual emissions due to leakage decreased substantially, depending on age and type of installation (Novem/Ecofys 1997b, p.21-24).

In this study it is assumed that for existing small and medium installations regulation concerning control and maintenance reduces leakage from 15% to 5% for existing installations, a marginal reduction of 66%. All new installations are assumed to have an average annual leakage of 5%.

Rough estimate of cost of leakage reduction for a refrigerant system: fl. 5000 concerning replacement of parts of the installation and labour cost (Novem/Ecofys 1997b, p.36).

Ad C. Alternatives:
Main alternative refrigerants are ammonia and hydrocarbons.
The use of hydrocarbons is said to be cost-effective as they use less refrigerant, are more energy efficient and are compatible with most compressor oils and materials. Main disadvantage is their flammability, which can give rise to significant costs, especially during production of the installations (Prospect 1997 p. 23-24).

Additional cost of installations using ammonia are about 20-30% higher than the smaller installations using H(C)FC.
Despite these initial additional costs, on the long term the use of ammonia as refrigerant will probably be cheaper than chemical refrigeration, due to the lower price of ammonia compared to H(C)FC's and lower energy use of ammonia cooled installations.
Besides, price differences may level out due to increasing demand for ammonia installations.

Ad. D. Process modifications
The use of indirect and compact systems reduces the quantity of refrigerant with 90-95%.

3.4 COMMERCIAL REFRIGERATION

3.4.1 Emissions

Commercial refrigeration concerns refrigeration systems in supermarkets and the hotel and catering industry.
Up to now mainly direct systems are used, containing chemical refrigerants (including HCFC-22). Part of those (smaller) installations have been retrofitted from CFC-12 and/or HCFC-22 to HFC-134a.
Natural cooling agents are scarcely used so far, due to safety conditions.

3.4.2 Current national or EU policies

See par. 0

3.4.3 Measures

Table 0.3 gives an overview of emission abatement options and alternatives for commercial refrigeration.

Table 0.3 Reduction measures Commercial refrigeration

Name of measure	Reduction	Remarks	Data source
A. Leakage			
Reduction of leakage	80% reduction of leakage (decrease leakage from 15% to 3%)	Improved maintenance (RLK), technical and material improvements	Novem/Ecofys 1997b p.25
B. Alternatives			
Propane/butane as cooling agent	100%		Novem/Ecofys 1997b, p.26
Ammonia as cooling agent	100%		Prospect 1997 p.23-24; Novem/Ecofys 1997b, p.26
CO_2 as cooling agent	100%		Novem/Ecofys 1997b, p.26
D. Modifications			
Installation of indirect and compact systems	90-95%	Reduction by use of harmless transport mediums, such as ice crystals, brine, CO_2	NOVEM/Ecofys 1997b, p. 26

The following 3 abatement options for an average installation for commercial refrigeration are distinguished:

A. Leakage reduction
B. Alternatives
C. Modifications

Ad A. Leakage

With regulation with respect to leakage, the annual emission in existing commercial refrigeration is assumed to decrease from 15% to 3% of the refrigerant in the installation, a marginal emission reduction of 80%.

The percentages mentioned above are averages: installations installed before the early 90's still had emission percentages of 40%, annual leakage of new installations are about 3%.

Assumption additional investment costs: fl. 5.000 [Novem/Ecofys 1997b].

Ad C. Alternatives:

Alternative refrigerants in commercial refrigeration are ammonia, CO_2, propane/butane.

Assumption additional cost of ammonia installation:
fl. 10.000 [Novem/Ecofys 1997b].

It is expected that in The Netherlands and other countries in the next 5 to 7 years 60-65% of all new installations in supermarkets will contain ammonia.

Ad D. Modifications:

The use of indirect and compact systems reduces the quantity of refrigerant with 90-95%

In this study it is assumed that replacement of a direct installation takes place after amortisation of the old installation, reducing the amount of refrigerant from 30 kg to 3 kg.

Costs of this measure concern additional investment costs (if compact and indirect installation is more expensive than direct installation) and cost savings in terms of reduced amount of refrigerant and/or energy use.

3.5

TRANSPORT REFRIGERATION

3.5.1 Emissions

About 99% of cooling agents in transport refrigeration are chemical refrigerants [Novem/Ecofys 1997b, p. 24].

3.5.2 Current national or EU policies

See par. 0

3.5.3 Measures

Table 0.4 shows abatement options for Transport refrigeration.

Table 0.4 Reduction measures Transport refrigeration

Name of measure	Reduction	Data source
A. Leakage		
Replacement copper piping by steel, improved maintenance	Decrease leakage from 30-50% to 7% is possible	NOVEM/Ecofys 1997b, p. 28
C. Alternatives		
Replacement chemical refrigerant by hydrocarbons	100%	NOVEM/Ecofys 1997b p.28

The following abatement options for HFC emissions in transport refrigeration are distinguished:
A. Leakage reduction
C. Alternatives

<u>Ad A. Leakage</u>
Due to regulation with respect to leakage the yearly average emissions due to leakage are assumed to decrease from 40% to 7%, a reduction of about 80%. New installations in transport refrigeration have leakage percentages of 7%.

<u>Ad C. Alternatives:</u>
Alternative refrigerant mentioned in literature in transport cooling are hydrocarbons.

3.6

MOBILE AIR-CONDITIONING

3.6.1 Emissions

Car airco's contain 0.8 to 0.9 kg refrigerant, new cars with HFC-134a, older cars with (regenerated) CFC-12 or HFC-blends.

3.6.2 Current national or EU policies

See par. 0

3.6.3 Measures

Table 0.5 shows emission reduction measures for mobile airco's.

