

**Meeting Report**  
**of the**  
**Joint IPCC/TEAP Expert Meeting on**  
**Options for the Limitation of Emissions of**  
**HFCs and PFCs**

*Petten, The Netherlands*  
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# **REPORT OF 'THE JOINT IPCC/TEAP EXPERT MEETING ON OPTIONS FOR THE LIMITATION OF EMISSIONS OF HFCs AND PFCs'**

## **1. INTRODUCTION**

### **1.1 Background**

This meeting report presents the major findings and discussions from the Expert Meeting on 'Options for the Limitation of Emissions of HFCs and PFCs' jointly sponsored by the IPCC Working Group III and the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol (referred to in this document as the 'Joint Expert Meeting').

In 1998, developing countries expressed concern that actions taken under the Kyoto Protocol to control HFCs and PFCs could have implications for their development process. Manufacturers of products that use or might use HFCs and PFCs also sought clarification. It is for this reason that Sri Lanka tabled a proposal at the Open Ended Working Group (OEWG) meeting under the Montreal Protocol in Geneva, June 1998. Two decisions were taken on the issue of limitation of HFC and PFC emissions, one decision was adopted by the Parties to the UNFCCC, and at their 10th Meeting in Cairo, the Parties to the Montreal Protocol adopted a complementary decision.

In November 1998, the 4th Conference of the Parties to the UNFCCC adopted a decision (Decision 13/CP.4, document FCCC/CP/16/Add.1), which invited organisations, including the relevant bodies of the Montreal Protocol, '...to provide information by July 15, 1999....', and encouraged 'the convening of a workshop by the IPCC and the Technology and Economic Assessment Panel of the Montreal Protocol in 1999 which will assist SBSTA to establish information on available and potential ways and means of limiting emissions of hydrofluorocarbons and perfluorocarbons...'. In November 1998, the Parties to the Montreal Protocol adopted a decision in which they requested the TEAP (in Decision X/16) to provide such information to the UNFCCC and to assess the implications to the Montreal Protocol of the inclusion of HFCs and PFCs in the Kyoto Protocol and to report these findings to the Eleventh Meeting of the Parties to the Montreal Protocol. In addition, the Parties to the Montreal Protocol also encouraged the IPCC and TEAP to jointly convene a workshop on 'available and potential ways and means' of limiting emissions of HFCs and PFCs. The Technical Support Unit of the IPCC WGIII and the TEAP took the responsibility for co-organising the Joint Expert Meeting.

### **1.2 Interrelations**

Parties to the UNFCCC and Parties under the Montreal Protocol took similar decisions because the issues of ozone depletion and climate change are scientifically and 'technically' interrelated. They are scientifically interrelated because changes in ozone affect the Earth's climate and changes in temperature, greenhouse gases and climate affect the ozone layer (see section 1.4). The Montreal and Kyoto Protocols are 'technically' interrelated because HFCs included in the basket of gases of the Kyoto Protocol are significant substitutes for some ozone depleting substances (ODSs) controlled under the Montreal Protocol. CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, PFCs, and SF<sub>6</sub> are all included in the basket of gases of the Kyoto Protocol. Of these, CO<sub>2</sub> has been proposed as a potentially significant substitute to ODSs and HFCs used as refrigerants and blowing agents. The

other gases are insignificant substitutes to ODSs. The above requests by the UNFCCC/SBSTA and the Montreal Protocol suggest that it is important that strategies and technologies be developed that address both climate and ozone protection, and that actions be taken in a manner that promotes sustainable development in developing countries.

The issue of energy efficiency is of crucial importance in relation to indirect global warming impacts arising from CO<sub>2</sub> emissions arising from energy production. Using a non-HFC substance or technology avoids any emission, however, may significantly influence energy usage. In some cases the effect can be beneficial. However, in other situations there is an energy penalty, which can actually lead to an increase in CO<sub>2</sub> emissions that outweigh the benefits of reduced HFC emissions. These effects are strongly application- and design-dependent and must be carefully taken into account when considering HFC emission reduction strategies.

### 1.3 Joint Expert Meeting Organisation

During January-April 1999 the Joint Expert Meeting was organised by a local organising committee chaired by Lambert Kuijpers (TEAP) and Remko Ybema (IPCC) working with a technical advisory committee consisting of 12 members with IPCC or TEAP background, and members of the Ozone and UNFCCC Secretariats<sup>1</sup>. It sent out invitations to broad groups of technical experts, identified via IPCC and TEAP lists of experts. Every organisation requesting participation was allowed at least one registration but governments and industry organisations were asked to limit participation to two experts. Environmental NGOs were also invited and in some cases expenses were funded out of the Joint Expert Meeting budget.

The Joint Expert Meeting was held at ECN Petten, The Netherlands, 26 – 28 May 1999. It was attended by approximately 100 participants from 24 countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, India, Japan, Kenya, Malaysia, Mexico, Netherlands, Poland, Sri Lanka, Sierra Leone, Sweden, Switzerland, Thailand, Uruguay, UK, USA, and Vietnam)<sup>2</sup>. Ten participants were from developing countries and Countries with Economies in Transition (CEIT)<sup>3</sup>. A list giving the names and affiliations of all the participants is given in Annex 8.

Participants represented the European Commission; ministries of environment, fisheries, transportation, industry and foreign affairs; technical, chemical, and research institutions, universities, and consulting organisations; industry associations and environmental organisations; fluorocarbon, hydrocarbon, foam and speciality chemical suppliers; the Global Environment Facility (GEF); UNEP Montreal Protocol Multilateral Fund Secretariat, the UNEP TEAP and its Technical Options Committees and Task Forces; the UNFCCC Secretariat; the Ozone Secretariat; the IPCC; UNEP Technology, Industry and Economics (TIE), UNDP, and UNIDO; and automobile, foam, refrigerator, refrigeration, air conditioning, fire protection, electronics industries and electric utility companies.

Funding for the Joint Expert Meeting was received from both the Netherlands Ministry for Housing, Spatial Planning and the Environment and the US Environmental Protection Agency.

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<sup>1</sup> Members of the technical advisory committee were Stephen O. Andersen, USA (TEAP), Paul Ashford, UK (TEAP), Kornelis Blok, Netherlands (IPCC), Suely M. Carvalho, Brazil (TEAP), Ogunlade Davidson, Sierra Leone (IPCC), Sukumar Devotta, India (TEAP/TOC), Barbara Kuznerowicz-Polak, Poland (TEAP), Mack McFarland, USA (IPCC), William R. Moomaw, USA (IPCC), Ramon Pichs-Madruga, Cuba (IPCC), K. Madhava Sarma (Ozone Secretariat), Dennis Tirpak (UNFCCC Secretariat), and Lambert Kuijpers and Remko Ybema.

<sup>2</sup> One environmental NGO wishes to register its concerns about the potential bias of the HFC review process at the Joint Expert Meeting due to its perceived over-representation of the fluorocarbon industry and related corporate industries at the Joint Expert Meeting and wishes to note that it is of the opinion that the organisers of the meeting could not ensure sufficient participation of experts from not-in-kind industries.

<sup>3</sup> One environmental NGO wishes to register that stronger efforts must be made to include developing countries in this process.

The Joint Expert Meeting was co-chaired by Ogunlade Davidson, co-chair IPCC WGIII, and Lambert Kuijpers, co-chair TEAP. The meeting consisted of one day of plenary presentations by experts from both developed and developing countries. The plenary also heard presentations from three environmental NGOs. Subsequently, experts from various application sectors met separately in working group meetings during two days, followed by a concluding plenary discussion. The working groups were asked to list and prioritise options to limit emissions, to catalogue opportunities and barriers, and to give estimates for future emissions under different scenarios<sup>4</sup>. The meeting concluded with plenary presentations of summaries of the working group discussions and by four government representatives. The government representatives described approaches being taken by Denmark, Germany, Japan and the USA to limit emissions of HFCs and PFCs.

The drafting committee for the meeting report consisted of Ogunlade Davidson (IPCC), Stephen O. Andersen (TEAP), Ray Gluckman, Jochen Harnisch, Mack McFarland (IPCC), William R. Moomaw (IPCC), Suely M. Carvalho (TEAP), Lambert Kuijpers (TEAP) and Remko Ybema (IPCC). After that a zero order draft had been developed, it was sent out to the full Technical Advisory Committee for comments. A first order draft was then developed which was sent out to all the participants for review. Thirty-five review reactions were received, at a total of about seventy pages. These review comments were included after careful study, whether it concerned necessary additions for clarity, issues discussed at the meeting, etc. The last draft of the meeting report was again sent to the Technical Advisory Committee for final comments, after which it was despatched to the UNFCCC secretariat, as was requested in the relevant decisions.

Lambert Kuijpers and Remko Ybema chaired the local organising committee, co-ordinated the different stages in the drafting and review process of the meeting report and were involved in the assembly of the papers presented at the Joint Expert Meeting.

#### 1.4 Montreal and Kyoto Protocols linked via the atmosphere

The Joint Expert Meeting started with a presentation on the linkage between the Montreal and the Kyoto Protocol by one of the co-chairs of the Montreal Protocol Science Assessment Panel/Meg99/. A summary is given below.

The issues of ozone depletion and global climate change are linked through physical and chemical processes in the atmosphere. Gases controlled under the Montreal Protocol contribute to the Earth's radiation balance, gases that could be controlled under the Kyoto Protocol affect the ozone layer, and climate change can have an influence on the ozone layer. Most of the ozone depleting substances (ODSs) are also significant greenhouse gases, and increases in their atmospheric concentrations tend to have a warming effect on the Earth's surface. At the same time, because stratospheric ozone also plays a role in the radiation balance of the atmosphere, ozone depletion caused by increasing concentrations of ODSs tends to have a cooling effect on the Earth's surface. Therefore, the net climate effect of an individual ODS depends on its direct global warming potential relative to its ozone depleting potential.

Nitrous oxide and methane, two gases that could be controlled under the Kyoto Protocol, have direct effects on global atmospheric chemistry that can influence ozone depletion. Increasing concentrations of these gases have multiple effects on stratospheric chemistry including interactions with the ozone destruction cycles of chlorine and bromine carried to the stratosphere by ODSs. Methane concentrations also affect global tropospheric chemistry and, hence, atmos-

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<sup>4</sup> Two environmental NGOs wish to have their concerns highlighted in this meeting report in relation to the approach followed at the Joint Expert Meeting. In their opinion, HFCs and PFCs are not necessary and therefore the limitation of emissions of fluorocarbon substances should have been explored only after that alternative technologies and substances would have been thoroughly discussed. They expressed deep regret that the thrust of the discussion and report reviewing process has been the other way around, implying that HFCs and PFCs are necessary.

pheric lifetimes of those ODSs that contain hydrogen atoms (e.g., HCFCs, HFCs, methyl chloroform, methyl bromide) and hence are removed in the troposphere. In addition, stratospheric ozone depletion allows greater amounts of UV-B solar radiation to reach the troposphere. Increased amounts of UV-B also affect atmospheric chemistry and can shorten the lifetimes of those ODSs containing hydrogen.

Global climate change is expected to shift air circulation patterns and alter the temperature structure of the atmosphere. In particular, the addition of CO<sub>2</sub> to the atmosphere has led to an additional cooling of the stratosphere, which in turn causes extra ozone loss from chlorine and bromine containing ODSs. Current understanding of all these chemical and physical changes suggests that recovery of the ozone layer could be delayed. In other words, recovery could be slower than one would anticipate based on projected declines in the amounts of chlorine and bromine in the stratosphere alone. More information on these effects can be found in the most recent scientific assessment conducted under the Montreal Protocol: 'Scientific Assessment of Ozone Depletion: 1998' /Sci98/.

## 1.5 Structure of the report

This report is divided into five sections. The first section provides background material. The second covers current uses of HFC, PFC and SF<sub>6</sub> chemicals and projected consumption and emissions as presented in plenary and working group sessions during the Joint Expert Meeting. Working group discussions are summarised in the third section. Background information on the issues discussed is summarised, areas of convergence and divergence are highlighted and major findings are listed. The overall outcome and a list of issues that need additional study are presented in the fourth - conclusions - section. Additional material from the working group sessions is presented in Annexes. Papers presented at the meeting are provided in a separate volume (the Table of Contents of this volume can be found in Annex I).



## 2. PAST, CURRENT AND PROJECTED CONSUMPTION AND EMISSIONS

### 2.1 Introduction

Unlike the case for most greenhouse gas emissions where release to the atmosphere occurs at the time of production of the gas (e.g. carbon dioxide is emitted to the atmosphere when it is formed in the combustion of fossil fuels), HFCs and PFCs are often stored in equipment and products for many years after they are produced and sold into the market. However, as soon as the products are used, HFC and PFC emissions start to occur. The timing of large scale emissions, comparable to product inventory, varies from less than a year for applications such as use as an aerosol propellant, to over a decade for some refrigeration applications, to many decades for some insulating foam applications. Both consumption and emission estimates are presented in this report and the reader is cautioned not to confuse the two.

