

**MONTREAL PROTOCOL
ON SUBSTANCES THAT DEplete
THE OZONE LAYER**



UNEP

**HFC and PFC Task Force of the
Technology and Economic Assessment Panel**

**“THE IMPLICATIONS TO THE MONTREAL PROTOCOL OF THE INCLUSION OF
HFCs AND PFCs IN THE KYOTO PROTOCOL”**

October 1999

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THE PROCESS

In November 1998, the Parties to the Montreal Protocol in Decision X16 requested the TEAP 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 Parties. The Eleventh Meeting is scheduled for November 29 - December 3, 1999 in Beijing. The TEAP established a Task Force chaired by **Dr. Stephen O. Andersen** to prepare this report. The members of the Task Force were **Dr. Radhey S. Agarwal, Dr. Stephen O. Andersen, Mr. Steve Anderson, Mr. Paul Ashford, Dr. Paul J. Atkins, Mr. James Baker, Dr. Walter Brunner, Dr. Nick Campbell, Dr. Suely Machado Carvalho, Dr. Denis Clodic, Mr. Jorge Corona, Mr. Yuichi Fujimoto, Dr. Mike Jeffs, Dr. Michael Kauffeld, Dr. Barbara Kucnerowicz-Polak, Dr. Lambert Kuijpers, Dr. Mohinder P. Malik, Dr. Mack McFarland, Mr. Abid N. Merchant, Mr. E. Thomas Morehouse Jr., Mr. Haruo Ohnishi, Dr. Roberto de Aguiar Peixoto, Mr. Wiraphon Rajadanuraks, Ms. Sally Rand, Mr. Robert J. Russell, Mr. Lee Kheng Seng, Mr. Rajendra M. Shende, and Dr. Helen Tope. Dr. Ashley Woodcock, Mr. Gary M. Taylor, and Ms. Lalitha Singh** served as advisors. **Ms. Jill Phillips** was the co-ordinating editor and production manager.

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1 EXECUTIVE SUMMARY

1.1 The Montreal and Kyoto Protocols are linked

1. Ozone depletion and global climate change are linked through physical and chemical processes in the atmosphere. Changes in ozone affect the Earth's climate and changes in climate and meteorological conditions affect the ozone layer. Because ozone-depleting substances (ODSs) are also greenhouse gases, the ODS phaseout helps protect the climate. Because ozone depletion has a cooling effect on the Earth's surface, ozone depletion partially masks climate change, creating an offset to the direct GWPs of these substances.
2. The Montreal and Kyoto Protocols are interconnected because HFCs included in the basket of gases of the Kyoto Protocol are significant substitutes for some important uses of ozone-depleting substances. CO₂ is a significant replacement for ODSs in foam blowing, a minor replacement for halon in fire extinguishing, and a potential replacement for refrigerants. The climate effect of the direct emissions of CO₂ from these applications is negligible. Other chemicals in the Kyoto basket – PFCs, SF₆, N₂O and CH₄ – are currently insignificant substitutes for ODSs.
3. Stratospheric ozone protection efforts and climate protection efforts are financially linked because co-ordinated investment would often be highly cost-effective and could encourage conversion to ODS alternatives demonstrating better Life Cycle Climate Performance.¹
4. At the time the Montreal Protocol developed its phaseout strategy, it was not technically or economically possible to contain CFC and HCFC emissions and little effort was made to recover and recycle. Furthermore, it was believed that zero-ODP refrigerants and insulation foam blowing agents would provide equal or better energy efficiency. At a future date, Parties to the Montreal and Kyoto Protocols may wish to revisit the HCFC phaseout decision mindful of the condition of the ozone layer and the need to protect the climate. At that time, a technical assessment could present the relative environmental performance of all available options.

1.2 HFCs are substitutes for ODSs

5. Use of HFCs has allowed the rapid phaseout of CFCs and halons in developed countries for applications where other alternatives were not available. HFCs are still important to the safe and cost-effective phaseout of CFCs and (to a lesser extent) halons in countries with economies in transition and developing countries. In developed countries, 8% of ODS was replaced by HFCs, 12% with HCFCs and 80% by reducing emissions and non-fluorocarbon technologies. HFCs typically have lower global warming potentials (GWPs) than the ODSs

¹ The Life-Cycle Climate Performance (LCCP) calculates the cradle-to-grave climate impact of direct and indirect greenhouse gas emissions including inadvertent emissions from chemical manufacture, energy used in chemical manufacture, energy embodied in components, operating energy, and emissions at the time of disposal or recycle.

they replace and have generally been selected for applications where they provide superior technical or safety performance.

6. HFC use is also technically and economically necessary for the phaseout of HCFCs in both developed and developing countries in applications where other alternatives are not yet available. HFCs are expected to replace no more than half of HCFC demand for insulating foams with non-fluorocarbon substances replacing the other half over the next five years. HFCs are expected to replace two-thirds of the demand for HCFCs in refrigeration, air conditioning, and heat pumps with “natural refrigerants,” containment, and recycling replacing the other one third. An increasing portion of new air conditioning equipment serves markets in developing countries.
7. HFCs are currently essential substitutes for some other highly important uses of ODSs including: 1) replacement of CFC propellants used in MDIs; 2) replacement of halon 1301 used in specialised fire protection where space and weight are critical; 3) replacement of CFCs and HCFCs for foam blowing where necessary for product and process safety or where local environmental regulations rule out alternatives; and 4) replacement of very limited uses of CFC-113 in cleaning, drying, fingerprinting, aircraft rain repellent, and solvent carrier applications.
8. HFC-134a is currently the only energy efficient substitute endorsed by vehicle manufacturers to replace CFC-12 used in vehicle air conditioners. HFCs are also currently necessary to replace CFCs and HCFCs as refrigerants in certain other refrigeration and air conditioning applications, to replace HCFC-141b and HCFC-142b in insulating foam and some other foam applications, and to replace CFC-114 in submarines and nuclear facilities.
9. It is not technically or economically feasible to phaseout ODSs from mission-critical military applications without the use of HFCs for refrigeration and fire protection. Mission-critical applications include use in occupied spaces of ships, aircraft, armoured vehicles, and military command and control stations.