Table 0.5 Reduction measures Mobile air-conditioning

Name of measure	Reduction	Remarks	Data source
A. Leakage			
Decreasing leakage by using r e-frigerant as lubricant for co m-pressors	50%?	already applied in some types of cars	Novem/Ecofys 1997b
Courses, certificates for tapping refrigerants from car wrecks	?		Novem/Ecofys 1997b p.32
C. Alternatives			
CO_2 as cooling agent	100%	testing phase: efficiency at least equal to CFC-12 airco's	Novem/Ecofys 1997b p.32
Hydrocarbons as cooling agents	100%	not yet accepted due to safety regulations	Novem/Ecofys 1997b p.32
D. Modifications			
Indirect system (eventually using propane/butane as refrigerant) and brine as transport medium	reduction use of refrigerant at least 10-15%	development in next two years	Novem/Ecofys 1997b p.32

Assumption in database: emission reduction for mobile air-conditioning consist of the following abatement options for an average installation:
A. Leakage reduction
C. Alternatives
D. Modifications

<u>Ad A. Leakage</u>
Estimates about yearly emissions due to leakage vary between 10-50%.
Decrease in leakage of 50% possible due to modification, improved maintenance and tapping agent from car wrecks.

Measure in database (assumption): "Decrease leakage 30% to 10% due to maintenance and better removal in discard phase".

Ad C. Alternatives:
Alternative agents mentioned in literature are ammonia, hydrocarbons, CO_2, propane/butane, oxygen, electricity.
Assumption in database: use of hydrocarbons as alternative agent.

Ad D. Modifications:
Measure: Indirect systems to reduce the quantity of agent: from 0.8 kg to 0.7 kg agent.
Costs: 10% more expensive than current airco's.

3.7

HOUSEHOLD REFRIGERATION

3.7.1 Emissions

The amount of refrigerant in household refrigeration (about 0,5 kW) is about 0.1 kg. At least in Germany, Scandinavia and The Netherlands, sales of new appliances containing propane/butane are clearly dominating. However this is not evident for the EU as a whole. Older appliances use CFC-12 and HFC-134a. Annual leakage are relatively low: 1% of refrigerant.

3.7.2 Current national or EU policies

See par. 0

3.7.3 Measures

Table 0.6 gives reduction measures for household refrigeration.

Table 0.6 Reduction measures Household refrigeration

Name of measure	Reduction	Remarks	Data source
B. Recycling/reuse			
Structure for recollection and removal of refrigerants from discarded household appliances	?	Already common practice in Netherlands	Novem/Ecofys 1997b p.33
C. Alternatives			
Propane/butane as cooling agent	100%	Netherlands: 90?% of new appliances with propane/buthane Germany: (>?)90%	Novem/Ecofys 1997b p.34
Ammonia as cooling agent	100%		Novem/Ecofys 1997b p.26

Assumption database: emission reduction consist of the following 2 abatement options:
B. Recycling
C. Alternatives
Due to high labour costs in combination with relatively low leakage percentage, retrofit of existing refrigerators is not considered as an option.

<u>Ad B. Recycling</u>
Recollection and recycling for CFC's and HFC's in old refrigerators.

<u>Ad C. Alternatives:</u>
Alternative agent is propane/butane, with no additional cost.
Measure in database: use of propane/butane as alternative agent, for new refrigerators, without additional cost.

3.8

LARGE STATIONARY AIR-CONDITIONING

3.8.1 Emissions

In The Netherlands, more than half of all stationairy airco's still contain CFC's. Besides, HCFC's and HFC's are used.
Residential use of air-conditioning, ventilation and heat pumps in The Netherlands is expected to rise by 10% within the next 10 years (Verac 1998).
Leakage are very small, so up to now expensive regenerated CFC's can be used for refill.

3.8.2 Current national or EU policies

In The Netherlands, for air-conditioning systems with a capacity above 500 Watt leakage are controlled by the RLK directive (see par. 3.3.2).

3.8.3 Measures

Table 0.7 gives an overview of emission reduction options for stationary airco.

Table 0.7 Reduction measures stationary air-conditioning (Offices)

Name of measure	Reduction	Remarks	Data source
C. Alternatives			
Ammonia as cooling agent	100%		NOVEM/Ecofys 1997b p.29.
D. Modifications			
Installation of indirect and compact systems	90-95%	Quantity of cooling agent is reduced by use of harmless transport mediums, such as ice crystals, brine	NOVEM/Ecofys 1997b, p. 29

In this study the following abatement options for stationary airco are considered:
C. Alternatives
D. Modifications

As current leakage are relatively limited (less than 2%), no additional measure concerning leakage reduction is assumed.

<u>Ad C. Alternatives:</u>
One of the alternative refrigerants for stationary airco is ammonia.

<u>Ad D. Modifications:</u>
Measure: Indirect and compact systems to reduce the quantity of agent.

3.9 HEAT PUMPS

Many abatement options for refrigerators also apply to heat pumps of similar capacity.
Incentive programs NOVEM and IEA are directed to the development and use of natural mediums and the adjustment of installations [Novem/Ecofys 1997 b p.41].

3.10

FOAM

3.10.1 Emissions

Before the Montreal Protocol, CFC's (CFC-11 and CFC-12) were used as blowing agents for both open foams (cushioning and packaging) and closed foams (insulation foams).

HCFC's are the major current alternative for foam blowing as transitional substance (as long as use of HCFC's is allowed).
Most important zero-ODP alternatives for blowing agents are CO_2, hydrocarbons and HFC's (HFC-152a, HFC-134a). About 30% of polyurethane foams for the construction industry in the European Union was blown with hydrocarbons in 1996.

European H(C)FC producers mention liquid HFC's (245, 356 and 365) as most effective future alternatives [Prospect 1997, p.35].
Moreover, alternative materials and technologies exists. Examples are vacuum panels for domestic refrigeration.