HFC, PFC and SF<sub>6</sub> emission scenarios are usually developed using:

- Historic production and consumption data.
- Assumptions on the difference between production and consumption (substances may be stored for a certain time before they are consumed).
- Forecast for future production and consumption based upon GDP, population and usage growth.
- Substitution of CFCs and HCFCs with certain HFCs and other alternatives.
- Estimates of the time dependent release from different types of applications (which includes assumptions on leakage).
- Assumptions on the results of technological change in the absence of climate policies.

Estimates of the time dependent release from certain applications, as well as of the short term development of end user markets and technological changes, already yield uncertainties in the current and near future emission levels. Furthermore, when comparing emission scenarios based upon these types of data and estimates for the long term (i.e., a period of 50-100 years) it is very likely that one will conclude substantial differences in the forecast of emissions by different experts. Several papers presented at the Joint Expert Meeting /Fen99, Glu99, Joh99, McC99/ show these large differences, as well as smaller differences for the shorter term. It should therefore be emphasised that one should not focus too much on the differences; the purpose of the Joint Expert Meeting has not been directed towards a determination of the most appropriate and adequate ways to judge the value of emission scenarios. This will ask for a substantial amount of work within a different framework in the near future.

### 2.2 Past and current consumption

The current generation of HFCs were introduced in the early 1990's as substitutes for CFCs with almost no use before 1990. The only significant emissions of HFCs before 1990 resulted from production of HFC-23 as a byproduct of the production of HCFC-22. Thus, HFC emissions grew from a very small, although important base if considered on a basis of global warming (since it concerned mainly emissions of HFC-23, a very potent greenhouse gas). The emission levels of HFCs in the year 1997 were approximately 55 ktonnes (this comprised 43 ktonnes of HFC-134a /AFE99/, 7 ktonnes of HFC-23 estimated by certain experts /Ora98, Mid93/ and by AFEAS /AFE99/ from HCFC-22 production data, and 5 ktonnes of HFC-152a.

The main sources of PFC emissions (from aluminium smelting and from the electronics industry) were already established by 1990. Few reliable publications on world-wide PFC and SF<sub>6</sub> emission data for 1997 or 1998 can be found /Har99, Mai98/; certain individual countries (such as the UK and the USA) have recently published well researched data.

The main uses of HFCs in the 1990's are in the refrigeration and (mobile) air conditioning sectors (80-90%). Growing markets that are expected to be significant by 2008 include Metered Dose Inhalers (MDIs), insulating foam and possibly aerosol products. Global production of all HFCs (mainly HFC-134a) has increased by a factor of five between 1993 and 1998, according to figures published recently /TEA98/.

Production and consumption of CFCs and halons was phased out in developed countries in less than a decade through use of a variety of alternative chemical substances, technologies and practices. However, the total production and consumption of CFCs and halons (and some other ODSs) in the developing countries will not be phased out until 2010; these efforts are largely supported by the Montreal Protocol Multilateral Fund. Furthermore, a phaseout of production and consumption does not automatically mean a phaseout of all uses. Numerous refrigeration equipment (e.g. domestic refrigerators) is still in use and could emit to the environment if not adequately recovered at disposal. Many chillers operated using CFCs are still in use in the developed and developing countries, and it will take substantial amount of time before these have all been retrofitted or replaced.

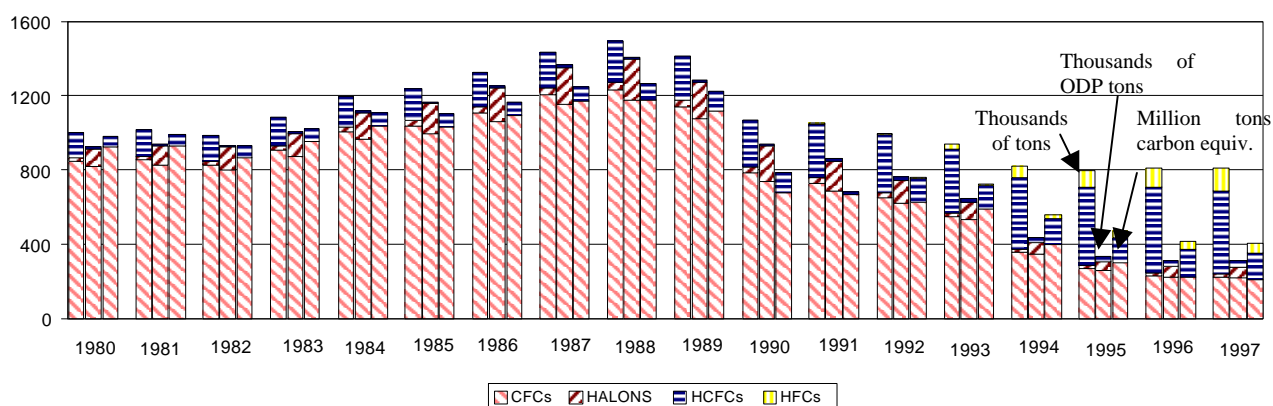


Figure 2.1 *Global CFC, halon, HCFC and HFC consumption, in tonnes, ODP tonnes, and tonnes of carbon equivalent for the developed and the developing countries, for the period 1980-1997; figures were calculated using AFEAS and UNEP data /AFE99, UNE98/, ODPs listed in the Montreal Protocol /Mon98/ and GWPs from the IPCC Second Assessment Report /IPCC96/ and the 1994 Science Assessment of Ozone Depletion /Sci94/*

Estimates of total global consumption of CFCs, halons, HCFCs and HFCs in thousands of metric tonnes (the left bar for each year), in thousands of ozone depleting potential (ODP) weighted tonnes (bar in centre for each year) and as million tonnes of carbon equivalent (the right bar for each year) are shown for the years 1980 to 1997 in Figure 2.1. For each bar, CFCs are represented by the bottom section, halons the next section up, HCFCs the next section and HFCs the top section. The net global warming potentials, taking into account both the direct heat trapping effects of the compounds and the cooling effect due to ozone depletion, were used to convert to carbon equivalents /Sci94/. CFCs and halons have been combined in the carbon equivalent bars because halons have a net negative global warming impact due to their relatively large ozone depletion effects.

Figure 2.1 clearly shows the large environmental gains that have been achieved in terms of both reductions in ozone depleting potential and contributions to global climate change as CFCs and halons have been phased out in developed countries. They also show what additional gains can be expected as CFCs and halons are phased out in developing countries while ensuring that climate change activities do positively support this phaseout. However, it should be noted that, where Figure 2.1 shows the change in production this does not automatically imply that emissions to the atmosphere will change at the same rate. If not recovered at the end of the useful life, emissions will be delayed due to banking mainly in refrigeration equipment and in foams, and a possible time dependent emission figure will be different.

Table 2.1 *Non-fluorocarbon technologies and chemicals applied in the developed countries in the conversion away from CFCs and halons per application sector; percentage replacement in 1997 on a metric ton base of CFCs with HCFCs and HFCs*

Application	Non-Fluorocarbon Technologies in the Conversion Away from CFCs and halons	Replacement of CFCs and halons with HCFCs and HFCs [%]
Refrigeration and Air Conditioning	Emission reductions (containment, recycle, recovery); hydrocarbons and ammonia	30
Closed Cell Foam	Hydrocarbons Carbon dioxide Alternative insulating materials	<50
Open Cell Foam	Water and Hydrocarbons	15
Aerosol Propellant	Hydrocarbons and dimethyl-ether (DME) Alternative dispensing technologies;	3
Fire extinguishants	Emission reductions (containment, recycle, recovery); Powders, Water based technologies (mist, sprinklers, foams), Carbon Dioxide, Inert Gases	<5
Other (Primarily Solvents)	'No-clean technologies', aqueous and semi-aqueous systems and other not-in-kind	3
All Applications	HCFCs HFCs	12 8

Note: The substitution rates in the tables have been calculated by dividing the 1997 HFC plus HCFC consumption in uses formerly met by CFCs and halons by the difference between the extrapolation to 1997 of the CFC consumption growth during the 1980s and the actual consumption of CFCs in 1997 [AFEAS company sales /AFE99/]. This table does not take into account historical (1980's) HCFC use and its eventual replacement (quantities are estimated to be of a comparable order of magnitude as the quantities of HCFCs and HFCs used for the replacement of CFCs).

HCFCs and HFCs have significantly replaced CFCs and halons (20% compared to extrapolated growth), see Fig. 2.1. However, this substitution varied considerably per former application of CFC and halons. On the one hand, substitution by HCFCs and HFCs contributed to 30% of the CFC reduction in the case of refrigeration and air conditioning and to 50% of the CFC reduction in case of closed cell foams (see Table 2.1). On the other hand, substitution by HCFC and HFC played a small role in case of aerosol propellants, fire extinguishants and solvents.

HCFCs and HFCs are primarily used in applications where they have been promoted as alternatives and where their 'CFC-like' properties have eased the transition and reduced short-term transition costs. In some applications their properties provide important advantages. In addition, emission rates have been reduced in applications such as air conditioning and refrigeration through better containment, servicing practices and recovery at end of product life. The global use pattern of fluorocarbon gases has changed substantially as a result of these changes in technologies and practices.

All SF<sub>6</sub> emissions and virtually all PFC emissions are from sources unrelated to ODS substitution (e.g. aluminium smelting, magnesium production, high voltage switchgear, windows and shoes etc.).

## 2.3 Projected Long Term Consumption and Emissions

### *Global Emissions*

A production forecast that is given in the 1998 TEAP Assessment report /TEA98/ is that by the year 2015 there will be a global HFC production of about 340 ktonnes. It is estimated that by 2010-2015 the annual growth in production will be about 2.5% per year; these data were derived from estimates submitted by a large number of chemical manufacturers. Although production estimates may exist, for the years beyond 2015 these estimates cannot be referred to since they were not explicitly presented at the Joint Expert Meeting.

Several papers that were presented dealt with emission scenarios until the year 2100. One of these papers /Fen99/ covers four emission projections that were developed for the IPCC Special Report on Emission Scenarios (SRES). None of these scenarios assumes a climate policy to mitigate emissions of HFCs, PFCs or SF<sub>6</sub>. Harnisch /Har99/ presented PFC emission scenarios from aluminium production until the year 2030, as well as an overview of global emissions of different PFCs in 1995; his data strongly differ from the ones presented by Fenhann /Fen99/.

Relevant for the halocarbon projections is that the scenarios vary in their assumptions for population and GDP growth and environmental policies other than for climate change. HFC emissions in 2010 are projected to amount to less than 1,100 Mton CO<sub>2</sub> equivalent (this number compares to 22,000 Mton CO<sub>2</sub> emissions from fossil fuel use in 1998). However, the projection results in an annual emission range of 1,500-5,000 Mton CO<sub>2</sub> equivalent for the period 2030-2100 with three out of four scenarios projecting emissions near the higher end of the range. HFC emissions are estimated to give the largest contributions followed by PFCs and SF<sub>6</sub>.

By contrast, another paper /McC99/ reported on a scenario by analysing in more depth the markets for ODS that they replace. This scenario projects emissions to be near the lower end of the range projected by the scenarios in the IPCC SRES Report.

### *Regional Emissions*

Emissions projections of HFCs and PFCs vary significantly by region. These differences are based on a number of factors including climate, building standards, risk management procedures, strengths of commercial vested interests, recycling programs and consumer attitudes. For example, due to their climate, the United States and Japan traditionally rely heavily on air conditioning; air conditioning used to be low in Europe, however, A/C market penetration here has changed substantially during recent years. Many developing countries in Africa, Asia and South America are likely to have high cooling demands as their economies develop. Regional differences have led to different strategies and approaches to both the CFC phaseout and the impending HCFC phaseout in different regions. Some European governments are using technology forcing regulations to achieve a near term shift to zero ODP and low GWP gases such as hydrocarbons and ammonia.

The United States is supporting voluntary responsible use practices of HFCs to allow the phase-out of HCFCs particularly in insulating foams and as refrigerants. Japan is pursuing a highly targeted strategy with goals of developing technology options that support their specific requirements, which are closer to the US approach.

Several detailed emission projections were presented at the meeting; e.g. two papers dealt with emission projections for the UK /Glu99, Joh99/. These papers disagree fundamentally on the significance of the impact of HFCs on global warming; it asks for further near future research as emphasised earlier in this meeting report. It shows that one should be cautioned from relying on forecasts from only one source.

*Table 2.2 Estimated EU Emissions of ODS Related HFCs and /Glu99, Mar99/; rounded figures*

Market Segment	HFC Emissions	Business-as-Usual Scenario,	
	1995	2010	
	[Mton CO <sub>2</sub> eq.]	[Mton CO <sub>2</sub> eq.]	% of total emissions
Refrigeration/air-cond. (HFC):	4	28	43
<i>Supermarket refrigeration</i>		<i>(9.0)</i>	<i>(14)</i>
<i>Mobile Air Conditioning</i>		<i>(8.9)</i>	<i>(14)</i>
<i>Industrial refrigeration</i>		<i>(3.4)</i>	<i>(5)</i>
<i>Direct Expansion A/C</i>		<i>(2.6)</i>	<i>(4)</i>
<i>Other uses</i>		<i>(4.1)</i>	<i>(6)</i>
Foam	0	14	21
HFC-23 from HCFC-22 manuf.	35	10	15
Cosmetic and General Aerosols	1	7	10
MDIs	0	5	7
Solvents	0	2	3 <sup>1</sup>
Losses from HFC manufacture	0.1	0.5	1
Fire-fighting	0	0.2	0.3
<b>TOTAL EU EMISSIONS</b> (rounded figures)	<b>40</b>	<b>67</b>	<b>100</b>

<sup>1</sup> probably even less than 3% with the implementation in 2004 of the EU VOC directive.