1.3 The Kyoto Protocol need not interfere with the Montreal Protocol

10. The inclusion of HFCs, PFCs, and SF₆ in the basket of gases to be controlled in the Kyoto Protocol need not have adverse implications for the implementation of the Montreal Protocol—provided that implementation by each country allows HFC use where other viable alternatives to ODSs are not available.
11. However, overly restrictive national regulations on the use of HFCs where alternatives are not available could delay and increase the cost of the phaseout of CFCs in CEITs and developing countries and could delay the global phaseout of HCFCs. Potential restrictions on HFC uses create business uncertainty that can slow phaseout of HCFCs in both developed and developing countries. Companies intending to commercialise new HFCs as a substitute for HCFCs could postpone or cancel investment and force product manufacturers to either prolong the use of ODSs or compromise product performance, with the potential for increased energy use and associated greenhouse gas emissions.

12. Overly restrictive national regulations on the use of HFCs, PFCs and/or SF₆ could also have unintended consequences for industries that use and emit these high GWP gases from applications where ODSs were never used. PFCs and SF₆ are used in applications requiring highly inert or fully fluorinated chemicals. For example, no substitutes exist for SF₆ globally used in high-voltage electric power distribution, PFCs used in semiconductor manufacturing, and in a number of other minor but technically essential applications.

1.4 The Montreal Protocol need not interfere with the Kyoto Protocol given careful technology choices

13. Use of HFCs as substitutes for ODSs is not likely to impede Parties to the Kyoto Protocol from meeting emission reduction obligations because HFCs are a very small part of national emission targets.

14. Use of HFCs can contribute to efforts to meet the Kyoto targets in applications where HFCs have an energy efficiency advantage. The impact on climate of any technology results from the “direct” emissions of greenhouse gases and the “indirect” emissions from the generation of energy used over the expected life of the product. The indirect emissions are usually far more significant than direct emissions, except in locations where electricity is generated from hydropower, nuclear, wind or solar.

1.5 CEIT & Developing Countries Depend on Information, Access to Technology, and Financing

15. CEIT and developing countries depend on technical and environmental information on technology options, access to technology, and affordable financing. Financing by the Multilateral Fund or other organisations for training and capacity building is also critically important.

16. UNEP TIE’s OzonAction Programme in Paris has been mandated under the Montreal Protocol to facilitate bilateral and multilateral co-operation, create environmental awareness, and to collect and distribute up-to-date information. The scope of OzonAction Programme could be expanded to become a Climate Action Programme.

17. Restrictions by developed countries on the import of products made-with or containing HFCs for applications where HFCs are the only technically and economically feasible alternatives to ODSs or in applications where HFCs provide energy efficiency advantages over other alternatives could severely impact the implementation of the Montreal Protocol in CEIT and Article 5(1) countries. These countries often depend on export markets for revenue and could delay conversion from ODSs if HFCs are subject to regulatory uncertainty.

18. All enterprises in both developed and developing countries will want to select technologies to protect the stratospheric ozone layer and to achieve climate protection while satisfying other environmental and safety concerns. However, there is concern that some developed countries may try to impose their own preferred choice of technology on developing countries. One

approach is to work for fully informed choices but to respect investment decisions—regardless of which technology is selected to replace ODSs.

19. Co-ordinated investment for ozone and climate protection would often be highly cost-effective and could encourage conversion to ODS alternatives demonstrating better Life Cycle Climate Performance. Parties may wish to invite energy efficiency investment under the Global Environment Facility (GEF), the Clean Development Mechanism (CDM), and/or Joint Implementation as supplements to Multilateral Fund ozone protection investments. Cost-effectiveness criteria can be separately applied to ozone and climate benefits.

1.6 Many Factors determine the choice of ODS replacements

20. Categories of ODS replacement based on chemical nomenclature such as “HFC,” “HCFC,” “HFE” or “natural refrigerants” are unreliable indicators of environmental acceptability. This is because toxicity, safety, ODP, and GWP of the compounds within these categories vary widely and technical options exist to manage safety and environmental issues for many applications. Furthermore, energy efficiency depends on other factors including the application, the engineering, and on the component performance.
21. In some circumstances, the capital cost and rate-of-return on energy cost savings may be more attractive for HFC technology than for technology based on other substitutes, encouraging ODS phaseout. When technically, economically, and environmentally feasible, HFC technology can be avoided by leap-frogging to zero-ODP, low-GWP options.
22. Hydrocarbons and ammonia can be environmentally acceptable, energy efficient, alternatives to CFC, HCFC, and HFC refrigerants in applications where products can be safely manufactured, operated, and maintained. European companies, with the encouragement of environmental NGOs and national governments, have fully commercialised hydrocarbon refrigerators and other hydrocarbon appliances requiring small refrigerant charges. Manufacturers and government research organisations are demonstrating equipment with increasingly large hydrocarbon and ammonia refrigerant charges. Companies with the technical and managerial ability to safely handle flammable and toxic refrigerants will want to select these refrigerant options if they achieve better LCCP than HFCs.
23. Government mandates to use specific refrigerants or blowing agents do not assure that products made with those chemicals will achieve high energy efficiency, low emissions or appropriate product safety. However, product environmental performance standards can be crafted to minimise the impact on climate from the combination of direct chemical emissions and indirect emissions from energy used by the products. Environmental performance standards can be voluntarily adopted or compelled by regulation, as necessary.