Emissions take place during foam blowing, use and when foams are discarded. The following variables are relevant for estimating emissions: emission rates, former (H)CFC markets and the share of (H)CFC's used for foam blowing, the rate of substitution of (H)CFC's by HFC's, and the mix of HFC's used with their GWP-values.

Estimations about emission rates of handling losses during production and servicing vary between 5% and 10% of production [BRUFMA 1997, fax 10-3-97; A-Gas 1997, fax 6-3-97]
Different estimations of emissions during use of foams are given: 0% (when foam is completely covered in the application), 10-15% [EPFA 1996, fax 29-11-96] or 40-45% [Expert Group 1997, p. 89]. The residual part will be emitted in the discard phase or recovered.
Maximum emissions (emission = use) occur when no recovery takes place. On the other hand, assuming full recovery and 10% emissions during life time, emissions will be 15% of the used blowing agent.

Sales of CFC and H(C)FC in the EU have been - according to McCullogh & Midgley [ICI 1997] - 353 kt in 1986, 219 kt in 1990, 190 kt in 1992 and 120 kt in 1995. Share of H(C)FC for foam blowing was 42.1% in 1992 according to ECFCTC (European fluorocarbon technical committee).

Estimations of average GWP values to calculate emissions in CO_2-equivalents vary between 1300 [ICI 1997, fax 13-02-97] and 800 [Elf ATOCHEM 1997, fax 4-11-97; Solvay group 1997, fax 3-1-97], the latter GWP value being valid for HFC-245fa and HFC-365mfc whose use is currently planned, while HFC-236, -245ca and -143a are NOT planned for foam blowing [Solvay group 1997, fax 3-1-97].

In this report it is assumed that in 1995 no substitution of CFC's and HCFC's by HFC's has taken place yet.
Industry assumes for the demand of HFC for rigid foam a range of 0 to 40 kt in 2020 [Elf Atochem 1996]. Taking into account a GWP of 800 and 0% recovery, maximum emissions could be calculated as 32 Mt CO_2-equivalents (in 2020).

3.10.2 Current national or EU policies

In the new EU Rregulation (Common position 5748/99), the use of HCFC's is banned:
- from 1 January 2000, for the production of integral skin foams for use in safety applications and polyethylene rigid insulating foams;
- from 1 January 2002 for the production of extruded polystyrene rigid insulating foams, except where used for insulated transport;
- from 1 January 2003, for the production of polyurethane foams for appliances, of polyurethane flexible faced laminate foams and of polyurethane sandwich panels, except where these latter two are used for insulated transport;
- from 1 January 2004, for the production of all foams, including polyurethane spray and block foams.

Some Member States have legislation aiming at an earlier phase out: Sweden already phased out the use of HCFC's, Denmark, Germany, Austria and Finland will phase out the use of HCFC's between now and 2002 at the latest.

3.10.3 Measures

Table 0.8 gives an overview of emission reduction options for closed foam.

Table 0.8 Reduction options closed foam

Name of measure	Reduction	Remarks	Data source
C. Alternatives			
CO_2, hydrocarbons as alternative blowing agents	100%	Use of CO_2 may lead to a loss in energy efficiency of about 5% or more, but this can be compensated by increasing thickness of the material in some cases.	Prospect 1997, p.34
Vacuum panels as alternative material in domestic refrigeration	100%	20% lower energy consumption, 25% increase in internal volume, higher cost	Prospect 1997, p.39

Other insulation materials: e.g. fibreboard, mineral fibre, cellular glass	100%		
New technologies/substances: aerogels, alginsulate process	100%		Ecofys 1996, p.45; Prospect 1997, p.53.
E. Miscellaneous			
Incineration			Prospect 1997, p.36

Ad C. Alternatives

Alternative blowing agents

Use of hydrocarbons and CO_2 may increase product cost by increasing thickness of the material in order to compensate for the loss in energy efficiency (energy efficiency loss about 5% or more for hydrocarbons, CO_2 as well as HFC-134a). Use of hydrocarbons in addition require a one-time capital investment in safety equipment. Long-term operating costs however are generally lower. However, cost increases represent only a small percentage of the total price of most products [Prospect 1997, p. 34-35].

Alternative insulation products

There are various - proven - alternative insulation products. Some of them are more costly (like vacuum panels), others are as expensive as foams, or even less expensive if energy savings are reckoned with [Ecofys 1996, p.46].

Ad E. Incineration

As recycling and reuse is not yet considered as a technically feasible option by the foam sector [Prospect 1997, p. 36], incineration is the last option in the discard phase of foams.

3.11

SPECIFIC APPLICATIONS HFC/PFC

3.11.1 Emissions

This paragraph deals with the use of HFC's and PFC's as solvents, for etching and as isolation medium. These HFC's and PFC's are substitutes for CFC-11, CFC-113 and 1,1,1-trichloorethaan, of which production is prohibited from respectively 1995 and 1996.

After 2000, PFC's are mainly used for etching; For other applications (excluding the aluminium industry) a decrease of use is expected.
HFC's are used for a.o. precision cleaning and new applications in space aviation and the computer sector.