Nevertheless, as an example, the results from one of the papers presented /Glu99/ are summarised here. It contained a summary of a study carried out for the European Commission DGIII /Mar99/ on 'opportunities to minimise emissions of HFCs from the European Union member states'. Because of the regional differences described above, the reader is cautioned against extrapolating these results to other regions. However, the result of this study does provide insight into the breakdown of HFC emissions into market sectors and the relationship between HFC emissions and the rest of the Kyoto basket.

Table 2.2 shows a breakdown of ODS related HFC emissions in the EU member states estimated for both 1995 and 2010. The 2010 figures are based upon a Business-as-Usual Scenario /Mar99/ taking into account existing market trends and policies in response to concerns for climate change.

The approach taken in the development of the Business-as-Usual Scenario was to incorporate existing market trends, rather than to assume a -worst case- 'like-for-like' substitution of CFCs and HCFCs. As already illustrated in Table 2.1, there is clear evidence from the market that future consumption and emissions of HFCs will be much lower than the historical levels of CFCs and HCFCs.

The study cited /Mar99/ mentions here that ‘it is important to recognise that an accurate emission forecast for the first Kyoto Commitment Period (i.e., 2008-2012) is virtually impossible to make because there are numerous uncertainties regarding the development of HFC end user markets’.

The table shows significant growth of emissions in end user markets partially offset by the reduction in HFC-23 emissions, which are emitted as a by-product of HCFC-22 production. The 2010 projections show that 80% of emissions relate to refrigeration and air-conditioning, foam blowing, general aerosols and MDIs and that fugitive HFC-23 emissions from HCFC-22 manufacture are still expected to be significant.

Table 2.3 *Split of EU Kyoto Gas Emissions in a Business As Usual Scenario /Mar99/; the EU study estimated that HFC, PFC and SF<sub>6</sub> emissions accounted for 1.6% of EU greenhouse gas emissions in 1995 and projected that this number will have risen to 2.4% in the year 2010*

Global Warming Gas	Total EU emission 1995 [%]	Total EU emission 2010 [%]
CO <sub>2</sub>	78.5	81.6
CH <sub>4</sub>	13.0	8.9
N <sub>2</sub> O	6.9	7.1
HFCs	1.0	1.7
SF <sub>6</sub>	0.3	0.4
PFCs	0.3	0.3
Total	100.0	100.0

The EU study /Mar99/ asserted that there is technical potential to reduce the Business-as-Usual Scenario emissions by about 45% with a package of measures with an average cost effectiveness of \$10/tonne CO<sub>2</sub> equivalent saved. If this reduction is achieved, EU member state emissions of HFCs in 2010 will be 15% below those of 1995.

Table 2.3 shows a comparison of the split of the six Kyoto Gases for the EU in 1995 and a forecast for 2010. None of the 1995 PFC emissions were related to ODS alternatives. HFC emissions were about 1% of total EU GHG emissions in 1995 and are forecast as 1.7% in 2010. These data were questioned in another paper /Joh99/ due to the uncertainty of the emission factors; this paper derived forecasts which suggest that HFCs will account for 2-4% of the total emissions in the EU in 2010. However, these forecasts are based on a -worst case- ‘like-for-like’ substitution of CFCs and HCFCs, which is not reflected by the actual market conditions.

It is important to note that, as a result of different United States and Japanese climates and markets, these figures are most likely not representative for their regions.

### 3. WORKING GROUP FINDINGS

#### 3.1 Refrigeration and Air Conditioning

##### 3.1.1 Stationary Sources

A working group of more than 30 experts intensively discussed the various aspects of limitations to emissions of HFCs in refrigeration. Many papers were presented to provide context for this work. The group was co-chaired by an industry consultant and an academic researcher (TEAP HFC Task Force).

##### *Working Group Highlights*

Refrigeration and air-conditioning covers a wide range of application types, sizes, and temperature levels with regional variation in the applications of technology. It was suggested that this market diversity requires a range of flexible responses rather than uniform prescriptive solutions.

Prior to 1986 the main refrigerants in use were CFCs, HCFCs and ammonia. Other refrigerants such as brominated chemicals and hydrocarbons were used in niche markets. As a response to the Montreal Protocol, HFC, ammonia and HC refrigerants have been promoted as the primary alternatives to ODSs. A very small quantity of PFCs is being used in certain alternative refrigerant blends.

From a life-cycle perspective, refrigeration systems have two distinct global warming impacts. A 'direct impact' occurs if the refrigerant used has a positive GWP and is emitted to the atmosphere. All refrigeration systems also have an 'indirect impact' linked to the CO<sub>2</sub> released in the production of energy to operate the refrigeration units<sup>5</sup>. It is estimated that for all fluorocarbon refrigeration systems the direct impact is about 15 to 20% of the total. For the more emissive HFC systems (e.g. supermarket refrigeration) the direct impact a decade ago was 50-60%, but has been much reduced with new equipment and service practices to less than 20% /TOC91, TOC98/. The direct impact for stationary A/C systems (centrifugal chillers) can be less than 3% in the case of high pressure (HFC-134a) chillers and less than 0.2% in the case of low pressure (HCFC-123) chillers. For hermetically sealed systems (e.g. domestic refrigerators) the direct impact averages only about 1-3% of the total, except where refrigerators suffer large or frequent leakage rates. This calculation depends on the mix of fuels used to generate the electricity used for production and operation of the equipment.

Direct emission impacts of below 5% have been achieved by the developed countries (e.g. domestic refrigeration and stationary A/C), at the expense of considerable effort and discipline. Matching this to the developing countries in general would be a challenge and underscores their call for capacity building (see section 3.7). Here, manufacturing methods and service practices need to be significantly improved compared to the approach followed with CFCs, if one would try to keep the direct effect of the HFC emissions below 15 to 20% of the total (even for domestic refrigerators the direct effect may be larger than a few percent). This is of crucial importance if HFCs will be increasingly applied in future.

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<sup>5</sup> These two impacts have been added to give the so called Total Equivalent Warming Impact (TEWI) (which adds CO<sub>2</sub> from energy production to CO<sub>2</sub> equivalent from refrigerants emitted). In general the indirect impact is larger than the direct impact over the lifetime of the equipment.

The working group discussed issues including (1) regulatory regimes and their effectiveness (2) emission scenarios (3) energy standards, and (4) the validity of the TEWI concept (see above) versus life cycle cost analysis and life cycle performance analysis.

### *Major Findings*

The working group agreed upon five possible strategies, which can be followed to reduce HFC emissions (the best strategy will depend on individual circumstances of the installation):

- ❑ *Use of non-HFC refrigerants*      These include ammonia, hydrocarbons and CO<sub>2</sub> and are normally associated with technically developed and commercially available refrigeration systems. It may involve adequate addressing of safety issues.
- ❑ *Use of alternative technology*      These include absorption, desiccant cooling and air cycle technologies which are fully developed. There are other options, however, so far, not commercialised. Care must be taken to fully assess the energy efficiency implications of these alternatives – in many situations the global warming impact would be higher than conventional technologies due to higher energy consumption.
- ❑ *Containment by design and quality of components*      This involves incorporating measures into the design and manufacture of the equipment in order to reduce leakage potential.
- ❑ *Containment during operation*      This revolves around the installation, maintenance and servicing procedures that are designed to reduce leakage potential.
- ❑ *Containment on disposal*      This means that HFCs are properly recovered from any equipment upon disposal and recycled or destroyed.

The participants discussed the crucial importance of energy efficiency in relation to indirect global warming impact. Using an alternative refrigerant or an alternative technology can have an important influence on energy usage. In some cases (e.g. evaporative cooling) this is a beneficial effect. In other cases (e.g. use of direct fired absorption equipment or low temperature indirect systems) the effect is an energy penalty which can lead to CO<sub>2</sub> emissions that far outweigh the benefits from reduced HFC emissions. These effects are strongly application and design dependent and must be carefully taken into account when considering emission reduction strategies, according to many experts in the Joint Expert Meeting.

Where it concerned the CO<sub>2</sub> emissions from energy production, a minority of the participants interpreted the mandate of the relevant decision more narrowly than others; they argued that indirect emissions should be disregarded and that the issue of energy efficiency was beyond the scope of the Joint Expert Meeting.

### 3.1.2 Mobile Sources

#### *Working Group Highlights*

The report of the working group on Mobile Air Conditioning, originally a sub-group of the Refrigeration and A/C Working Group, was included in the meeting report as a separate item; this is due to the importance of mobile air conditioning to potential HFC emission reductions. The working group consisted of eight experts from automotive and component manufacturers, and the chemical industry, as well as university and independent consultancies (representing all major car manufacturing regions in the world). The report was based on one presentation in plenary, several past publications and the working papers and the experience of the participants.



All of the cars manufactured in developed countries and most currently manufactured in the developing countries have energy efficient (according to manufacturer's standards) HFC-134a air conditioning systems. These systems have current typical emissions of about 170 g HFC-134a per year per car. This would imply a total annual leakage of 60,000 tonnes of HFC-134a, assuming a global fleet of 350 million cars, if they were all equipped with HFC-134a air conditioning, which does not reflect the current situation. During the 1980's, the net emission rate associated with auto air conditioners was about 450 g CFC-12 per year per car.

### *Major Findings*

Three major options were identified to reduce emissions of HFCs: (1) containment and improved servicing practices, (2) carbon dioxide systems, and (3) the use of hydrocarbons combined with secondary loops. The latter two options would result in zero HFC emissions. There is the potential that more than one technology will be present in the market, but the desire for simplicity for servicing drives towards a single technology.

Substantial reductions in HFC emissions from mobile air conditioners has already been achieved by producing tighter systems, and redesigning them so as to reduce the amount of refrigerant needed compared to the CFC systems. Additional emission reductions can be gained by improving service practices, requiring certified service personnel and, especially, proper on-site recovery, recycling and recharging. Although there are no technical barriers to achieve these leak reductions, incentives by governments are necessary to initiate the required investments and training. Such combined measures could lead to an average reduction of emissions to 80 g per year, with some regional emissions down to 50 g per year by 2008 in developed countries (approximately 85% of the global fleet). For certain regions, this may imply a reduction of about 60% per car compared to the order of magnitude of the current emissions. In 2008, total emissions in the developed countries will be between 27,000 tonnes and 36,000 tonnes of HFC-134a assuming a fleet of 450 million cars with air conditioning systems. In developing countries, containment measures should focus on similar steps. These measures may be applicable to certain markets. However, in most developing countries and in countries with economies in transitions the optimum recovery, recycling and recharging scenarios will be difficult to achieve.

Carbon dioxide and secondary loop hydrocarbon systems are potential future options for automotive air conditioning systems. For both systems, significant issues remain requiring further research and development work. Experts in the working group reported that current designs utilising alternative refrigerants show an efficiency decrease and cost increase in comparison to HFC designs. However, this requires further verification; not all participants in the working group agreed on the estimates given, some were confident that optimised designs could be energy efficient. The challenge is to bring alternative refrigerant systems to an efficiency, cost, safety and reliability level comparable with present and future HFC systems. Further discussions on energy efficiency should wait until adequate standards have been developed by which mobile air conditioning energy efficiency is measured across different technologies.

## 3.2 Foams

### *Working Group Highlights*

A group of between 10 and 15 experts, covering technical, economic and regulatory aspects of insulating foams, were able to review the potential for lowering the emissions of HFCs from these applications. In doing so, the group needed to assess the likely future usage, since most applications that will use HFCs are still currently based on HCFCs. Six papers were presented to provide context for this work. This formed the basis for the numbers given below under 'major findings'. The group was co-chaired by an industry consultant (TEAP) and an academic researcher (IPCC).

There is little current use of HFCs as blowing agent in the foam sector; without regulations mandating responsible use, a considerable growth may take place in future. It should be noted that future use will be limited to only some of those applications where CFCs and HCFCs are currently utilised with HFCs replacing less than 50% of the HCFCs and approximately 25% of the CFCs on a weight basis. The primary application of HFCs will be in closed cell thermal insulation foams.