1.7 Further reductions in HFC emissions are possible

24. Adherence to responsible use principles can lead to reductions in HFC emissions beyond current projections. Principles for responsible use include: 1) Use HFCs only in applications where they provide safety, energy efficiency, environmental, or critical economic or public health advantage; 2) Limit emissions of HFCs to the lowest practical level during manufacture, use, and disposal of equipment and products and; 3) If HFCs are to be used, select the compound with the smallest climate impact that satisfies the application requirements.
25. The safe use of hydrocarbon and ammonia refrigerants depends on technology and training that eliminate uncontrolled emissions. Containment strategies are equally applicable to HFC and HCFC refrigerants, allowing manufacturers to choose the refrigerant with the best Life-Cycle Climate Performance.
26. Technology is commercially available to recover and recycle HFC refrigerants, but the revenue from recovered refrigerant is typically too small to make such efforts profitable. Regulations that require recycling have been enacted in many countries including Denmark, France, Germany, Iceland, Netherlands, Norway, Sweden, United Kingdom, and the United States, but are not always enforced. Australian and Japanese industry associations have voluntarily implemented HFC recovery and reuse. It is currently technically, but not necessarily economically feasible, to destroy HFCs from insulating foams during their disposal.
27. ASTHMA AND CHRONIC OBSTRUCTIVE PULMONARY DISEASE: HFC Metered-dose inhalers (MDIs) are essential for the near-term CFC phaseout because other available options including dry powder inhalers (DPIs), nebulizers, and oral and injectable drugs cannot currently replace CFC products for all patients. DPIs are, however, an alternative inhalation product acceptable for a large proportion of patients. Development of new respiratory delivery technology continues at an impressive pace, but at least ten years is required for commercialisation and implementation.
28. TECHNICAL, PESTICIDE, COSMETIC, CONVENIENCE, AND NOVELTY AEROSOL PRODUCTS: Hydrocarbon, dimethyl ether (DME), carbon dioxide (CO₂), and nitrogen are satisfactory propellants for virtually all non-medical aerosol products with important exceptions where HFCs are necessary to comply with safety or environmental regulations. The aerosol product industry has every incentive to use HFCs responsibly. HFCs cost more than other propellants and unnecessary HFC use has the potential to re-ignite consumer boycotts. Boycotts could threaten sales of all aerosol products because consumers may not be able to distinguish targeted HFC products from acceptable HC products.
29. INSULATING FOAM: There is little current use of HFCs as foam blowing agents and future use will be almost exclusively for applications where CFCs and HCFCs are currently used—primarily in closed cell thermal insulation foams. Insulating foam is used to save energy and, consequently, to reduce CO₂ emissions. The use of selected HCFC and HFC blowing agents with updated technology produces foam with up to 15% better energy efficiency than the best non-fluorocarbon-blown options (hydrocarbon, H₂O and CO₂). It is particularly

important to use the most efficient foam blowing agent where foam thickness is constrained. It is anticipated that emerging technologies could begin reducing the need for HFC and HCFC blowing agents in the period from 2015 – 2020.

30. FIRE PROTECTION: Only 20% of applications previously using halon now use HFCs in new installations, and less than 1% has been replaced by PFCs. For 5% of existing and new applications there is still no technically or economically feasible alternative to halon – currently supplied from recovered and recycled halons under the “halon bank” concept. These critical uses include civil and military aircraft, military vehicles, oil production facilities, and other specialised, high-risk situations.
31. SOLVENTS: Almost all ODS solvent have been eliminated by no-clean flux, aqueous, semi-aqueous, and hydrocarbon technologies. HCFCs, HFCs, and PFCs are used for some limited and unique applications where environmentally acceptable alternatives have not been identified. New processes are being developed that do not require HCFCs, HFCs or PFCs.
32. REFRIGERATION AND AIR-CONDITIONING: The energy efficiency and emissions of refrigeration and air conditioning equipment depends on the choice of refrigerant, the quality of the components, and on proper maintenance. Use of flammable and toxic refrigerants typically requires more expensive manufacturing facilities and equipment safety features and requires greater care in operation and service. In some cases, systems using flammable and toxic refrigerants provide the best life-cycle climate performance (LCCP). In other cases, equivalent investment using HFC refrigerants would provide better LCCP.

2 INTRODUCTION

When the Montreal Protocol was signed in 1987, alternatives to CFC and halons were not commercially available for most applications. The Montreal Protocol galvanised public concern for stratospheric ozone layer protection and motivated industry to innovate. By 1989, the first Technology Assessments Panel concluded that not-in-kind alternatives would be important but reported that fluorocarbons HCFCs and HFCs were necessary in order to make substantial reductions in CFC and halon dependence. By 1990, scientific information showed that the impact of CFCs and halons on stratospheric ozone was more significant than believed in 1987 and the Protocol was amended to require a phaseout of these ozone-depleting substances (ODSs). With new scientific information increasing concerns over depletion of stratospheric ozone and with technical advances delivering new alternatives, the phaseout schedule has been accelerated and additional ODSs have been added. The use of HCFCs and HFCs remain a portion of the current solutions adopted by non-Article 5(1) Parties to meet the 1994 halon phaseout and the 1996 CFC, methyl chloroform, and carbon tetrachloride phaseout.