3.11.2 Measures

Table 0.9 Reduction measures HFC's, PFC's for specific applications

Name of measure	Reduction	Remarks	Data source
B. Recycling/reuse			
Development of collection and re-use of PFC's and HFC's	?	Suppliers of substances are developing recollection systems. Initiatives in semiconductor industry (US, Japan, Europe) concerning reduction of PFC, SF_6 emissions	Novem/Ecofys 1997, p.48
C. Alternatives			
Oxygenated organic solvents (esters, alcohol, ketones)	100%		Novem/Ecofys 1997, p.47
Other solvents (terpenes, benzofluorids)	100%		Novem/Ecofys 1997, p.47
Cleaning with hydrocarbons such as petroleum	100%		Novem/Ecofys 1997, p.47
Cleaning processes on water basis	100%		p.47
D. Modifications			
Alternative processes to avoid use of CFC's in cleaning processes	100%	cleaning with air, nitrogen (high pressure); no cleaning	Novem/Ecofys 1997, p.47
Application in closed systems	100%		Novem/Ecofys 1997, p.47/48
Optimisation of processes	?	reduction processing time	Novem/Ecofys 1997, p.48
Optimisation installations by producer	?		Novem/Ecofys 1997, p.48
E. Miscellaneous			
Incineration of rest products	?		Novem/Ecofys 1997, p.48

Ad B. Recycling/reuse

Recycling of HFC's is already technically possible. Within two years, the quantity of HFC's recollected will be sufficient to make it also economically feasible. Cost of recycling are 10-15 ECU/kg, about 8-12 ECU/t CO_2-eq. [Novem/Ecofys 1997b, p. 48].

Ad C. Alternatives

In a number of cases alternatives are available. Cost of using alternatives are assumed to be below 0 ECU/t CO_2-eq. [Novem/Ecofys 1997b, p. 48].

Ad D. Process modifications

Cost of process optimisation are assumed to be below 0 ECU/t CO_2.
Cost of application of closed systems will be about 1 ECU/t CO_2-eq. [Novem/Ecofys 1997b, p. 48].

Ad E. Miscellaneous

Cost of incineration of PFC's have been estimated to be about 100-150 ECU/t CO_2-eq [Novem/Ecofys 1997b, p. 48].

4.

PFC'S

Potential sources of PFC emissions are mainly: production of primary aluminium by electrolysis (CF_4, C_2F_6), the use of CF_4 in the semiconductor industry, incineration plants, the production of fluorine gas, steel mills and cement works. Largest contributor is the primary aluminium industry which is treated below. The other applications of PFC's have been described in paragraph 0.

4.1 PRIMARY ALUMINIUM PRODUCTION

4.1.1 Emissions

Currently, the primary aluminium industry is responsible for a large part of PFC emissions in the EU. Emissions consist mainly of CF_4 and for a smaller part of C_2F_6. Global warming potentials of these two gasses are respectively 6500 and 9200 tonne CO_2-equivalent per tonne gas emitted.

Table 0.1, gives an overview of primary aluminium production in EU and in some EU Member States. Data are given for the year 1995, in terms of both production and production capacity (between brackets), in kt Al/year. Also an indication is given of future developments of production.

Table 0.1 Aluminium Industry in Europe, annual primary aluminium production and production capacity in 1995

	kt Al/year in 1995	% of EU production
France	355 (430)	17%
Germany	575 (603)	27%
Greece	131 (160)	6%
Italy	178 (178)	8%
Netherlands	216(273)	10%
Spain	362 (362)	17%
Sweden	94 (98)	4%
UK	238 (246)	11%
EU	2149 (2350)	100%

Source: European Aluminium Association 1997, Position paper, fax dd. 18-02-97, included in: Expert Group 1997, Annex HFC industry comments.

PFC emissions from primary aluminium production are related to the "anode effect", forming CF_4 and C_2F_6 (ratio CF_4/C_2F_6 approximately 10%).
In the past, according to EAA emission factors already decreased from about 2 kg CF_4 before 1985 to 0.75 kg CF_4 in 1990-1995 (for C_2F_6 from 0.13 kg to 0.09 kg per tonne aluminium).
A EAA survey carried out in 1994 found an average emission factor for CF_4 in the EU of 0.55 kg/t Al [EAA 1996].

4.1.2 Current national or EU policies

National aluminium industries in EU countries already reached some emission reduction within the framework of agreements with national governments and own initiatives.

4.1.3 Measures

Table 0.2 gives reduction measures in the primary aluminium production.

Table 0.2 Reduction measures primary aluminium production

Name of measure	Reduction	Remarks	Data source
D. Modifications			
Optimisation oven design, process optimisation	50-90%	Measure not primarily for PFC reduction	Ecofys 1997, p.9; EAA 1997
New electrolitic process?	100%	Large-scale application not before the year 2010	Ecofys 1997, p.10

Emission reduction is achieved by optimisation of the oven design and process optimisation.
An example of another future option is the introduction of new electrolytic processes with an electricity saving potential of 35% [Novem 1994, p.90]. However, this technology is expected not to be in operation on short term. Therefore, we do not take this second option into account in this study.

D. Process modifications
Modifications and adjustments of the production process will further reduce the CF_4 and C_2F_6 emissions with 50-90%, resulting in an emission factor up to 0.07 kg CF_4/t Al for new plants.

Based on information from Pechiney [Ecofys 1997], investment cost for process modifications amount to about Dfl. 150000 per oven. Expected emission reduction is 85%, a reduction of the emission factor from 1.2 - 0.2 kg CF_4/t Al, with an aluminium production per oven of about 0.35 kt (175000 tonnes Al in about 500 ovens). This is equivalent to annual marginal costs of 5.6 ECU/t CO_2-equivalent.

5.

SF_6

5.1 INTRODUCTION

SF_6 (sulpherhexafluorid) is being applied in electrical appliances for about 30 years. It is non-flammable and inert. Its GWP is 23900.
Nowadays, SF_6 is being used in high and mid-voltage switches, semiconductor manufacturing, insulating windows, in tyres and in laboratories. Its use for noise insulating windows and tyres is mainly reported by Germany. Its is unknown whether these applications are important in other EU countries. Other potential applications are use of SF_6 in sport shoes and tennis balls. Besides, SF_6 emissions results from magnesium production.