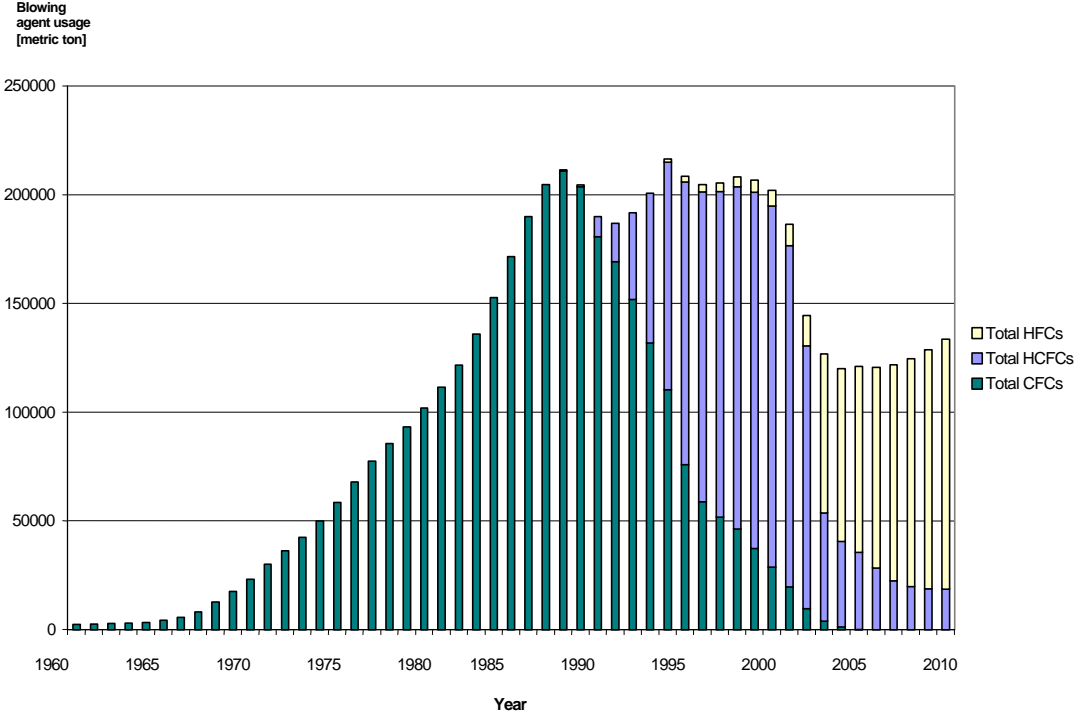


Fig. 3.1 CFC/HCFC/HFC blowing agents in use or expected to be in use globally in rigid foams /Ash99/

Insulation material use is driven by the desire to save energy and, as a consequence, reduce CO<sub>2</sub> emissions. The uses extend to the buildings, building services, industrial and food preservation sectors.

*Major Findings*

It is estimated that the HFC use in the foam sector will be approximately 75,000 tonnes in 2005, growing to 115,000 tonnes in 2010. Thereafter, the foam market growth is anticipated to run at 4-6% per annum, although there may be some gradual reduction in HFC use within the extruded polystyrene sector, which will offset this growth to some extent. This could leave HFC use in foams at a level of between 160,000 and 205,000 tonnes in 2020 /Ash99/. The situation is summarised for the period to 2010 in Figure 3.1.

Table 3.1 *The advantages and potential disadvantages of the emission reduction options available to the foam sector.*

Option	Advantages	Disadvantages
1 Alternative Blowing agent	<ul style="list-style-type: none"> <li>➤ No HFC emissions</li> <li>➤ Long term alternative</li> <li>➤ Lower material costs</li> </ul>	<ul style="list-style-type: none"> <li>➤ Possible VOC emissions</li> <li>➤ Flammability (process)</li> <li>➤ Flammability (product)</li> <li>➤ Investment costs (SME)</li> <li>➤ Investment costs (Dev. C.)</li> <li>➤ Potential Insulation loss</li> <li>➤ Density increase</li> <li>➤ Greater use of associated materials</li> </ul>
2 Not-in-kind insulation	<ul style="list-style-type: none"> <li>➤ No HFC emissions</li> </ul>	<ul style="list-style-type: none"> <li>➤ Potential insulation loss</li> <li>➤ Decrease in structural strength leading to increased weight and use of support materials</li> <li>➤ Lower moisture resistance</li> <li>➤ Fibre concerns</li> </ul>
3 Minimising HFC blowing agent	<ul style="list-style-type: none"> <li>➤ Less HFC emissions</li> <li>➤ Lower cost</li> </ul>	<ul style="list-style-type: none"> <li>➤ Potential insulation loss</li> <li>➤ Flammability</li> <li>➤ Density increase</li> <li>➤ Greater use of associated materials</li> </ul>
4 Reduction of emission on manufacture through changes in processing practice	<ul style="list-style-type: none"> <li>➤ Less HFC emissions</li> <li>➤ Cleaner factory environment</li> </ul>	<ul style="list-style-type: none"> <li>➤ Unproven technical and economic feasibility</li> <li>➤ Investment costs</li> </ul>
5 Reduction of emission in use through facing changes	<ul style="list-style-type: none"> <li>➤ Better retention of insulation value</li> </ul>	<ul style="list-style-type: none"> <li>➤ Increased cost</li> <li>➤ Questionable market acceptance</li> </ul>
6 Reduction of emission on de-commissioning through use of municipal incineration	<ul style="list-style-type: none"> <li>➤ Major reductions in HFC releases</li> </ul>	<ul style="list-style-type: none"> <li>➤ Needs development of separation technology and practice</li> <li>➤ Requires investment in incineration and infrastructure</li> <li>➤ Require regulation</li> <li>➤ Requires consistency of policy</li> </ul>

The replacement of HCFCs by HFCs is on less than a ‘one for one’ basis by 2010 and reflects less than a 50% replacement level when corrected for market growth. A lower replacement rate of HFCs for HCFCs is anticipated if neither of the liquid HFCs (those with boiling points above room temperature) became available. In this case a number of users could switch to HFC-134a which, incidentally, has a better blowing efficiency (less use of the chemical for the same product). However, the low boiling point of HFC-134a would be likely to limit its use to around 50% of the applications that would otherwise have been justified had liquid HFCs been available.

The justifications for use of HFCs are limited to thermal efficiency, product performance and process safety. It is recognised that one of the key measures to reduce HFC emissions is not to use them in unjustified applications and this is reflected by the inclusion of options 1 and 2 in Table 3.1. An additional four abatement options are also included and their advantages and disadvantages listed.

Up to approximately 50% of potential emissions subsequently arising from consumption in 2010 could be abated by the introduction of options 4, 5 and 6. However, the majority of these savings will depend on incineration procedures (see Annex B) which, whilst technically proven, may not be logistically or economically viable. Accordingly, a target of 25% destruction may be more realistic unless evidence emerges to the contrary.

### 3.3 Aerosol Products

#### 3.3.1 Non-Medical Uses

##### *Working Group Highlights*

The UNEP Aerosols Technical Options Committee has estimated that use of HFCs (HFC-134a and HFC-152a) in 1998 does not exceed 15,000 metric tonnes globally. Data voluntarily reported by companies based in Europe, Japan and North America for HFC-134a sales into 'short-term' emission- applications (which include sterilants, non-medical aerosols, one component polyurethane foam and open-cell foam) were 9,342 metric tonnes in 1996 /AFE99/ (sales into all short term uses, with the exception of medical aerosols was 6,293 tonnes in 1997 /AFE99/). With the assumptions that CFC use in non-medical aerosols have been almost entirely replaced by alternatives and that non-critical uses are likely to be constrained in the future, it is unlikely that use/emission in 2010 will exceed 20,000 metric tonnes.

##### *Major Findings*

The working group concluded that one option is currently available to limit HFC emissions in non-medical aerosols:

- the development of criteria, either at a national or international level which determine the criticality of the use and the availability of viable alternatives, based on real safety concerns, and adoption of these 'responsible use' criteria by corporations and industry to ensure that the use of HFCs is limited to those meeting pre-determined criteria.

#### 3.3.2 Medical Uses - MDIs

##### *Working Group Highlights*

CFC-containing metered dose inhalers (MDIs) are reliable and effective therapy for asthma and Chronic Obstructive Pulmonary Disease (COPD), such as chronic bronchitis and emphysema. CFC propellants are now being replaced with HFC-134a and HFC-227ea. Both have been approved by health authorities as acceptable and safe propellants for use in MDIs. The transition from CFC to HFC MDIs is likely to continue into the first decade of the 21<sup>st</sup> century. Alternatives to MDIs in some cases are dry powder inhalers (DPIs) and nebulisers, which do not use a propellant.

##### *Major Findings*

Compounds identified as potential substitutes for CFCs must meet particularly strict requirements for use in MDIs. After extensive investigation, only two compounds emerged as acceptable substitutes: HFC-134a and HFC-227ea. At present, there are no other known alternative propellants for use in MDIs. CFC-free MDIs will use approximately 30% less propellant, on average, than CFC based MDIs.

MDIs constitute approximately 75% of inhalation therapy in the world's fifteen largest populations of patients. To date, HFCs have started to play a significant role in the shift away from CFC propelled MDIs. A concern was expressed that the transition away from CFC use in MDIs may be slowed unless a long term solution such as HFCs is clear to patients and their physicians. However, the most serious barrier to the transition to non-CFC MDIs seems to be the rate at which new products are entering the market. DPIs constitute approximately 15% of the market, and their market share is growing (the percentage is much higher in countries such as Sweden that have mandated DPI use (80% share)). At current growth rates, DPIs are not expected to -fully- replace MDIs by 2020. Assuming that current trends continue, worldwide emissions of HFCs from MDIs in the year 2010 are projected to reach a level between 7,500 and 9,000 metric tonnes.

### 3.4 Industrial and PFC and SF<sub>6</sub> Emissions

#### *Working Group Highlights*

The working group consisted of 18 experts from industry (representing chemical manufacture, electric equipment insulation, semiconductor manufacture and miscellaneous industrial uses) and from consultancies. Eight technical papers were presented in this working group.

Unlike the ODS-replacement industries, this was generally the first time experts had gathered to consider global emissions and emission reduction opportunities from aluminium, electric power distribution, HCFC-22 production, magnesium, chemical manufacturing and distribution, and miscellaneous industrial uses. Consequently, significant gaps in global and regional data on uses, emissions, emission reductions and costs were identified.

Two PFCs - CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> - are inadvertently emitted as emission by-products during primary aluminium smelting. SF<sub>6</sub> has been used for the past 30 years in electrical power distribution equipment such as high and very high voltage equipment, i.e. circuit breakers and transformers. SF<sub>6</sub> is a highly effective dielectric insulator that has no readily available substitutes for high voltage applications in densely populated areas. Magnesium processing (primary smelters, secondary smelters, die casting) amounts to about 10% of total global use of SF<sub>6</sub>. High GWP fluorinated compounds including PFCs, HFC-23, SF<sub>6</sub> and NF<sub>3</sub> are currently used in the manufacture of semiconductors. These chemicals were considered essential to current semiconductor manufacturing technology by several participants of the working group.

During the production of HCFC-22 the chemical HFC-23 is produced and emitted. It is believed that 6 out of 11 plants in Europe will have some level of HFC abatement by around 2000. HCFC-22 producers in the USA have voluntarily committed to reduce HFC-23 emissions by 5 million metric tonnes carbon equivalent from 1990 levels. Reduction activities include process optimisation and abatement.

#### *Major Findings*

The Petten PFC/SF<sub>6</sub> expert work group focused on PFC emissions from aluminium manufacture, HFC-23 from HCFC-22 production, SF<sub>6</sub> from electric power systems, and PFCs from semiconductor manufacture.

Although it is not currently technically feasible to eliminate all emissions from these industries, ways and means of reducing emissions have been identified. Very little global emissions data and cost information was available through the workgroup, except for PFC emissions from the aluminium industry /Har99/. PFCs from aluminium and HFC-23 from HCFC-22 are inadvertent production by-products. Process optimisation for both of these industries are technically feasible, currently available and cost-effective. Other methods exist for further emission reductions but may not be cost-effective for all production sites.

Most companies in developed countries with aluminium and HCFC-22 production are engaging in emission reduction activities, and other companies can be encouraged to join these efforts. No information was available on operations in developing countries.

SF<sub>6</sub> is used in high and very high voltage circuit breakers and electric transformers as a dielectric to quench electric arcing. SF<sub>6</sub> emissions in this sector result from distribution, original equipment manufacture, and operation and maintenance of equipment. Japan has adopted an aggressive national action plan to significantly reduce emissions in this application by 2010. Other countries (e.g. Germany and the United States) and companies have also initiated action to reduce emissions from this sector.

PFCs, HFC-23, NF<sub>3</sub> and SF<sub>6</sub> are used by the semiconductor industry for etch and plasma cleaning of chemical vapour deposition tools. In April 1999, the World Semiconductor Council which represents manufacturers from Europe, Japan, Korea, Taiwan and the United States adopted a voluntary global emission reduction target of 10% absolute reduction from 1995 emissions by 2010. This target encompasses over 90% of total semiconductor manufacture, and will result in significant emission reduction given high industry growth rates and anticipated increased intensity of PFC use in the manufacturing of more sophisticated products.