The phaseout of production of CFCs, carbon tetrachloride, methyl chloroform, and halons is virtually complete in most non-Article 5(1) countries with essential use exceptions for metered-dose inhalers (MDIs), laboratory and analytical uses, rocket motors and fire protection. Countries with Economies in Transition (CEIT) have begun, but not completed, the phaseout of these compounds. Analysis by UNEP TIE shows that almost all Article 5(1) countries are expected to meet or exceed the freeze of production and consumption of CFCs required in 1999. Developing countries are just beginning the phaseout of HCFCs as refrigerants and as blowing agents in insulating foam. HFCs have been a critical factor in replacing CFCs as refrigerants and fire extinguishing agents, and are the current majority choice to replace HCFC refrigerants and foam blowing agents in both Article 5(1) and Non-Article 5(1) countries. However, hydrocarbons and ammonia are preferred refrigerant choices in some European countries, and hydrocarbons are significantly penetrating insulating foam markets in Europe, Japan, and North America.

2.1 The Interrelationship of Montreal and Kyoto Protocols Requires Co-ordination

The issues of ozone depletion and climate change are scientifically, technically and financially interconnected. Ozone depletion and global climate change are linked through physical and chemical processes in the atmosphere. Changes in ozone affect the Earth's climate and changes in climate and meteorological conditions affect the ozone layer. Because ozone-depleting substances (ODSs) are also greenhouse gases, the ODS phaseout helps protect the climate. Because ozone depletion has a cooling effect on the Earth's surface, ozone depletion partially masks climate change.

The Montreal and Kyoto Protocols are interconnected because HFCs included in the basket of gases of the Kyoto Protocol are significant substitutes for some important uses of ozone-depleting substances. CO₂ is a significant replacement for ODSs in non-insulating foam blowing, a minor replacement for halon in fire extinguishing, and a potential replacement for refrigerants. The climate effect of the direct emissions of CO₂ from these applications is negligible. Other

chemicals in the Kyoto basket – PFCs, SF₆, N₂O and CH₄ – are currently insignificant substitutes for ODSs.²

Activities related to stratospheric ozone protection and climate change mitigation are financially linked because co-ordinated investment would often be highly cost-effective and could encourage conversion to ODS alternatives demonstrating better Life Cycle Climate Performance.³

3 INSTRUCTIONS FROM PARTIES

In November 1998, the Conference of the Parties to the Framework Convention on Climate Change (FCCC/CP/1998/16/Add. 1)⁴ invited organisations, including the relevant bodies of the Montreal Protocol, "...to provide information by July 15, 1999 on available and potential ways and means of limiting emissions of hydrofluorocarbons and perfluorocarbons, including their use as replacements for ozone depleting substances." In November 1998, the Parties to the Montreal Protocol in Decision X16⁵ requested the TEAP to provide such information to the FCCC 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 Parties. The Eleventh Meeting is scheduled for November 29 - December 3, 1999 in Beijing. In addition, Parties to the Montreal Protocol accepted the FCCC invitation to jointly convene a workshop on available and potential ways and means of limiting emissions of HFCs and PFCs.

4 RESPONSE TO PARTIES BY TEAP

TEAP created the Task Force on HFCs and PFCs (HFC/PFC Task Force) to undertake the assessment requested by Parties. The Task Force includes 30 experts from 17 countries (Australia, Belgium, Brazil, Canada, Denmark, France, Germany, India, Japan, Mexico, Netherlands, Poland, Singapore, Switzerland, Thailand, UK, and USA). A roster of members and short biographies are included in Appendices I and J. Task Force members held meetings and technical workshops in Australia, Germany, Hungary, Indonesia, Japan, Jordan, Republic of

²Carbon dioxide (CO₂) and methane (CH₄) are also controlled under the Kyoto Protocol but are not evaluated in this report. Carbon dioxide is a traditional not-in-kind alternative to halon in firefighting and an alternative to CFC and HCFC refrigerants and foam blowing agents. Nitrous oxide is used as an aerosol propellant for whipped cream. In the early 1990's SF₆ was used to replace halon in tests to confirm that protected spaces were leak-tight to contain halon long enough to completely extinguish fires. This discharge test was replaced by computer modelling and room-pressurised tests not using chemicals.

³ The Life-Cycle Climate Performance (LCCP) calculates the cradle-to-grave climate impact of direct and indirect greenhouse gas emissions including inadvertent emissions from chemical manufacture, energy used in chemical manufacture, energy embodied in components, operating energy, and emissions at the time of disposal or recycle.

⁴ Attached in Appendix G of this report.

⁵ Ibid.

Korea, Mexico, Netherlands, Singapore, Switzerland, Taiwan, Thailand, United States, and Vietnam.

The Task Force solicited information from TEAP and its Technical Options Committees, from company and industry experts, from national ozone units, from government, and from non-governmental environmental organisations. The joint TEAP/IPCC Workshop with one hundred participants from 22 countries was convened May 26-28 in Petten, Netherlands and Task Force members solicited additional information in Geneva Switzerland during the June 1999 meeting of the Open-Ended Working Group. Lists of workshops and conferences where Task Force Members made presentations and solicited advice are included in Appendix K.

This report considers the full range of implications of the inclusion of HFCs and PFCs in the Kyoto Protocol, including investment and export concerns of Countries with Economies in Transition (CEIT) and Article 5(1) countries, the technical and economic feasibility of the phaseout without HFCs and PFCs, and the financial implications and opportunities under the Multilateral Fund (MLF) and Global Environment Facility (GEF). This report summarises technically feasible options for achieving the goals of the Montreal Protocol while minimising the emissions of PFC and HFC greenhouse gases consistent with the goals of the FCCC and its Kyoto Protocol.

5 THE MONTREAL AND KYOTO PROTOCOLS ARE LINKED VIA THE ATMOSPHERE⁶

5.1 Ozone depletion and global climate change are linked through physical and chemical processes in the atmosphere

Ozone-depleting substances controlled under the Montreal Protocol are also greenhouse gases that cause climate change. Phasing out ODSs has a long-term benefit to the climate.