5.2 HIGH (AND MID-)VOLTAGE SWITCHES

5.2.1 Emissions

Until 2010 emissions will slightly rise due to an increase in the use of switches. Between 2010 and 2020, the first generation switches containing SF_6 will be removed. At least in some countries (The Netherlands, Germany) SF_6 from replaced switches is recollected and reused.

This generation, installed in the seventies, has an annual leakage percentage of 2%. From 2020, when all first-generation switches containing SF_6 have been removed, all new switches that are being installed, have annual leakage of 0.4%.

5.2.2 Current national or EU policies

The international norm IEC 694 (by the International Electronical Commission) defines maximum leakage standards of 3% for appliances older than 1979 and 1% for other appliances [Novem/Ecofys 1997, p.51].
In Germany, in 1996, the energy companies (VDEW and ZVEI) have obliged themselves to recollection and reuse of SF_6 from replaced switches in a "Statement on the use of SF_6 in electronic switches in Germany" [Öko-Recherche 1996].

5.2.3 Measures

Table 0.1 Reduction measures SF_6 emissions high (and mid-)voltage switches

Name of measure	Reduction	Remarks	Data source
A. Leakage			
Reduction of leakage installations	Annual reduction from 2% to 0.4%	Leakage: 2% in switches from 70's, 0.4- 0.5% in new generation switches	Öko-Recherche p. 23.
B. Recycling/reuse			
Recycling of SF_6 from discarded switches	100%	Solvay/Dilo in Germany	Öko-Recherche p. 23.
C. Alternatives			
Use of liquid resin, air or oil in mid-voltage switches	100%	No reliable alternatives for high voltage switches	Novem/Ecofys, p.
D. Modifications			
Improved pumps for handling SF_6 during testing and regeneration	5% or 15-20%		Novem/Ecofys, p.53
Development of more compact switches	Annual reduction from 2% to 0.4% (see also A. L.eakages)	already limited quantity of leakage during use of switches	Novem/Ecofys, p.54

Emission reduction in this study consist of the following abatement options:
A. leakage reduction and modifications
B. recycling of SF_6 from discarded switches

A. Leakage and D. Modifications

The annual leakage percentage is assumed to decrease from 2% to 0.4%. In this reduction percentage is included the annual emission reduction by use of new switches and the reduction of losses during installation and repair of switches (which is said to be 5% to 15% but will be much lower if calculated on an annual basis).

Abatement costs are estimated to be about 1 ECU/tonne CO_2-eq. [Holec 1998].

B. Recycling of SF_6 from discarded switches

Recycling of SF_6 is done for example in Germany by Solvay (producer of SF_6), as part of recycling of own process gasses.

Costs of SF_6 recycling are estimated to be about 0.04 ECU/tonne CO_2-eq. abated (including testing and transport) [C.N. Smidt 1998].

5.3 MAGNESIUM PRODUCTION

5.3.1 Emissions

SF_6 is being used as insulation gas during melting of magnesium. Other magnesium production processes use SO2 or salt. In Germany for example, about 40% of the magnesium production uses SF_6.

In Germany, the demand for magnesium is expected to rise (due to increased use in weight reduction of steel components in car manufacturing, e.g. 3 l. car; half of the magnesium production in Germany is processed in the car manufacturing).

Emission factors per tonne of produced magnesium vary from 0.25 kg (new installations in 1996) to 11 kg. As average emission factor, Norsk Hydro mentioned 4 kg per tonne, other studies give 2.5 as emission factor [Öko-Recherche, p.41]. Despite an ongoing increase of magnesium demand, total SF_6 emissions are expected to fall between 1995 and 2005 due to a reduction of the emission factor on the one hand and the transition to using SO2 for magnesium production on the other.

5.3.2 Measures

Table 0.2 Reduction measures SF_6 emissions from magnesium production

Name of measure	Reduction	Remarks	Data source
C. Alternatives			
Argon as alternative	100%		Cook 1995 p.5
SO2 as alternative for SF_6 during magnesium production	100%		Öko-Recherche 1996
D. Modifications			
Reduction of emission factor during magnesium production	90%	from 2.5 to 0.25 kg per tonne Magnesium produced, a reduction of 90%.	Öko-Recherche 1996

<u>A. Leakage</u>

Reduction of emission factor during production: from 2.5 to 0.25 kg per tonne magnesium produced, a reduction of 90%.

<u>C. Alternatives</u>

SO2 or argon as alternative. No information was available on additional cost.

5.4

OTHER APPLICATIONS

5.4.1 Emissions

Although the use of SF_6 in the electricity sector is an important emission source in all countries, in some countries other applications are also important. For example at least in Germany SF_6 is applied in tyres and in noise insulation glass.

Noise-isolating windows

SF_6 emissions from use in insulation windows take place in three ways: during filling (50% of its content), leakage during life time (1% per year) and emissions due to discard (100% of the 75% of emissions that remain at the end of its life time) [Öko-Recherche 1996].

Until 1995, the use of isolating windows in new houses in Germany increased. From 2000, isolation windows, which life time lies between 20-30 years, will be replaced, causing an increase in SF_6 emissions related to discard if no recollection and recycling measures are taken.
In The Netherlands, use is limited to extreme cases of noise isolation, e.g. around Schiphol (Amsterdam airport). However, due to increasing noise hindrance and related regulation, use is increasing.

Car tyres

In Germany SF_6 is used for stabilisation purposes in the more expensive care types. After SF_6 in windows, it is the second largest SF_6 emission source in Germany. Use doubled between 1987 and 1995.
Use is assumed to halve between 1995 and 2000 and then stabilize [Öko-Recherche 1996]. With an average life time of 3 years, this means that emissions will decrease in the period 1998-2003.