### 3.5 Solvents

#### *Working Group Highlights*

PFCs such as C<sub>3</sub>F<sub>12</sub>, C<sub>6</sub>F<sub>14</sub>, C<sub>7</sub>F<sub>16</sub> and C<sub>8</sub>F<sub>18</sub> were introduced as substitutes for CFC-113 in the late 1980's and early 1990's. The applications included carrier fluid for fluoro-lubricants in the computer industry, particulate removal in precision cleaning, electronic applications such as cooling and as dielectric fluid and rinsing agent in a co-solvent process for cleaning printed circuit boards and precision cleaning of mechanical parts.

An HFC (C<sub>3</sub>F<sub>10</sub>H<sub>2</sub>, HFC-4310 mee) was introduced in late 1995 to replace CFC-113 and PFCs in some applications. Additional new compounds have been proposed in recent years but not yet commercialised. Some of the additional applications include uses in the aerospace and aerosol industries.

The PFC market is estimated to be around 2500 tonnes /Har99/. Current HFC uses are very small and are estimated to be around 500- 1000 tonnes. This represents less than 1% of the CFC-113 market in 1989. The vast majority of the market switched to not-in-kind technologies such as aqueous, no-clean technologies and hydrocarbons.

HFC and PFC solvents are primarily used in developed countries for specialty applications where not-in-kind alternatives are not technically feasible for reasons of safety, performance or compatibility demands.

#### *Major Findings*

There are several emission reduction efforts currently in use, such as recovery and recycle, abatement technology, the airless degreaser, and upgrading of old degreasers (additional free-board, secondary cooling coil, etc). An upgrading of the degreaser can reduce emissions by about 80% (e.g. the upcoming implementation of the EU directive on solvents VOC emissions should lead to the containment of HFC solvents and to an emission reduction of about 65%).

It is expected that PFCs will be replaced in most applications by the lower GWP alternatives (HFCs and HFEs, hydrofluoroethers) over the next 10 years, however, no suitable low GWP alternatives are available in some applications. In some cases HFEs may also replace HFCs. Overall growth of this market is not anticipated to be too large due to high cost of these alternatives, and already low usage rates of PFC and HFC solvents.

### 3.6 Fire Extinguishants

#### *Working Group Highlights*

The working group consisted of representatives of CEIT and developed countries, including representatives of governments, main users (the military sector), system suppliers, HFC manufacturers and an environmental NGO, and the group was chaired by present and former co-chairs of the UNEP Halons Technical Options Committee.

HFCs are important halon substitutes primarily in occupied areas where space and weight are constrained, or speed of fire suppression is important. HFC growth is limited by high system cost compared to other choices. PFCs are not technically necessary except in very rare circumstances. HFC emissions from fire fighting are forecast to be around 0.3% of all HFC emissions by 2010. HFC emissions from all sources are approximately 2% of GHG emissions, and fire fighting emissions account for only 0.006% of all GHG emissions on a GWP weighted basis.

Furthermore, there are a large number of halon alternatives applied in the substitution process as given in Table 2.1.

#### *Major Findings*

Restrictions on HFC use may increase halon use; the likelihood that an essential use exemption under the Montreal Protocol would be necessary to satisfy critical halon needs would then also increase. If restrictions were to be put in place for the use of halons, this would also guarantee availability of recovered halon for critical uses where no viable alternative has been found. This particularly applies to critical halon-1301 needs.

Annual loss rates from halon systems have declined from 25% of the installed base before the Montreal Protocol to around 4-6% today due to changes in industry practice in many developed countries to conserve halon. These include ending system discharge testing and training, use of leakage detection and improved maintenance. These practices were institutionalised in a number of countries and now apply to HFCs. Options available for implementation before 2010 that could reduce emissions of the new fluorocarbon systems by up to an additional 50% include: (A) Incentives to industry to invest in best installation and maintenance practice, (B) Field recovery and recycling, and (C) End-of-useful-life reclamation and transformation.

### 3.7 Developing Country Aspects

#### *Working Group Highlights*

The working group was co-chaired by a representative from the Multilateral Fund Secretariat and a representative from UNIDO. Participants represented developing country ozone officers, UNDP, GEF, TEAP members, chemical suppliers and some (environmental) research institutes.

Two papers were presented, one by a chemical supplier, and one by the ozone network manager for the Latin American and Caribbean region. The latter one presented the information gathered during a Latin American Ozone Officers Network meeting, a Regional Workshop on Refrigeration and Air Conditioning and additional comments provided by some Ozone Officers. It formed the basis for the discussions since it covered most of basic points to be addressed by the working group. The group first discussed general concerns relating to the specific situation of developing countries and then focused on the analysis of options to reduce HFCs emissions.

Developing countries share the global concerns for stratospheric ozone and climate protection. The choice of technology is a balance of technology maturity and availability, cost effectiveness, energy and other performance, and safety and safety costs. In addition to the guidance given by MLF decisions and implementing agencies in the evaluation of options, the choice is also influenced by: local circumstances, preferences of enterprises, their joint venture partners and customers, availability of training and other market circumstances and regulatory compliance.

Concerns were expressed related to the fact that the uncertainty on possible controls on HFCs in developed countries might adversely affect compliance with Montreal Protocol obligations particularly for the refrigeration, air conditioning and foam sectors. The importance of guaranteeing supplies of chemicals and components for maintenance and services was emphasised for those developing countries that have selected HFC technology.

The following can be stated where it concerns sector choices of substitutes in projects financed by the Multilateral Fund (MLF) (as % of sector ODP-tonnes total). No projects in the solvents sector used HFCs; in the aerosol sector only one project used HFCs, while in the halons sector 6 projects were identified replacing halon-1301 with HFCs. 21% of the total ODP-tonnes used in the refrigeration sector (including insulation foam) is being replaced by HFCs, 24% by HCFCs, 53% by hydrocarbons and 2% by other technologies. 93% of the refrigerant chemical replacement was with HFCs, and 7% with hydrocarbons. In the foam sector, the contribution of non-ODP and low-GWP alternatives as replacements for ODSs is about 75%, 24.6% of uses was replaced by HCFCs and only 0.2% by HFCs.

Enterprises, governments and implementing agencies need complete information on the merits of available options. Developing countries also need to have guidance on the implications of the selection of different alternatives, perceived risk related to technical and economic performance (including safety) and market structure. Deficiencies in infrastructure and lack of incentives are factors that inhibit best servicing practice.

### *Major findings*

In analysing options to reduce HFC emissions, constraints as well as several opportunities have been identified:

#### Constraints:

- The need to improve information on technology options that can help enterprises to have a fully informed choice; a clearer scenario on the implications of the selection of different alternatives, especially for small and medium enterprises (SMEs); the perceived risk related to technical and economic performance (including safety) and market structure; the deficiencies in infrastructure and lack of incentives as factors that inhibit best servicing practice; institutional weakness as a prejudice to regulatory enforcement; and lack of access to commercial financing sources that would allow enterprises to make needed investments in technology (that otherwise would pay by itself).

#### Opportunities:

- The selection of low-GWP alternatives in uses where non-GWP alternatives are not available or cannot be used; product redesign to acquire leak tightness and energy efficiency, better practices in production, servicing and recovery and recycling, improved performance standards, and supporting policy and regulatory initiatives; HFC recycling can build on expertise developed through Multilateral Fund (MLF) funded ODS recovery and recycling projects and associated training activities, and developed countries experience with HFC recovery, recycling and reclamation can aid the process. A blend of all the above options is needed depending on specific circumstances and applications.



The MLF finances the agreed incremental costs for ODS phaseout in the developing countries, and the Global Environment facility (GEF) assists in phasing out ODSs in countries with economies in transition. Under the MLF, enterprises are only eligible once for financial assistance. This makes it crucial for an enterprise to choose a technology that is cost effective, environmentally acceptable, and globally sustainable. The MLF is only empowered to invest in ozone layer protection while the GEF is empowered to invest in energy efficiency for climate protection (up to US\$ 10 per ton of carbon equivalent abatement over the life-cycle of the relevant investments) and also in low-GWP technologies. There was a strong sense expressed in the plenary that the MLF and the GEF should co-operate in funding the development of energy efficient refrigeration, air conditioning and other equipment, and that the MLF should also consider energy efficiency as well as ODP in the projects that it funds alone. Such an integrated approach will not only address goals of both Protocols, but will enhance the sustainability of the development process by reducing the demand for additional electric power production.

#### *Potential Cost-Effective Climate Protection During Conversion from ODSs*

Incremental investment could complement ozone protection technology sponsored by the MLF by providing improved energy efficiency. Incremental investment in energy efficiency during conversion from ODSs would be highly cost effective and institutionally efficient. Higher energy efficiency helps protect the climate and reduces operating costs. Unfortunately, such co-ordinated investment had not occurred until recently.

Participants in the Joint Expert Meeting strongly supported the expansion of dual-purpose ozone and climate projects. Representatives of the MLF and GEF agreed to co-ordinate consideration of such projects. They pointed out that applicants are responsible for proposing the joint funding. CEIT and Article 5(1) countries at the Joint Expert Meeting welcomed additional funding for climate protection enhancements to GEF and Multilateral Fund ozone protection investments.

#### *Investment Choices Should be Fully Informed and Respected*

The Montreal Protocol has encouraged CEIT and Article 5(1) countries to phase out CFCs by early adoption of new alternatives including HFCs and other options.

Some participants expressed their concerns that some developed countries may try to impose their own choice of technology on developing countries. Such efforts could undermine trust and mutual respect under the Protocol and would be counterproductive if developing countries began to doubt that advice given under the Montreal Protocol. This could undermine credibility of future global environmental treaties. It is also essential that technologies chosen to address climate change and ozone protection meet the sustainable development goals of developing countries. In addition, it appears that developing countries are choosing CFC replacements to some extent based upon historic or new commercial links to developed countries in addition to cost considerations.

## 4. CONCLUDING REMARKS

The IPCC/TEAP Joint Expert Meeting was the first opportunity for representatives of governments, international agencies, environmental organisations and the private sector to meet and explore co-ordinated actions that might be taken to address the atmospheric problems of stratospheric ozone depletion and climate change. It also provided the first opportunity for experts working on the climate problem through IPCC and those working on ozone depletion through TEAP to discuss their common and separate issues in the same forum. The meeting was held in Petten, the Netherlands, 26-28 May 1999, and was attended by over 100 participants from 24 nations.

Within the framework of the Montreal Protocol it has been recognised that substitutes for ozone depleting substances (ODSs) should be compatible with the goals of climate protection. Technical assessments have also utilised measures such as the Total Equivalent Warming Impact (TEWI) factor to study the implications for global warming of energy associated CO<sub>2</sub> emissions. However, the actual implementation of the Montreal Protocol cannot mandate climate change considerations since it only controls listed substances *directly* involved in ozone depletion. The Kyoto Protocol has created a more immediate need to further examine the relationship between the climate and ozone treaty regimes. It includes the hydrofluorocarbons (HFCs) among the gases that are to be controlled for climate protection, and these are the principal substances chosen as substitutes for ODSs under the Montreal Protocol.

The widely different replacement strategies for ODSs among countries demonstrate the need for more explicit international co-ordination of actions taken to address ozone depletion and climate protection simultaneously. The future choices of ODS substitutes are important for maintaining environmental quality and a sound economy, encouraging technological innovation, and for assuring developing countries an improved quality of life. These concerns formed the background, as well as a very important part for all discussions at the Joint Expert Meeting. Furthermore, the Meeting also provided an opportunity for specialists to examine the implications for both the global environment and the global economy of the Kyoto greenhouse gases which contribute to global warming, but which do not affect the ozone layer directly, such as CO<sub>2</sub>, SF<sub>6</sub>, and the perfluorocarbons (PFCs).

The Joint Expert Meeting consisted of a one day plenary followed by working sessions organised by end-use application. The sectors projected to consume the largest amount of HFCs, are the refrigeration, mobile and stationary air conditioning industry, followed by insulating foam manufacturing, solvent and fire extinguishants, aerosol applications and medical devices. Use of PFCs and SF<sub>6</sub> is more specifically confined to narrowly defined sub-sectors such as chemical and metals manufacturing, electronics and specialty products. At the Meeting, each working group identified numerous technical options and management techniques for limiting emissions from specific applications. Particularly for HFC substitutes for CFCs, the working groups developed unprioritised lists of available and emerging options.

The experts concluded that while alternatives may not yet be technically and economically feasible for some current uses, there are technologies for other uses that can further reduce of ODSs and global warming gases in the near future. Plenary presentations also made clear that different governments were pursuing alternative strategies for replacing CFCs, especially in the refrigeration and air conditioning sectors. While several European governments such as Denmark and Sweden are considering regulations to limit the use of HFCs and are encouraging hydrocarbon and ammonia refrigerants, the United States is encouraging the use of HFCs together with containment and recycling.

Japan is following a focused strategy to encourage low GWP substitutes for specific applications, while developing countries and countries with economies in transition are choosing various alternatives for CFCs depending upon commercial ties and their own industrial capacities.