Greenhouse gases controlled under the Kyoto Protocol affect the atmosphere and therefore influence the ozone layer. Climate change resulting from human induced emissions of greenhouse gases could delay recovery of the ozone layer.

Ozone depletion has a cooling effect on the Earth's surface. Climate change is partially masked by ozone depletion. Therefore, the total climate effect of ozone-depleting substances depends on both the global warming potential and ozone depleting potential.

⁶ More information on the interrelationship of the ozone layer and the climate can be found in the Scientific Assessment of Ozone Depletion: 1998, World Meteorological Organisation Global Ozone Research and Monitoring Project Report No. 44, Geneva, 1999.

5.2 Nitrous oxide and methane (controlled under the Kyoto Protocol) have direct effects on ozone depletion

Increasing concentrations of nitrous oxide and methane interact with the ozone destruction cycles of chlorine and bromine released in the stratosphere from ODSs. These gases also affect other chemical cycles that destroy stratospheric ozone.

Methane emissions affect the chemistry that destroys hydrogen-containing ODSs (HCFCs, methyl chloroform, and methyl bromide) in the troposphere, thus affecting the amounts of these ODSs reaching the ozone layer.

Stratospheric ozone depletion allows greater amounts of UV-B solar radiation to reach the troposphere, somewhat shortening the lifetimes of hydrogen-containing ODSs (HCFCs, methyl chloroform, methyl bromide) and reducing their impacts on stratospheric ozone.

5.3 Climate change affects global air currents and atmospheric temperatures.

Changes in air currents and atmospheric temperatures could increase stratospheric ozone depletion from chlorine and bromine – recovery of the ozone layer could be delayed.

6 SECTION I: ELABORATED SUMMARY

6.1 The inclusion of HFCs, PFCs, and SF₆ in the basket of gases to be controlled in the Kyoto Protocol need not have adverse implications for the implementation of the Montreal Protocol – provided that implementation by each country allows HFC and PFC use where viable alternatives are not available.

Use of HFCs as substitutes for ODS is not likely to impede Parties to the Kyoto Protocol from meeting emission reduction obligations because HFCs are a very small part of national emission targets. However, overly restrictive national regulations on the use of HFCs where alternatives are not available could delay and increase the cost of the phaseout of CFCs in CEITs and developing countries and could delay the global phaseout of HCFCs.

In non-Article 5(1) countries, approximately 80% of the former amounts of ozone-depleting compounds have been successfully phased out without the use of other fluorocarbons. So far, HFCs have been used to replace about 8% of the former ODS amounts and HCFCs have replaced approximately 12% of former ODS amounts. HFCs, along with other technologies such as HCs, are important substitutes for the remaining uses of HCFCs and CFCs. The Multilateral Fund has approved HFC to replace 7% of ODP tonnes and has approved HCFC to replace 17% of ODP tonnes in investment projects in Article 5(1) countries. In the refrigeration sector, 89% of ODP tonnes of refrigerants were replaced with HFCs while 66% of ODP tonnes of foam blowing agents were replaced with hydrocarbons.

With important exceptions for low-volume speciality applications, PFCs are not technically or economically necessary substitutes for ODSs. There are no identified uses requiring SF₆ as a substitute for ODSs.

HFCs are currently essential substitutes for a few highly important uses of ODSs, including propellants in metered-dose inhalers (MDIs) for treatment of asthma and chronic obstructive pulmonary disease (COPD) and fire extinguishants for occupied spaces in particular circumstances.

Global emissions from HFC/PFC uses will be no greater than 2 or 3% of the total GWP-weighted emissions of the basket of gases whose emissions are to be controlled under the Kyoto Protocol.⁷ Use of HFCs as substitutes for ODS is not likely to impede Parties to the Kyoto Protocol from meeting emission reduction obligations.

The use of HFCs and HCFCs for some refrigeration, air-conditioning and insulating foam applications are technically and economically necessary to maintain and improve energy efficiency necessary for compliance with the Kyoto Protocol. However, hydrocarbons, ammonia

⁷IPCC's 92A Scenario for 2050. Countries in Asia and North America that rely on air conditioning will allocate a larger portion of the allowable greenhouse gas emissions to HFCs than countries in other regions that face different cultural, climate, and industrial circumstances.

and other “natural refrigerants” can provide equivalent or higher energy efficiency in some applications; and water, CO₂, and other alternatives can provide equivalent energy efficiency in some applications of insulated foam.

6.2 National or regional restrictions on the import of products made-with or containing HFCs would have adverse implications for the implementation of the Montreal Protocol in CEIT and Article 5(1) countries.

Any restrictions on the import of products made-with or containing HFCs would severely impact the implementation of the Montreal Protocol in CEIT and Article 5(1) countries. These countries often depend on export markets for revenue and could delay conversion from ODSs if HFCs are subject to regulatory uncertainty.

The incremental cost of a conversion away from HFCs does qualify for financing from the Multilateral Fund since HFCs are not ozone depleting substances.

Leadership companies in Article 5(1) countries that took early action to protect the ozone layer when HFC was the only proven alternative could be harmed economically by HFC trade barriers and could become reluctant to make further environmental investment.

In many refrigeration and foam applications non-HFC options are up to 30% more costly. Without contributions to the Multilateral Fund and the Global Environment Facility, CEIT and Article 5(1) countries may not be able to comply with Protocol control schedules.

Hydrocarbons are particularly unsuitable for foam-blowing in small-scale manufacturing where capital is relatively more expensive to safely handle flammable chemicals and where worker training and discipline may be more challenging.