Semiconductor manufacturing

Compared to the other SF_6 emission sources, SF_6 emissions from the semiconductor manufacturing are very small and will further decrease due to systems for recollecting flue gasses during the production process.

Other applications

Although not verified in all cases, other applications are for example: electron microscopes, röntgen test materials and appliances, tracer gas, aeroplane radars, aluminium cleaning and sport shoes.

5.4.2

Measures

Table 0.3 Reduction measures SF_6 emissions from other applications

Name of measure	Reduction	Remarks	Data source
B. Recycling/reuse			
Recollection and recycling system for discarded tyres	100%	Currently such systems do not exist.	Glaverned 1998
Recollection and recycling system of discarded windows	100% of the 75% of emissions that remain at the end of its life time		Öko-Recherche 1996
Recycling of SF_6 from discarded products	?	e.g. development by Solvay of re-cycling system for SF_6 in insula-tion glass	Novem/Ecofys 1997, p.54
Recollection of flue gasses during semiconductor manufacturing	100%		
C. Alternatives			
Moulding resin as alternative in in-sulating windows	100%	Some producers in Germany al-ready turned to the use of moulding resin in asymmetric glass constructions.	Öko-Recherche p. 33
D. Modifications			
E. Miscellaneous			
No use of SF_6 in tyres	100%	no costs (cost reduction of 80-120 DM per set)	Öko-Recherche p. 34
Stop use SF_6 for non-essential ap-plications (car tyres, sport shoes, etc.)	?		p.54

Emission reduction for these other applications of SF_6 consist of the following abatement options:

A. Leakage
B. Recycling
C. Alternatives
D. Modifications

A. Leakage

Windows

During filling of the glass, 50% is emitted. Emission reduction is technically an option, but - despite the high price of SF_6 - too costly due to small scale use (at least in The Netherlands) of SF_6 in noise isolation glass.

No measures concerning SF_6 leakage from windows during life time (1% per year) are currently applied or intended as cost are estimated to exceed Dfl. 50/kg [Glaverned 1998].

B. Recycling

Windows

In Germany, no recycling system exists. Glass including SF_6 is being used in The Netherlands for the past 20 years and therefore there is no need for recycling on a large scale yet. However, N.C. Smidt (Solvay) is developing a recycling concept for SF_6 in switches [C.N. Smidt 1998; Novem/Ecofys 1997, p.82] which might also apply to SF_6 in windows.
Measure in database: recollection and recycling system of discarded windows (100% of the 75% of emissions that remain at the end of its life time).

C. Alternatives

Windows

Alternative with similar noise insulating properties is krypton. Disadvantage of krypton is its slightly radioactive property. In some states in Germany its use is forbidden [Glaverned 1998].

Tyres

Measure: refrain from application of SF_6 in tyres.
Cost: none (additional cost of SF_6 addition to tyres 80-120 DM).

D. Modifications

Windows

Another options for noise isolation is modification of the frame, for example by use of moulding resin [Glaverned 1998]. Some producers in Germany already turned to the use of moulding resin in asymmetric glass constructions, increasing costs by 30-40% [Öko-Recherche 1996, p. 33].

Semiconductor industry

Emissions can be reduced to zero when applying recollection of flue gasses during production.

For all abatement options mentioned above, it is assumed that abatement costs will be in the cost range of 0 - 100 ECU/tonne CO_2-eq. abated [Novem/Ecofys 1997, p.54].

6.

EU EMISSION REDUCTION POTENTIALS AND ABATEMENT COST

This chapter gives an overview of all abatement options (categories) with their marginal cost and maximum total reduction potentials within EU-15 for 100% implementation. These reduction potentials are based on the emission data set (business as usual scenario) presented in Table 0.1 below. *Note that the emission data in this table give a preliminary breakdown based on a number of assumptions. Further improvement of these estimates is necessary.*

Table 0.1 Preliminary emission data set for cost calculations, emission projections and breakdown EU-15 in 2010, Mt CO2-equivalents (business as usual)

Total halogenated gases[1)] 2010: 82 Mt		
HFC's[2)] 2010: 65 Mt	**PFC's** 2010: 5 Mt	**SF_6** 2010: 12 Mt
HCFC-22 production 2010: 10 Mt *Refrigeration* 2010: 25 Mt *of which:*[3)] Industrial: 1 Mt Commercial: 11 Mt Transport: 3 Mt Stationary airco: 1 Mt Mobile airco: 8 Mt Households: 0.2 Mt *Foam* 2010: 25 Mt[5)] *Other* 2010: 5 Mt[6)]	*Aluminium production* 2010: 5 Mt *Other* 2010: pm	*Electricity distribution* 2010: 6 Mt *Other*[4)] 2010: 6 Mt

1) Source: Expert Group 1998a. First country comments included (Expert Group 1998b).
2) Conservative (low) estimate of HFC emissions per emission source deducted from the emission ranges in table 2.1, par. 2.2.
3) Own preliminairy estimation of distribution emissions refrigeration, based on emission rates per application and estimations of numbers of installations.
4) Assumption: of which 3 Mt related to noise isolating windows.
5) Emissions might be lower as it could be argued that emissions from the foam bank might not yet have reached this level in the year 2010.
6) This should be considered as a minimum figure.

Table 0.2 presents emission reduction and cost data for each abatement option separately. It gives the maximum reduction, regardless of reduction already assumed in the scenario's for some countries for some options, and regardless of interactions between alternative measures (e.g. leakage reduction and alternative refrigerants). Therefore, marginal cost might be higher in some cases.

In some sectors/countries measures have already been taken (mostly as own initiative of these sectors and/or with subsidies from governments). This is the case for (at least in some countries):
- HCFC-22 production (HFC-23)
- Aluminium production (PFC)
- Electricity sector (SF_6)

Partly these reductions have already been incorporated in the emission figures reported by the individual countries.