The expert groups identified four distinct categories of options to reduce the emissions of HFCs, PFCs and SF<sub>6</sub>:

1. *Alternative Substances and Technologies.* When available, alternatives eliminate the specified gas emissions entirely. A few participants in the Joint Expert Meeting believed that such alternative substances are available and that these should be explored as the primary option. However, most of the participants cautioned that the reduction of direct global warming from the elimination of a gas might be outweighed by increased indirect global warming from carbon dioxide if energy efficiency is lowered.
2. *Containment.* Though there has been substantial technical progress in the containment and recycling of HFCs and PFCs as refrigerants, blowing agents or fire extinguishants, these procedures have not been applied to all markets; further improvements are expected to be feasible. In some cases, containment is driven by national regulations, but several voluntary industry initiatives have also been significant. While improved containment can substantially reduce releases, it cannot be 100% effective in practice.
3. *Improved System or Process Design.* Altering the process or system design can substantially reduce emissions as has occurred with PFC releases in aluminium smelting and from electronics manufacturing; it has substantially reduced emissions of HFCs and N<sub>2</sub>O associated with chemical manufacturing. Redesign of products can also permit the use of reduced chemical charge or use.
4. *End of Product Life Recovery for Recycling or Destruction.* Technology for recycling HFC refrigerants is fully commercialised, but so far employed only when mandated by regulation (e.g., USA), or when voluntary industry association or corporate programs are in place (e.g. Australia, Japan and France). Recovery for destruction is generally not economical, although destruction facilities exist in several locations. Destruction at end-of-life appears to have technical potential for major reductions in HFC releases from the foams sector, but it may not be cost effective. The procedures for promoting recycling or destruction may also differ.

For process related releases of HFCs and N<sub>2</sub>O in chemical manufacturing, or PFCs from aluminium smelting, recovery of inadvertent by-products should be a first requirement. In a second instance, optimising the chemical and smelting production efficiency and redesigning production processes will minimise the generation of inadvertent by-products thereby substantially reducing these incidental releases. Most efforts to date have been voluntary, but these practices can be disseminated to all manufacturers. The other alternative is end-of-the-pipe capture with disposal or recycling.

At the Joint Expert Meeting, the relationship between the global warming impact of HFC emissions and energy efficiency gains or losses, which may result from the use of non-HFC technologies, was discussed at great length. The insulation foam working-group considered energy efficiency as the most important element influencing the possible use of HFCs, while the refrigeration and air conditioning group was divided on the importance of considering energy efficiency. A small number of participants believed energy efficiency to be beyond the mandate of the Joint Expert Meeting whereas the majority of participants were of the opinion that it must be considered. Considering the full, life cycle global warming contribution when making choices of gases, technologies and processes under both the Montreal and Kyoto Protocols can help to meet both sets of treaty goals sooner and more cost effectively. Furthermore, the Meeting also noted that there is a need for standardised equipment testing procedures among technologies and countries.

One government representative explicitly emphasised that despite the global warming reductions from the elimination of CFCs, there continues to be a need to limit the emissions of HFCs and PFCs by prohibiting their use, while also doing more to increase energy efficiency of buildings and appliances.

There was a strong plea to assist developing countries and countries with economies in transition in simultaneously improving the energy efficiency of appliances and systems while assisting them in shifting away from CFCs in refrigeration, air conditioning, foams and other applications. While not required to eliminate CFCs until 2010, many developing countries have already proceeded in the transition process away from ODSs. The Meeting requested that more synergistic projects be financed jointly by the Multilateral Fund and the Global Environmental Facility, and that a simple, dual-goal application process be devised. An overcomplicated project application system on the other hand would discourage such efforts.

Developing countries expressed concern that some developed countries may try to impose their own choice of technology on developing countries. Such efforts could undermine trust and mutual respect under the Protocol and would be counterproductive if developing countries would begin to question the advice given within the Montreal Protocol framework. Specifically, concerns were expressed that uncertainty on possible controls to address climate change may adversely affect compliance with Montreal Protocol obligations particularly for the refrigeration, air conditioning and foams sector. This could undermine credibility of future global environmental treaties. It is also essential that technologies chosen to address climate change and ozone protection meet the sustainable development goals of developing countries.

Data presented at the Expert Meeting clearly demonstrated that consumption of CFCs and halons reached its peak in terms of their contribution to ozone depletion and global warming in the year 1988. In the ten years since, the actions taken under the Montreal Protocol have reduced the ODP weighted emissions of these substances and their HCFC substitutes by approximately 80% (with almost 18% due to continued CFC and halon consumption in some countries). These actions have also decreased the direct global warming impact of all the fluorocarbons by approximately two-thirds. The rate of reduction has, however, slowed between 1995 and 1997. Projecting into the future proved more difficult since it depends critically upon assumptions about technical feasibility of alternatives, and future demand for the services provided by these types of substances.

Several sector working-groups quantified the range of technically feasible emission reduction options available in the near term. More detailed analysis is still needed for the many sub-sectors of refrigeration, air conditioning and heat pumps. More information is also needed to derive global estimates of future emissions of HFCs under different system tightness and replacement scenarios, and alternative assumptions concerning different emission projections, life cycle analysis, cost performance ratios etc. In addition, more work is needed to quantify carbon dioxide emissions reductions that could be achieved at various costs through energy efficiency improvements in the refrigeration, air conditioning and heat pump sector and in building related insulation foam. Even for the EU where data is the most detailed, scenarios differed by more than a factor of two (1.7% to 4% of CO<sub>2</sub> equivalents) for the level of HFC use in the EU by 2010. Substantial increases in HFC use are anticipated in the refrigeration and air conditioning, insulating foam, medical and aerosol sectors, while major reductions will occur from lowered releases of HFCs in HCFC manufacturing.

While the precise HFC growth was uncertain, it appears that the use of HFCs will be substantially less in amount and in terms of contribution to global warming than the CFCs and HCFCs they replace. PFC use and release is expected to remain small because of its limited applicability, and also due to the high price of these chemicals.

Because of the early stage of substitution and numerous uncertainties regarding the development of HFC end user markets, it was concluded that an accurate emission forecast for the first Kyoto Commitment Period (i.e., 2008-2012) is virtually impossible to make at this time.

Presentations and discussions at the Joint Expert Meeting highlighted the complexity of the links between ozone depletion and climate change mitigation activities, the multiplicity of solutions required to address these two global change issues simultaneously, and the need for solutions tailored to regional or national needs. The different perspectives of the experts on the possible future emissions and current and future availability and feasibility of alternatives to HFCs, PFCs and SF<sub>6</sub> in each sector demonstrates the need for substantial additional research and analysis to provide a valid and consistent, qualitative and quantitative picture of potential options. Despite uncertainty and differing opinions expressed at the Joint Expert Meeting, many practical options for reducing emissions of these gases were identified.

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## ANNEXES

In this part of the report supplementary material as discussed in the meeting is presented. It has been done in the form of annexes, which vary in length. In some cases it was possible to bring all the material to one section in the main part of the report. In particular cases there is some redundancy due to the fact that the material presented should be understandable in its annex form.

### ANNEX A REFRIGERATION AND AIR CONDITIONING

#### *Stationary Sources*

Refrigeration systems may have two distinct global warming impacts. A 'direct impact' occurs if the refrigerant used is emitted to the atmosphere. All refrigeration systems also have an 'indirect impact' linked to the emissions from the energy consumed. In general the indirect impact is far larger than the direct impact over the lifetime of the equipment. It is estimated that for all refrigeration systems the direct impact is about 15 to 20% of the total. For the more emissive HFC systems (e.g. supermarket refrigeration) the direct impact a decade ago was 50-60%, but has been much reduced with new equipment and service practices to less than 20%. The direct impact for stationary A/C systems (centrifugal chillers) can be less than 3% in the case of high pressure (HFC-134a) chillers and less than 0.2% in the case of low pressure (HCFC-123) chillers. For hermetically sealed systems (e.g. domestic refrigerators) the direct impact is only about 1-3% of the total, except where refrigerators suffer large or frequent leakage rates.

There are a number of ways in which future emissions of HFCs and PFCs can be significantly reduced (the best strategy will depend on individual circumstances of the equipment):

- a) *Use of alternative refrigerants.* HFC refrigerants can be replaced using other alternatives such as ammonia or HCs, which forms a major way to reduce HFC emissions. Ammonia already has a significant market in the large industrial refrigeration sector and is gaining market share for smaller industrial systems, prototype air-conditioning applications and prototype supermarket systems. There are currently ammonia air conditioning systems in hospitals, shopping centres, universities, hotels, banks, airports, conference centres, office buildings and government buildings. HCs have established a significant market in domestic refrigeration. In Germany the whole industry has switched to HCs, and refrigerators and display cases using hydrocarbon refrigerants are also manufactured in Austria, Australia, China, Denmark, India, Italy, Sweden etc. Hydrocarbons are gaining market share in a range of small commercial, supermarket, air-conditioning applications and liquid chiller applications. Other refrigerants such as water are being used in niche markets. When flammable or toxic alternatives such as HCs and ammonia are used in public locations they must be designed to mitigate the potential hazard (e.g. by using secondary refrigerant heat transfer systems); this can be achieved by following the requirements laid down in published safety standards in many countries.
- b) *Use of alternative technologies.* HFC refrigerants can be replaced using other cooling technologies such as evaporative cooling or absorption refrigeration in the appropriate applications, which avoids any HFC emissions. In several cases the energy efficiency implications of the non-HFC technology are unknown and need evaluation for specific circumstances. Not-in-kind technologies such as acoustic compression helium cooling or Peltier thermoelectric are not yet commercially demonstrated.

- c) *Containment by improved design and manufacture of new equipment.* Original Equipment Manufacturers (OEMs) and other primary manufacturers have taken and are taking steps to reduce refrigerant charge, reduce component leak rates and improve leak testing and quality control.
- d) *Containment by improved installation, operation and maintenance.* Contractors and end users can improve on-site practices to reduce emission rates.
- e) *Containment by improved recovery, recycling and disposal.* Emissions at the end of life can be reduced by better disposal practices. For large systems this involves actions from end users and their contractors. For domestic and small commercial systems this will require an appropriate infrastructure which could be private contractors or municipalities. This technology currently exists and is being practised for refrigerants in a variety of refrigeration and A/C applications, such as domestic refrigeration, chillers etc.

A recent report /Mar99/ (submitted to European Commission DG III) showed that 1995 EU emissions from refrigeration and air-conditioning equipment were 4.3 Mtonnes CO<sub>2</sub> equivalent, which represented 10% of EU HFC emissions in that year. Estimates for a Business-as-Usual Scenario for 2010 showed a growth in emissions to 28.2 Mtonnes CO<sub>2</sub> equivalent. It should be noted that this Scenario took into account the fact that the climate change issue has already influenced many companies to improve refrigerant containment or use alternative fluids and that these improvements will continue. An analysis of emission reduction technologies showed that, by 2010, a substantial emission reduction could be achieved for about \$15 to 20/tonnes CO<sub>2</sub> saved.

One presentation demonstrated a global warming advantage for large HCFC-123 based water chillers (ODP 0.012 and GWP 120) <sup>6</sup>. HCFC-123 may be an interesting refrigerant from the point of view of energy efficiency; it should, however, be borne in mind that the current Montreal Protocol schedules require a virtual phaseout of all HCFCs by 2020 for the developed countries, and a total phaseout by 2030.

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<sup>6</sup> One presenter requests that this issue is elaborated upon since the working group allocated a substantial amount of time on this issue and he would like to see the following reflected: 'The working group addressed the question of refrigerant selections for large chillers. The majority of new centrifugal chillers currently use HCFC-123 as a replacement for CFCs. The next most common refrigerant in this application is HFC-134a (ODP 0 and GWP 1300); neither ammonia nor hydrocarbons are used in centrifugal chillers for safety and performance reasons. Data from peer reviewed journal publications were presented to show that the phaseout of HCFC-123 will increase net impacts on global warming by 14-20% (above non-HCFC chiller applications), owing primarily to its efficiency advantage, as contrasted to less than a 0.001% increase in peak bromine-chlorine loading. There was strong controversy in the working group on whether to consider an HCFC (an ODS) as an alternative to avoid increased use of HFCs. There was also controversy on whether energy related impacts should be addressed at this meeting. The working group voted to note that HCFC-123 use warrants examination for chillers based on its negligible impact on ozone depletion and strong benefit in reducing global warming.'



## ANNEX B FOAMS

As noted previously, insulation material use is driven by the desire to save energy and, as a consequence, reduce CO<sub>2</sub> emissions (the uses extend to the buildings, building services, industrial and food preservation sectors. To provide a measure of the importance of energy efficiency in the buildings sector, it should be noted that an average increase in global energy efficiency of 1% in buildings would equate to an additional reduction in emissions of approximately 80 Mtonnes of CO<sub>2</sub> annually).

Not-in-kind insulation materials such as mineral fibre have a major part to play in the saving of energy but the additional efficiency per unit thickness arising from the use of foams in some cases enables higher energy efficiency. Insulating foams already account for at least 30% of the overall global insulation market despite their higher cost per unit volume and this percentage is expected to grow. The energy efficiency of a foam type can be further affected by the choice of blowing agent, although the significance of these differences is dependent on the product type and application. Energy efficiency considerations will promote the utilisation of HFCs mainly in insulation applications. However, it should be noted that 25% of all insulating foam in the polyurethane sector is currently based on hydrocarbon blowing agents.