Co-ordinated investment for ozone and climate protection would often be highly cost-effective and could encourage conversion to ODS alternatives demonstrating better Life Cycle Climate Performance (LCCP).⁸ Parties may wish to invite energy efficiency investment under the Global Environment Facility (GEF), the Clean Development Mechanism (CDM), and/or Joint Implementation as supplements to Multilateral Fund ozone protection investments. Cost-effectiveness criteria can be separately applied to ozone and climate benefits.⁹

⁸ Life-Cycle Climate Performance (LCCP) calculates the cradle-to-grave climate impact of direct (primary) refrigerant emissions and indirect (secondary) greenhouse gas emissions including inadvertent emissions from chemical manufacture, energy embodied in chemicals and components, operating energy, and emissions at the time of disposal or recycle.

⁹The Multilateral Fund and the Global Environment Facility (GEF) recently entered into the first demonstration of jointly achieving ozone and climate protection goals. The project is to replace existing CFC-11 and CFC-12 air conditioning chillers in Thailand with high-efficiency HFC-134a and HCFC-123 chillers. The new equipment will typically be at least 30% more energy efficient and will pay back investment within two to five years.

Examples of such projects could include equipment improvements to increase energy efficiency and containment, investments in recovery and recycling of refrigerants, best-practices training and conversion to lower GWP fluids.

6.3 Overly restrictive national regulations on the use of HFCs could delay and increase the cost of the phaseout of CFCs in CEIT and developing countries and could delay the global phaseout of HCFCs.

Potential restrictions on HFC uses create business uncertainty that can slow phaseout of HCFCs in both developed and developing countries.

Companies intending to commercialise new HFCs as a substitute for HCFCs could postpone investment and force product manufacturers to either prolong the use of ODSs or compromise product performance, with the potential for increased energy use and associated greenhouse gas emissions.

It is important for the private sector and environmental authorities to co-ordinate pace of actions to protect the ozone layer and the climate.

Uncertainty on HCFC availability after around 2003/2004 has been a concern of developing countries. Developing countries need better information on technology options that can help enterprises to make informed choices. Enterprises, especially SMEs, can better select the alternatives with a clear understanding of the technical, market acceptance, and environmental implications.

6.4 Overly restrictive national regulations on the use of HFCs, PFCs and SF₆ could also have unintended consequences for industries that emit these high GWP gases from applications where ODSs were never used.

PFCs and SF₆ are used in applications requiring highly inert or fully fluorinated chemicals. For example, no substitutes exist for SF₆ globally in high-voltage electric power distribution, PFCs used in semiconductor manufacturing, and a number of other minor but technically essential applications.

6.5 Categories of ODS replacement based on chemical characteristics such as “HFC,” “HCFC,” “HFE” or “natural refrigerants” are unreliable indicators of environmental acceptability.

This is because toxicity, safety, ODP, and GWP of the compounds within these categories vary widely and technical options exist to manage safety and environmental issues for many applications. Furthermore, energy efficiency depends on the application, the engineering, and on the component performance.

The GWP, ODP, and toxicity of chemicals within chemical categories vary widely. For example, “natural refrigerants” methyl chloride, sulfur dioxide, ammonia, and carbon dioxide are toxic while “natural refrigerants” H₂O and hydrocarbons are not.

The direct climate, toxicity, and safety impact depends on the quantity of emissions, not the quantity in use. Available and emerging technology can virtually contain refrigerants during servicing and use with recovery for reuse or disposal at the end of equipment useful life. A portion of the foam blowing agents remaining in foam can be recovered for reuse or disposal at the end of product use.

The energy efficiency of refrigeration, air conditioning, and insulating products can be far more significant to climate than the emissions of refrigerant and/or foam blowing agents. These “indirect” effects result from emissions from electricity generation necessary to operate refrigeration, air conditioning, and heating equipment or from emissions from heating with fuels.

Government mandates to use specific refrigerants or blowing agents do not assure that products made with those chemicals will achieve either high energy efficiency or low emissions. However, product environmental performance standards can be crafted to minimise the impact on climate from the combination of direct chemical emissions and indirect emissions from energy used by the products. Environmental performance standards can be voluntarily adopted or compelled by regulation, if necessary.

7 AEROSOL PRODUCTS EXECUTIVE SUMMARY

HFCs are used in two categories of aerosol products: 1) Metered-dose inhalers and 2) Cosmetic, convenience and safety products.

7.1 Metered-dose inhalers (MDIs)

Metered-dose inhalers (MDIs) are reliable and effective therapy for asthma and chronic obstructive pulmonary disease (COPD). MDIs historically used CFC-12 as a propellant and most used CFC-11 and CFC-114 either alone or in a mixture to suspend or dissolve medication. CFC propellants are being replaced with HFC-134a and HFC-227ea (both zero-ODP gases). These alternative HFC propellants have been approved by health authorities as acceptable for use in MDIs.

The prevalence of asthma and COPD is increasing worldwide. There are estimated to be 300 million patients with asthma and COPD worldwide. Evidence now confirms that asthma prevalence is increasing as urbanisation of developing countries continues. Currently, approximately 450-500 million MDIs are used annually worldwide. Non-Article 5(1) Parties that requested essential use nominations for MDIs are estimated to have used 8,254 tonnes of CFCs in 1998. An estimated total of 10,000 metric tonnes of CFC is used annually worldwide.

Overall use of inhaled medication is increasing because of increased disease prevalence. World Health Organisation/US National Heart, Lung and Blood Institute-Global Initiative for Asthma (WHO/NHLBI-GINA) Guidelines in asthma management also encourage the inhaled route as the preferred method of administering medicine. The mainstay of therapy for asthma/COPD is likely to remain administered by the inhaled route, which includes not only MDIs, but also DPIs and nebulizers.