No data on abatement options and cost are available for the following emission sources:
- HFC emissions during handling (production and packaging of HFC's)
- magnesium production
- fire extinguishing

Note that Table 0.2 gives typical figures but that in fact wider ranges are possible depending on size of equipment and local circumstances.
The effects on energy cost and energy-related CO_2-emissions are not included in the figures in this table.

Table 0.2 Marginal cost and reduction potentials abatement options

Source	**Measure**	**Marginal emission reduction**	**Estimated emissions EU-15 in 2010 (Mt CO_2-eq.)**	**Maximum reduction potential EU-15 (Mt CO_2-eq.)**	**Marg**	
					< 0	
HFC						
HCFC-22 production	Incineration [1)]	90%	10	9		
Refrigeration general	Recycling	?	25	?		
Industrial refrigeration	Leakage reduction	67%	1	0.67		
	Alternatives	100%	1	1		
	Process modifications		1			
Commercial refrigeration	Leakage reduction	80%	11	8.8		
	Alternatives	100%	11	11		
	Process modifications	90%	11	9.9		
Transport refrigeration	Leakage reduction	80%	3	2.4		
	Alternatives	100%	3	3		
Stationary airco	Alternatives	100%	1	1		
Household refrigeration	Recollection [7)]	100%	0.2	0.2		
Mobile airco	Alternatives	100%	8	8		
Solvents, other	Process optimisations	100%	5	5		
Foam	Alternatives	100%	25	25		

Source	**Measure**	**Marginal emission reduction**	**Estimated emissions EU-15 in 2010 (Mt CO_2-eq.)**	**Maximum reduction potential EU-15 (Mt CO_2-eq.)**	**Marg**	
					< 0	
PFC						
Aluminium production:	Process modifications	85%	5	4.3		
Semiconductor industry	Alternatives, process optimisations	100%	pm			
SF_6						
High (and mid) voltage switches	Leakage reduction modifications	90%	6	5.4		
	Recycling	100%	6	6		
Magnesium production	Leakage red., alte r-natives, process mod.	90%	pm			
Semiconductor industry	Process modifications	100%	3	3		
Tyres	Alternatives	100%	pm			
Windows	Leakage reduction	50%	3	1.5		
	Recycling	75%	3	2.3		
All substances						
Other/new uses [10)]	pm					

Notes:

1) Another option that has been mentioned is recycling of HFC-23. However, as the market for HFC-23 is limited, this option may economically not be attractive [Du Pont 1998].
2) Cost of recycling used refrigerants given by industry vary between 1.6 to 2.7 ECU/t CO_2-eq. [Hotar 1998; Gasco 1998].
3) As at this moment only data are available concerning leakage reduction and switch to other refrigerants for refrigeration systems of about 100 kW, for large industrial systems absolute (investment) costs have been multiplied by factor 4 compared to the 100 kW system (working hypothesis). However, cost per tonne CO_2-eq. for industrial refrigeration are lower due to larger absolute emission reduction. Process modifications (compact and indirect systems) are expected to be especially adequate abatement options for larger industrial installations with cost expected to be in the range of 0 - 20 ECU/t CO_2-eq. However, specific cost data are not available yet.
4) As installations for commercial refrigeration diverge from small to large, these cost indications per tonne CO_2-eq. may also vary for different sizes of installations. At this moment only cost data are available for installations of 100 kW (investments of about 2500 ECU for leakage reduction and 5000 ECU for retrofit to ammonia). For this moment it has been assumed that additional investment cost of compact installations lie in the same range (2500 ECU).
5) For transport refrigeration the same cost have been assumed as for commercial refrigeration. However, due to higher initial leakage percentages, resulting cost per tonne CO_2-eq are lower.
6) For retrofit of stationary airco to ammonia the same cost have been assumed as for commercial refrigeration. However, due to very low initial leakage percentages, cost per tonne CO_2-eq are substantially higher.
7) It has been assumed that all new domestic refrigerators already use propane/butane as refrigerants, with eventual cost shifted on to the consumer. Regarding existing refrigerants containing H(C)FC's, cost of recollection and sound processing of discarded refrigerators, cost have been assumed to be about 20 ECU per refrigerator (average charge in refrigerators 0.1 kg, and GWP for HFC-134a is 1300).
8) Cost of application of closed systems will be in the range 0-100 ECU/ t CO_2-eq. [Novem/Ecofys 1997b, p.48]. Here: assumption 50 ECU/ t CO_2-eq. Concerning other applications of HFC's (solvents etc.), cost indications amount to 8-12 ECU/t CO_2-eq. [Novem/Ecofys 1997b, p.48]
9) Alternative blowing agents such as hydrocarbons and CO_2 may rise product cost by increasing thickness of the material in order to compensate for the loss in energy efficiency. Regarding alternative products, there are various - proven - alternative insulation products. Some of them are more costly, others are as expensive as foams, or even less expensive if energy savings are reckoned with [Ecofys 1996, p.46]. Assumption: cost 10ECU/t CO_2-eq.
10) This category includes other uses of SF_6 , aerosols etc. Applications are partly 'necessary', such as asthma sprays for which no reduction options

are available, partly 'non-necessary', for which for example bans on further development could be imposed. If no investments have been made yet, this can be considered as a zero-cost 'measure'.

In Table 0.3, total abatement cost for the EU-15 are summarised. Two variants have been indicated: i) maximum use of alternatives and ii) maximum leakage reduction. Where results for those variants differ - and that is mainly the case within refrigeration - cost and emission reduction of both variants have been indicated (i/ii). Table 0.3 shows that maximum substitution of HFC's by alternatives results in higher reduction and lower cost than in case of maximum leakage control.
If measures above 100 ECU/tonne CO_2-eq. are excluded (for commercial refrigeration and stationary airco), total abatement cost will be 1000/3400 mln ECU and emission reduction 62/58 Mt CO_2-eq.