In some cases, such as polyurethane spray foam, process safety is an issue. In other areas, such as polyisocyanurate and phenolic foams, the behaviour of the product during fires is the key determinant. In the 2002-2010 timeframe it is estimated that 50% of projected HCFC use in extruded polystyrene will switch to HFC blowing agents. In addition, for those applications in the polyurethane sector in developed countries which have not switched to hydrocarbons or CO<sub>2</sub> by 2004, liquid HFCs (liquid at room temperature) such as HFC-245fa and HFC-365mfc are the leading candidate alternatives, despite their projected higher cost. Similarly most polyisocyanurates and phenolics will also switch directly to HFCs.

The long lifetime of insulation foam applications (15-50 years) makes emission modelling a complex issue. The work that has been carried out so far on the use of HFC-134a in extruded polystyrene suggests a projected emission of around 12,000 tonnes (15.6 Mtonnes CO<sub>2</sub> equivalent) in 2010 from a 25,000 tonne annual usage level at that time. Given that applications using HFC-134a can be more emissive than others, the introduction of 40-55,000 tonnes of liquid HFCs is expected to less than double the annual emissions in 2010. Accordingly emissions of around 25-30 Mtonnes CO<sub>2</sub> equivalent are expected in 2010. With on-going optimisation of HFC use and some further blowing agent substitution continuing after 2010 it is difficult to forecast whether the HFC emissions from closed cell insulation foams will much exceed the 50 Mtonnes CO<sub>2</sub> equivalent emission level during the coming decades. The reason is that no reliable estimation methods are available to date.

A net effect of the long life-time of insulating foam applications is that emissions are spread over extended periods, which could be many decades. The impact of reduction measures will therefore equally be spread over significant periods and reductions may be achieved many years after the consumption of the blowing agent. Notwithstanding this fact, it has been possible to assess what might happen to the consumption scheduled for 2010 (115,000 tonnes). The outcome of this assessment is that up to 57,000 tonnes (49%) of potential emissions can be abated by the introduction of reduction measures 4, 5 and 6 alone. However, the important fact to note is that over 50,000 tonnes (88%) of these savings will depend on the use of incineration procedures at end-of-life. Whilst the technology of this approach is well understood (e.g. the European TAMARA study), the practical efficacy and economic viability are still unknown. A recent extended trial in the Netherlands has found the extraction and separation of foams from building waste difficult and it is clear that further work will be required to perfect separation techniques

and procedures. The situation may be eased somewhat in the future by the fact that insulation, particularly in the commercial and industrial sectors, is increasingly being installed in prefabricated elements (e.g. steel panels) which can be de-mounted and shipped for incineration. Indeed, it is only the more traditional boardstock applications which threaten real separation problems. However, boardstock currently accounts for nearly 20,000 tonnes of the potential savings based on current market splits.

The value of early action in the area of incineration infra-structure cannot be over-stressed, since there is a further opportunity to destroy a significant quantity of CFCs and HCFCs amassed in existing insulation materials. Although the net benefit of such action to the global climate change emission reduction strategy depends on the GWP assigned to the CFCs and HCFCs, it is estimated that annual CFC-11 emissions amounting to well in excess of 100 Mtonnes CO<sub>2</sub> equivalent could be abated. This is more than double the projected maximum annual emissions arising from the use of HFCs in rigid insulating foams.

## ANNEX C AEROSOL PRODUCTS

### *Non-medical Uses*

CFCs were used extensively as aerosol propellants. Sales by companies in the developed countries exceeded 430,000 metric tonnes in 1976. As a result of consumer pressure and industry innovation, the use of CFCs has been virtually eliminated in cosmetic and convenience aerosol products. By 1998, CFC aerosol consumption, excluding metered dose inhaler use, only occurred in developing countries and some CEITs with total use and emissions less than 10,000 metric tonnes.

Hydrocarbons, and not-in-kind substitutes (roll-on deodorants, mechanical pump sprays) have become the preferred alternatives for CFCs in non-medical aerosols. HFCs have been adopted in a small number of applications for technical and safety applications.

Virtually all aerosol consumer products can be manufactured without HFCs. For most products, hydrocarbon propellants are more economical and satisfy safety and environmental criteria. HFCs are much more expensive than common hydrocarbon aerosol propellants (HAPs) and Dimethyl Ether (DME). They are only used, therefore, where a unique HFC property is needed, or to comply with safety and/or volatile organic compound (VOC) regulations.

Applications identified where the unique properties of HFCs are required include: Laboratory, analytical and experimental uses; products that must meet non-flammability regulations or specify maximum VOC content; insecticide use on electrically energised equipment and on aircraft; and e.g. portable compressed gas dusters. Also critical technical applications can be mentioned such as cleaning and freezing products used near soldering posts, precision mechanical cleaning, deoxidising or lubricating near hot spots or electrical circuits (engines), and cleaning of electrical boards under tension (low voltage).

### *Medical Uses - MDIs*

The asthma guidelines of the World Health Organisation/US National Heart, Lung and Blood Institute (WHO/NHLBI-GINA) encourage the inhaled route as the preferred method of administering medicine. Inhaled medication includes MDIs, dry powder inhalers (DPIs), and nebulisers. Overall use of inhaled medication is increasing due to increased disease prevalence. MDIs remain the dominant inhaled delivery system in most countries and for all categories of drugs.

According to the 1996 TEAP Assessment Report, an estimated 300 million people world-wide suffer from asthma and as many again (an estimated 600 million cases) from Chronic Obstructive Pulmonary Disease (COPD). There is conclusive evidence that asthma prevalence is increasing as urbanisation of developing countries continues. Currently, approximately 450 million MDIs are manufactured annually world-wide. The use per capita of MDIs is low in developing countries, reflecting availability, cost, and health professional practice rather than a reduced need.

The pharmaceutical industry began an intensive search in the mid-1980s for alternatives to the CFC MDI. Three major initiatives resulted: testing of alternative propellants for MDIs; programmes to improve other existing delivery systems, including the DPI and nebuliser; and efforts to develop new, innovative delivery systems. Pharmaceutical companies are also actively engaged in research on alternative technologies for delivering medication to the lungs without a propellant.

Preliminary projections indicate that worldwide emissions of HFCs from MDIs in the year 2010 will be 7,500-9,000 metric tonnes. This amount translates to 10.8-12.9 million metric tonnes CO<sub>2</sub> equivalent. Using a 1998 baseline, projections for the year 2010 were calculated, assuming (i) all CFC MDIs will be converted to HFC MDIs by 2010 and (ii) two annual MDI market growth rate scenarios, 1.5 and 3%. HFC emissions were calculated by multiplying the projected unit data for 2010 by the average amount of HFC contained in each MDI unit. In addition, weighted GWPs for HFCs used in MDIs were calculated by taking into account each company's use of HFC-134a versus HFC-227ea. These projections were developed through a survey of MDI companies and with reference to information contained in the 1998 and 1999 Technology and Economic Assessment Panel Reports.

## ANNEX D INDUSTRIAL AND PFC AND SF<sub>6</sub> EMISSIONS

### *PFCs from Aluminium Smelting*

Two PFCs -- CF<sub>4</sub> and C<sub>2</sub>F<sub>6</sub> -- are inadvertently emitted as emission by-products during primary aluminium smelting. PFCs are generated by 'anode effect' which is an interruption of the electrolytic reduction process. Globally the aluminium industry is working to reduce the duration and frequency of anode effects which has the dual benefit of reducing PFC emissions and increases production yield.

Although it is not currently technically feasible to eliminate all PFC emissions, reductions are feasible by improved process control (anode effect management, including alumina feed strategies, improved quality of anodes and alumina) through worker awareness training by retrofitting smelters to improve operations through computer system upgrades and adding point feeders, by conversion of smelters to low-PFC emission technologies (side-work prebake to point feeder prebake) and by improved gas capture and post-combustion for Soderberg plants. Secondary (recycled) aluminium production does not result in PFC emissions so increased rates of aluminium recycling reduces overall emissions per unit of aluminium produced. Research on next generation technologies for non-carbon anodes may ultimately lead to manufacturing processes that do not generate PFCs.

### *SF<sub>6</sub> From Gas Insulated Electrical Equipment*

SF<sub>6</sub> has been used for the past 30 years in electrical power distribution equipment such as high voltage circuit breakers and transformers. SF<sub>6</sub> is a highly effective dielectric that has no readily available substitutes in the application for high voltage equipment. Its GWP (100 year time horizon) of 23,900 is the highest value for all gases considered by the IPCC. The stock amounts are very large and amounted to approximately 14,000 tonnes in 1995.

### *Size of emissions*

#### D1. With unconstrained application of techniques

Within the 'Electrical equipment sector' (equipment manufacturers and utilities) one could distinguish four phases of SF<sub>6</sub> use and thus define the sources of emissions:

- (1) Production in equipment plant (handling, filling/testing by manufacturers).
- (2) Erection on site (e.g. assembly, commissioning, handling, filling, shipment).
- (3) Usage by utilities (leakage, maintenance).
- (4) Disposal by utilities (venting or recovery).

#### D1.1 Production of electrical equipment

For GIS equipment, European manufacturers estimated the following default overall emission factor for equipment manufacturing: prior to 1995: 15% of total amount used at the facility; 6% from 1996 onwards; Japanese manufacturers estimated this factor at 35%. For GIS equipment, the uncertainty in default overall emission factors is about 25%: in Europe 15 ±5% of total amount used at the facility prior to 1995 and 6 ±2% from 1996 onwards; in Japan 35 ±10%.

## D1.2 Use of electrical equipment

### D1.2.1 Site erection

Default emission factors expressed as percentage of SF<sub>6</sub> stock additions are not well established. Global analysis showed that for GIS this value may be about 15% for historical emissions in general, whereas recent European experience indicates that this factor may currently be about 6%.

### D1.2.2 Usage

Default emission factors expressed as percentage of installed SF<sub>6</sub> stock are not well established. Global analysis showed that for GIS this value may be about 5% for historical emissions in general, whereas recent European and Japanese experience indicates that this factor may currently be about 3% and 1% in Europe and Japan, respectively.

### D1.2.3 Disposal

Emissions from disposal of discarded equipment can be estimated from (a) estimated lifetime of the equipment to determine the erection year(s) of the vintage of existing equipment that is discarded, (b) stock of discarded equipment based on estimated initial stock addition in the year of erection and default 95% remainder at the time of disposal, and (c) estimated recovery fractions. Where recovery programmes are not in place, emissions would be equal to what is disposed from the tank.

Estimated uncertainty ranges for default factors are:

- Default erection losses: 15 ±5% for historical emissions in general 6 ±2% for current practices (based on European experience).
- Default leakage rates: 3 ±2% for stock installed <1980; 1 ±0.5% for the period 1980-1995; 0.1 ±0.1% for years after 1995.
- Default annual maintenance losses, including refill and leakage compensation: 5 ±2% for years up to 1995 (based on global analysis of sales data); 2 ±1% for years after 1995 (regional estimates are Japan 1% and Europe 3%).
- Default amount left: 95 ±5% of the initial stock.
- Default lifetime: 30 ±5 years.

## D2. With application of the major options

The amount in the equipment at the time of disposal will usually be between 90 and 100% of the full initial stock. This amount will be emitted upon disposal, except when part of the gas is recovered for reuse or recycling. Recovery rates up to 95% are technically feasible, so the residual remains in the tank that are emitted could be as low as 5% of the initial stock.

### *Major options to limit emissions*

- Promotion of recovery (or improvement of recovery rate) at each stage (gas production, equipment manufacturing, usage and disposal by utilities)
- Training of personnel who are related with gas handling, even of highly polluted SF<sub>6</sub> after electrical discharge and for the equipment at the end of its life
- SF<sub>6</sub> reuse and recycling, even of highly polluted SF<sub>6</sub>, whenever possible
- Minimisation of the size of equipment for saving of SF<sub>6</sub> gas amount enclosed
- Extension of periodical maintenance interval
- Application of non-SF<sub>6</sub> gas equipment considering all of the related constraints.

### *HFC-23 from HCFC-22 plants*

During the production of HCFC-22 a certain amount of HFC-23 is produced (in the order of 1.5 to 4 percent). The HFC-23 is separated as a vapour from condensed HCFC-22 and either vented to the atmosphere as an unwanted by-product or recovered.

Three opportunities are demonstrated and commercially available to reduce emissions:

- (1) Process optimisation to minimise the quantity of HFC-23 produced.
- (2) Thermal oxidation to destroy the substance.
- (3) Pyrolysis using high temperatures in the absence of oxygen to fracture or transform the HFC-23 molecule into compounds usable as chemical feedstocks.

There are a total of 11 HCFC-22 manufacturing plants in Europe. It is believed that 6 plants will have some level of HFC abatement by around 2000. In the United States there are four plants. HCFC-22 is also produced in Japan, Korea, the Russian Federation, India and China.