Currently available alternatives to MDIs not using CFCs or HFCs are primarily dry powder inhalers (DPIs) (single or multi-dose), nebulizers (hand held or stationary), orally administered drugs (tablets, capsules or oral liquids) and injectable drugs. Development of new respiratory delivery technology continues at an impressive pace, but cannot be commercialised and implemented to replace CFC and HFC MDIs in the next 10 years.

The use of MDIs is likely to continue to grow, although the introduction of new DPIs and new technology will also continue. It is anticipated that MDIs will continue to dominate inhaled delivery in the next decade.

HFCs are necessary for use in metered dose inhalers to enable a CFC phaseout that:

- ensures safety of asthma and COPD patients,
- achieves minimal use of CFCs by 2005 in non-Article 5(1) Parties,
- provides essential medication for patients that cannot use DPIs, either due to the patient's condition or due to the current global availability or regulatory acceptance of DPIs, and
- guarantees that asthma and COPD patients will still receive these cost effective inhaled medicines.

7.2 Cosmetic, Convenience and Safety Products

Hydrocarbon, dimethyl ether (DME), carbon dioxide (CO₂), and nitrogen are satisfactory propellants for virtually all non-medical aerosol products with important exceptions where HFCs are necessary to comply with safety or environmental regulations. The aerosol product industry has every incentive to responsibly use HFCs. HFCs cost more than other propellants and unnecessary HFC use has the potential to re-ignite consumer boycotts. Consumer boycotts could threaten sales of all aerosol products because consumers may not be able to distinguish HFC products from acceptable HC products.

Non-medical aerosol products typically use six aerosol propellants: hydrocarbons (hydrocarbon aerosol propellants) dimethyl ether (DME), and to a lesser extent carbon dioxide (CO₂), nitrogen, HFC-134a, and HFC-152a. Virtually all aerosol consumer products can be manufactured without HFCs. For most products, hydrocarbon aerosol propellants are more economical and satisfy safety and environmental criteria. Because HFCs are much more expensive than common

hydrocarbon aerosol propellants and dimethyl ether, they are only used where a unique HFC property is needed or to comply with safety and/or VOC regulations.¹⁰

HFC-134a is the propellant of choice for products that must be completely non-flammable¹¹ for use in airplanes and in some industrial environments, such as aerosol insecticide use on electrically energised equipment.¹² These uses represent a very small percentage of all aerosol applications.

HFC-134a and HFC-152a are the propellant of choice for miscellaneous uses such as laboratory, analytical, and experimental uses where chemical properties are important and flammability may be a concern.

HFC-152a is the propellant of choice in the United States for products that must meet regulations that specify maximum U.S. VOC content. In large cities with poor atmospheric dispersion conditions, such as Los Angeles and Sao Paulo, unhealthy levels of photochemical smog can be generated when VOCs react in the presence of NO_x. However, in many locations, limiting VOC emissions is not as critical and hydrocarbon aerosol propellants or DME propellants can be used.

8 REFRIGERANTS EXECUTIVE SUMMARY

There are only five important refrigerant options for the vapour compression cycle:

- Hydrofluorocarbons and blends (HFC-134a, R-400 series, R-500 series) have advantages similar to those of CFCs: they are non toxic or very low toxic, they are non-flammable, they offer good efficiency with proper system design, and they are compatible with many commonly used materials. HFCs are not miscible with mineral oil and lubrication is more challenging. HFCs are the refrigerants of choice to replace CFCs and HCFCs for most applications.
- Ammonia has long been used for industrial refrigeration plants and is now being used mainly in Europe in other applications such as supermarket refrigeration systems and water chillers in centralised air conditioning systems. Energy efficiency is limited under 50kW cooling capacity due to heat exchange limitations.

¹⁰DME is a medium pressure, flammable, liquefied propellant with solvent properties that are desirable in some aerosol product formulations. It can be blended with other solvents and propellants. Use of DME requires the same safety practices employed with hydrocarbons.

¹¹HFC-152a can be used in some applications where flammability is less critical because it is less flammable than hydrocarbon aerosol propellants and dimethyl ether.

¹²This product instantly immobilises wasps and hornets by the action of “fast knock down” insecticides and chilling action. The HFC propellant product provides a long reaching jet that allows the insect to be killed from a safe distance. Repair of high-voltage power lines and transformers requires work in confined spaces or high on power poles where it is impossible to escape from wasps and hornets and where a misstep can be fatal.

- Hydrocarbons and blends (HC-290, HC-600a, and HC-1270) have only recently been re-commercialised for non-industrial applications. They were first marketed in the 1920s before being replaced by CFCs. These refrigerants are now used in domestic and commercial refrigeration appliances, unitary air conditioning, heat pumps, and in some large oil and chemical plants.
- Carbon dioxide (R-744) is currently being revived. Demonstration systems are being tested in: secondary loop systems in commercial refrigeration, reversible heat pumps and mobile air conditioning.
- Water is used as a refrigerant in less than 10 very large chillers worldwide with the exception of absorption LiBr-H₂O systems.

Furthermore, a number of other non-vapour compression options exist such as absorption, adsorption, air cycle, thermoelectric cooling, Stirling and other cycles. Except absorption, none of those technologies have so far gained significant market share.