Table 0.3 Summary of total abatement cost estimate for 2010, EU-15

	Cost (mln ECU)	Reduction (Mt)
HFC	4190/5496	63/48
PFC	24	4
SF_6	8	7
Total	4222/5528	74/69

The abatement cost estimates presented in Table 0.3 result from a first exercise and a rough indication of the extent of the EU-wide abatement cost.

7.

BARRIERS FOR IMPLEMENTATION

This chapter gives a first inventory of the barriers for implementing the identified emission reduction options limitations mentioned in this report.
Table 0.1 summarises some of the most important emission reduction options (column 1-3), indicates potential barriers that may prevent this introduction (column 4) and suggests in which ways these barriers can be reduced by the government, on a national level or EU-wide (column 5). The indication of the policy options for a certain technical abatement option is related to the occuring barriers for development or implementation of those options. For example, the implementation of certification systems - to guarantee optimal maintenance in order to reduce leakages from refrigeration - can be encouraged by (national) regulation.

Table 0.1 Barriers concerning the reduction of HFC's, PFC's and SF_6 emissions

Option	Sector/application	Description measure/instrument	Barrier
Leakage prevention/reduction	Industrial and commercial refrigeration (HFC's)	Maintenance of installations to reduce and prevent leakage (cf. STEK, RLK in The Netherlands).	*Institutional* : no systems tion and control are in pla countries *Juridical:* certification a system has to be impc member states
	Semiconductor industry (PFC/SF_6)		Confidentiality of data
	Electricity sector	SF_6 leakage from handling switches	
Recycling/reuse			
	Household refrigeration (HFC)	Implementation of a system of recollection of refrigerators and recycling of refrigerants.	Costs of collection anc system
	Refrigeration (HFC)	Development of recycling plants; creating recollection systems between producers and users of refrigerants	*Costs/market:* price recyc has to compete with nev HFC's
	Semiconductor industry (PFC/SF_6)	Development of recycling plants; creating recollection systems between producers and users of solvents	*Institutional/Juridical* : I systems between produc ers are difficult due to cur tion concerning trans-nat port of certain goods or s as producers and users

			ways located in the same c
	HCFC-22-production (HFC23)	Recycling of recollected HFC23	*Market:* demand for recyc is small and therefore recy cost-effective (besides, HI enter the atmosphere in th
	High (and mid) voltage switches (SF_6)	Recollection and reuse of SF_6 from discarded switches	*Cost:* qualitatively good ec recollection used SF_6 fro is costly
Alternatives			
	Refrigeration	Introduction and use of alternative refrigerants.	*Technology:* Not for a tions/situations alternative are considered to be good *Juridical :* Safety regulatio be adapted in order to in dards on use of natural refr *Institutional* : Lack of info alternative systems at the of time to show all alterna install company
	Solvents	Introduction and use of alternative solvents	*Institutional :* Lack of info alternatives, mainly at s prises
Process modifications			
	Primary aluminium production	Further reduction of process emissions by adaptation of existing plants (assuming that new plants	*Cost:* adaptation of exis requires additional investm *Technology:* technology

		already have low emission factors). Further development and introduction of other processes, e.g. the AlCOa process.	processes has to be fur oped so that it become cally feasible.
Miscellaneous			
Incineration HFC emissions	HCFC-22-production	Full incineration of flue gasses	*Cost* of incineration
'Non-necessary' use of PFC, SF_6	production of tyres, sport shoes, tennis balls etc.	Preventing development and further introduction of products using SF_6 for non-nescessary applic ations	Definition of 'necessary

8. FIRST CONCLUSIONS AND RECOMMENDATIONS

Main emission sources
Process emissions are responsible for large part of emissions in countries locating these production processes: HFC23 emissions during HCFC-22 production, PFC emissions from primary aluminium production, SF_6 emissions from magnesium production.
In the future, other emission sources become relatively more important, due to achieved emission reduction in those production processes, and an increasing demand for certain applications (c.f. stationary and mobile airco, specific applications for SF_6).

Cost and emission reduction
A first rough estimate of total abatement cost and emission reduction for the EU-15 in 2010 shows that with maximum application of abatement measures mentioned in this report a emission reduction of about 85% of total emissions in EU 15 for these three gases together can be reached for about 5000 mln ECU.
Considering the measures included in this report, HFC reduction accounts for 85% of emission reduction and 99% of abatement cost.
Also relative cost are largest for HFC emission reduction, with average abatement cost of 60-90 ECU/t CO_2-eq. (or 20 ECU/t CO_2-eq. when measures > 100 ECU/ t CO_2-eq. are excluded). For PFC and SF_6 average abatement cost are about 1 - 6 ECU/t CO_2-eq.

Conclusions
It should be noted that these results have a preliminary character and that further elaboration is necessary. However some conclusions may be drawn at this stage:
- There is a substantial potential for reducing emissions of HFC's, PFC's and SF_6.
- There are a number of low-cost options, including emission reduction at HCFC-22 manufacturing (HFC-23 incineration) and at primary aluminium production (process modifications) and leakage reduction and recycling of SF_6.

Recommendations
Further development of the emission data set and check of by national experts of emissions per application is needed. Differences in data and methodologies between countries should be identified. Furthermore, more data on measures and cost are needed to complete and check the information currently available. A workshop with main stake holders and experts may accelerate the information gathering (and reviewing) process.
This report can be considered as a basis for further elaboration in the directions mentioned above. With a more detailed and consistent emission data set for EU-15 countries and with further completed and differentiated cost data, these first rough cost estimates can be refined.

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