### *SF<sub>6</sub> in Magnesium Metallurgy*

Magnesium processing (primary smelters, secondary smelters, die casting) amounts to about 10% of total global use of SF<sub>6</sub>.

Magnesium production is still growing because use of light alloys is increasing in the automotive and aeronautics sectors. There is a potential to reduce emissions per kg of magnesium produced through technology improvement (handling, recovery and other slanting operations), and by substitution of other substances. SO<sub>2</sub> is technically viable but toxicity must be addressed; other mixtures (e.g. with argon) are being evaluated.

### *Manufacturing Losses for HFCs, PFCs and SF<sub>6</sub>*

Manufacturing losses occur during the production, storage and shipping of SF<sub>6</sub>, HFCs and PFCs. The total fugitive emissions of HFCs amount to about 2% of production (AFEAS, 1999). There are a number of cost-effective measures including changing the conditions of temperature and pressure of appropriate process streams so that the chemicals condense and can be recycled.

It is very difficult to believe that eliminating non-returnable containers is the most significant option. Only about 10% of HCFCs (that will be phased out with some replacement by HFCs) and HFC amounts are distributed through this mechanism.

Total elimination of fugitive emissions is difficult and costly, requiring redirecting of the vent stream through a destruction facility, such as a thermal oxidiser. However, the emissions of CO<sub>2</sub> from the fuel used to oxidise these substances may also be significant.

### *HFCs, PFCs and SF<sub>6</sub> in Semiconductor Manufacture*

High GWP fluorinated compounds including PFCs, HFC-23, SF<sub>6</sub> and NF<sub>3</sub> are currently used in the manufacture of semiconductors. These fluorocompounds (FCs) are used in etch, chemical and mechanical polishing, and plasma cleaning of chamber vapour deposition tools. Fluorinated compounds are technically useful because they are convenient sources of fluorine ions and radicals that are used to etch silicon dioxide, silicon nitride and other films, and they possess unique characteristics in plasmas. Both carbon and fluorine are needed simultaneously for selective and anisotropic etching of submicron band widths and shrinking features.

Global emissions from semiconductor manufacture are currently small compared to other high GWP applications, however, this industry has a high growth rate. The semiconductor industry is proactively pursuing an international goal to reduce absolute emissions by 10% by 2010 from the 1995 baseline. The goal was negotiated by the World Semiconductor Council whose members are from Europe, Japan, Korea, Taiwan and the USA, representing over 90 percent of global semiconductor production. This is the first and, to date, only industry-wide global emission reduction goal for greenhouse gases.

Some emission reduction methods are technically proven and commercially available. Other promising technologies are emerging and expected to be available within 1-3 years, assuming continued success in on-going semiconductor PFC emissions reduction research and development.

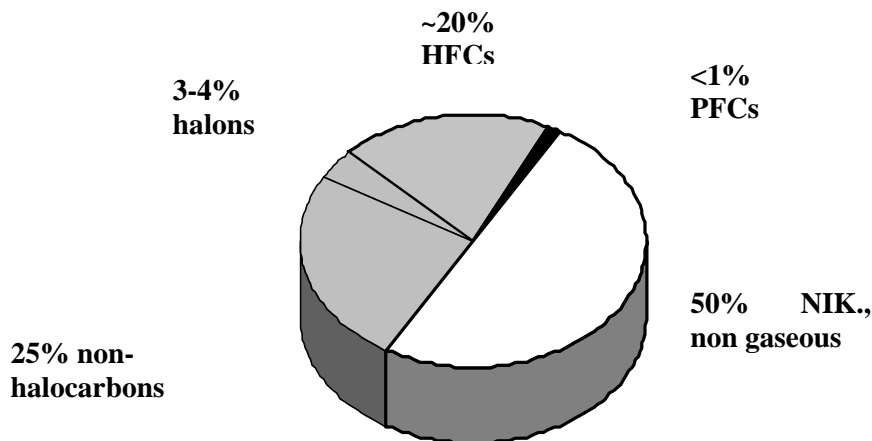


## ANNEX E SOLVENTS

See text in the body of the report.

## ANNEX F FIRE EXTINGUISHANTS

HFC/PFC use for fire fighting represents a very small share of total use. In about 50% of new fire protection systems in which halons have been previously used, not-in-kind non-ODP alternatives are now utilised. These include water-based systems, foam, dry powder, and fire-protection engineering approaches involving risk analysis, prevention steps, and early detection systems combined with portable extinguishing equipment. About 25% have been replaced with non-halocarbon gaseous agents such as carbon dioxide, or certain inert gas mixtures.



Despite the consumption phaseout in developed countries, there remain some critical halon uses in existing and new applications for which no technically or economically feasible alternatives have yet been developed. These include civil and military aircraft, military vehicles, and other specialised, high-risk situations. These needs are being met using recovered and recycled halons under a 'halon bank' concept. Only 20% to 22% of systems that would formerly have used halons now use HFCs, and less than 1% use PFCs. This low system substitution rate, combined with the factor of about 5 reduction in emissions from systems compared to practices of the 1980's, has resulted in HFC and PFC emissions that are less than 5% of what halon emissions would have been on a business as usual basis (the factor of five reduction comes from the earlier section 3.3.2 where it is stated that emissions have been reduced from about 25% of installed capacity per year to 4-6% per year. 21 to 23% divided by 5 is less than 5%).

Aggressive marketing is driving relatively strong HFC/PFC growth in developing countries and CEIT. Awareness campaigns and institutional capacity building for fire protection experts and their customers could help limit unnecessary HFC use.

## ANNEX G ACRONYMS

AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
BAU	Business-As-Usual
CEIT	Country with Economy In Transition
CFC	Chlorofluorocarbon
COPD	Chronic Obstructive Pulmonary Disease
DME	Dimethylether
DPI	Dry Powder Inhaler
ECN	Energieonderzoek Centrum Nederland
GEF	Global Environment Facility
GHG	Greenhouse Gas
GWP	Global Warming Potential
HAP	Hydrocarbon Aerosol Propellant
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
IPCC	Intergovernmental Panel on Climate Change
MDI	Metered Dose Inhaler
MLF	Multilateral Fund
MP	Montreal Protocol
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
OEM	Original Equipment Manufacturer
OEWG	Open Ended Working Group
PFC	Perfluorocarbon
R/A/C	Refrigeration and Air Conditioning
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TSU	Technical Support Unit
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
VOC	Volatile Organic Compound
WHO	World Health Organisation

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## ANNEX I TABLE OF CONTENTS OF THE PROCEEDINGS - PAPERS PRESENTED

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### Introductory papers

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|----|---|--|
| 1. | <i>Gérard Mégie</i>   | The Scientific interlinks between the Montreal and the Kyoto Protocols.  |
| 2. | <i>Jorgen Fenhann</i>   | HFC, PFC and SF <sub>6</sub> emission scenarios: recent developments in IPCC special report on emission scenarios. |
| 3. | <i>Mack McFarland</i>   | Applications and emissions of fluorocarbon gases: past, present and prospects for the future.                      |
| 4. | <i>Tony Hetherington</i><br><i>Omar El-Arini</i>                | The implementation of HFC based projects under the multilateral fund: developments and future trends               |
| 5. | <i>Janaka Ratnasiri</i>   | The Kyoto Protocol impact on developing country HFC policies for implementing the Montreal protocol.               |
| 6. | <i>Frank Pinto</i><br><i>S. Si-Ahmed</i><br><i>Steve Gorman</i> | Options for reduction of emissions of HFCs in developing countries.  |
| 7. | <i>Ray Gluckman</i><br><i>Duncan Yellen</i>                     | Financial implications of emission reduction options for HFCs, PFCs and SF <sub>6</sub> .                          |
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### Emissions and emission projections

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- |    |                         |   |
|----|-------------------------|---|
| 1. | <i>Archie McCulloch</i> | Halocarbon greenhouse gas emissions during the next century.    |
| 2. | <i>Eric Johnson</i>     | Getting HFC/PFC emissions right: towards more robust estimates. |
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## Refrigeration and Air-conditioning

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1. *Denis Clodic* Emissions from HFC-based refrigeration and A/C equipment: historical development and future trends.
  2. *Donald Bivens* Refrigeration and air-conditioning with reduced environmental impact.
  3. *James M. Calm* Emissions and environmental impacts from air-conditioning and refrigeration systems.
  4. *Corcoran  
Spatz  
Shankland  
Vink* HFC emission reduction options for air-conditioning and heat pump systems.
  5. *James Crawford* Limiting the HFC emissions of chillers.
  6. *Yasuo Watanabe* Trend in the usage of refrigerant and heat insulation foaming agent for domestic refrigerator in Japan.
  7. *Sekiya  
Misaki  
Beppu* Joint research by RITE and NIMC in new refrigerants, foam blowing agents and solvents and new research on PFC use in semiconductor manufacturing.
  8. *Colbourne  
Blacklock* Limiting HFC emissions through the use of non-HFC technologies.
  9. *James Baker* Mobile air-conditioning: HFC-134a emissions and emission reduction strategies.
  10. *Guenther Reiner* Reduction of greenhouse effect on refrigeration plants.
  11. *Stephen Sicars* Potential of low GWP alternatives in refrigeration.
  12. *Ewald Preisegger* Automotive air-conditioning impact of refrigerant on global warming.
  13. *Yoshiyuki Tujibayashi* Action plan related to emission control of HFC-134a refrigerant for automobile air-conditioning systems.
  14. *McInerney  
Haworth  
Johnson  
Swatkowski* Domestic refrigeration refrigerants.
  15. *R.S. Agarwal*
  16. *Sukumar Devotta* Indian R&AC sector: HFC future demand and emissions
  17. *Haruo Ohnishi-Yokoi* The importance of HFC to certain refrigeration and AC use.
  18. *Ian Maclaine-cross* Replacement refrigerants for water chillers
  19. *John Maté* How to limit HFC emissions? Eliminate them
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## Foams, Aerosols/MDIs and Fire Extinguishants

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1. *Paul Ashford* Considerations for the responsible use of HFCs in foams.
  2. *Pierre Barthelémy* Contribution of HFC blowing agents to global warming, a producer's view.
  3. *Johnson  
Haworth  
McInerney  
Swatkowski* HFC blowing agents for domestic refrigerator insulating foam.
  4. *Seiji Ishii* Blowing Agent in PU Foam Industry in Japan
  5. *Jeffs  
De Vos* Zero ODP blowing agent options for rigid polyurethane insulating foams.
  6. *Paul Ashford* Emissions from foams- predicting, monitoring, reporting and reducing.
  7. *Robert Russell* Extruded Polystyrene Foam (XPS) - Technical options & decision making criteria
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## Solvents, Aerosols/MDI

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1. *Nick Campbell* Technical, pesticide, cosmetic, convenience, and novelty aerosol products.
  2. *Abid Merchant* Alternative to ODS Solvents and emission reduction technologies
  3. *John Owens* Segregated hydrofluoroethers: low GWP alternatives to HFCs and PFCs.
  4. *Paul Wright* Patient care issues in HFC emissions policy.
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## Fire Extinguishants

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1. *Barbara Kucnerowicz-Polak* Fluorocarbon alternatives in the fire protection sector.
  2. *Cisneros  
Robin* An integrated approach to achieve low environmental impact in the special hazards fire suppression industry.
  3. *Brian Ward* Climate change and environmental protection in the European Union. The need for fluorocarbons in fire protection.
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#### PFC and SF<sub>6</sub> emissions from manufacturing

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1. *Rand  
Ottinger  
Branscome* Opportunities for the reduction of HFC-23 emissions from the production of HCFC-22.
  2. *Rollet  
Micozzi* SF<sub>6</sub> recycling.
  3. *Harnisch  
Wing  
Jacoby  
Prinn* Primary aluminium production: climate policy, emissions and costs.
  4. *Laurie Beu  
Paul Brown* Use and emissions mitigation of PFC, HFC and SF<sub>6</sub> in the semiconductor industry
  5. *Wolfgang Bloch*
  6. *Takuya Suizu* Partnership Activities for SF<sub>6</sub> gas emission reduction from gas insulated electrical equipment in Japan.
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#### Implementation of non-ODP projects in developing countries

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1. *Frans Gruncharde* Mitigation of the global warming impact of fluorocarbons in developing countries.
  2. *Sharma  
Bagai* Interface of Montreal protocol with Kyoto protocol: some issues.
  3. *Cathalina Mosler* Developing countries concerns on the use of HFCs – Latin America and the Caribbean
  4. *Wiraphon Rajadanuraks* Leadership companies in Thailand and elsewhere choose HFCs to replace CFCs
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#### Government policies to limit emissions

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1. *Per Henrik Pedersen* Ways of reducing consumption and emission of potent greenhouse gases (HFCs, PFCs and SF<sub>6</sub>) in the Nordic countries
  2. *Petra Mahrenholz* Possible emission reduction measures for HFCs in Germany
  3. *Haruhiko Kono* Promotion of measures to limit HFC, PFC and SF<sub>6</sub> emissions in Japan
-