Refrigerants choices are application dependent, taking into account reliability, component availability, historical experience, price, regulations, and design constraints. The following summary indicates those choices:

- Domestic refrigeration covers a wide range of products and available technical options are country dependent. The size of the refrigerant charge is a function of the capacity of the refrigerator. It is easier to select isobutane in Europe and certain developing countries where refrigerators are small. There are minimum energy standards for Europe, Japan, and the United States.
- Commercial refrigeration covers a wide range of cooling capacity from several hundred watts to 1 Megawatt in large supermarkets. Whatever the refrigerant of choice (mainly R-404A but in some European countries ammonia or HCs), efforts are underway to limit the refrigerant charge, the level of emissions and to improve the energy efficiency. Indirect systems are under intensive evaluation in many European countries.
- Air-cooled air conditioners and heat pumps currently use HCFC-22 refrigerants. Significant progress has been made in developing alternatives to HCFC-22. Two HFC blends, R-410A and R-407C, are the leading candidates to replace HCFC-22 in these products.
- New mobile air conditioning systems have used HFC-134a since 1995. CO₂ direct expansion systems and HC indirect systems are under evaluation by car manufacturers.

Naturally occurring substances already circulating in large quantities in the biosphere and historically used as refrigerants are defined as “natural refrigerants.”¹³ “Natural refrigerants” are alternatives to HFC and HCFC refrigerants in many applications but are not the most energy efficient and/or environmentally acceptable choice in all applications.

“Natural refrigerants” ammonia (NH₃), hydrocarbons (HC), carbon dioxide (CO₂), and water (H₂O) have the advantage of very low direct effect on climate from refrigerant emissions and in some applications have comparable or superior energy efficiency and therefore superior LCCP. Sulfur dioxide and methyl chloride are naturally occurring substances once used as refrigerants, but these “natural refrigerants” are typically considered to be too toxic to be used in most modern applications. Lithium bromide, another naturally occurring substance, is used as an absorbent in systems where water is the refrigerant.

“Natural refrigerants” are recapturing market share in an increasing range of refrigeration and air conditioning options and are highly promoted by many countries and environmental non-governmental organisations (ENGOS).¹⁴

It has been technically and economically demonstrated that HC refrigerants can provide equal or better life-cycle climate performance (LCCP) compared with HFC-134a for residential refrigerators and small commercial refrigerated cases. These products are commercialised in Europe and Asia. It is technically demonstrated that in some mid- and large-scale systems, HCs or ammonia refrigeration have significantly better energy efficiency than the HFCs and would therefore have a superior LCCP. It is technically demonstrated (in Sweden, Switzerland and Norway) that CO₂ has significantly better energy efficiency in supermarket refrigeration systems. This has also been demonstrated for heat pump water heaters. The first CO₂ bus air conditioning prototype system is being field tested in Germany.

The energy efficiency and emissions of refrigeration and air conditioning equipment depend on the choice of refrigerant, the design, the quality of the components, and on proper maintenance.

The choice of refrigerant for maximum energy efficiency depends on the application and must consider the desired cooling temperature and the climate conditions. Safety, availability, and price are also important factors. The choice of a potentially high efficiency refrigerant, such as ammonia, does not ensure a high efficiency systems, since the design of the actual systems will have great influence on the actual efficiency.

LCCP (Life Cycle Climate Performance) integrates all total effects on the atmosphere from the raw material production (including refrigerants) to the direct emissions of refrigerant during all the lifetime of the equipment including disposal, and the indirect CO₂ emissions associated with the energy consumption. For most applications, indirect emissions represent the dominant factor.

¹³ “Natural refrigerants” are primarily manufactured and refined in chemical and petrochemical facilities.

¹⁴ Greenpeace is widely credited for successfully promoting hydrocarbon refrigerant in refrigerators.

9 HALON EXECUTIVE SUMMARY

HFC/PFC use for fire fighting represents a very small share of total use. About 50% of previous halon use have been replaced with not-in-kind, non-ODP alternatives. 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% of previous halon use has been reduced with non-halocarbon gaseous agents such as carbon dioxide or inert gas mixtures. Despite the consumption phaseout in developed countries, there remain some critical halon uses in existing and new applications (5%) 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.¹⁵ Only 20% of applications previously using halon now use HFCs in new installations, and less than 1% by PFCs. Depending on the type of industry and risks to be protected, this share can be lower in different countries.

HFCs are important halon substitutes primarily in occupied areas where space and weight are constrained, or speed of 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. Halocarbon emissions have declined from 25% of installed base before the Montreal Protocol to around 4-6% today due to changes in industry practice in many countries to conserve halon.¹⁶ 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 by up to an additional 50% include:

- A. Incentives to industry to invest in best installation and maintenance practice.
- B. Field recovery and recycling.
- C. End-of-useful-life reclamation and transformation.

HFC emissions from fire fighting are forecast to be around 0.3% of all HFC emissions in the EU by 2010.¹⁷ HFC emissions from all sources are approximately 2% of GHG emissions, and from fire fighting approximately 0.006% of all GHG emissions.¹⁸

¹⁵ UNEP HTOC Reports, 1989, 1991, 1993. In 1992, UNEP TIE was requested to establish the International Halon Bank Management Information Clearinghouse. Since then, in conjunction with UNEP Halon Technical Options Committee, UNEP TIE's OzonAction Programme collects and disseminates information relevant to international halon bank management and co-ordinates its activities with other implementing agencies. This has promoted use of recycled halons and avoided new production of halons for non-essential uses.

¹⁶ UNEP HTOC Report 1998

¹⁷ March Consulting Group Report for DGIII, September 1998

¹⁸ IPCC IS92 second assessment report 1995

Restricting HFC use would increase halon use and reduce availability of recovered halon for critical uses. Restricting HFCs would also increase the likelihood that an essential use exemption under the Montreal Protocol would be necessary to satisfy critical halon needs.

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.

10 SOLVENTS EXECUTIVE SUMMARY

CFC-113 and 1,1,1 trichloroethane uses have been primarily replaced in non-Article 5(1) countries by three key alternative technologies. They are:

- No Clean Flux
- Aqueous or semi-aqueous cleaning
- Organic Solvents

It is estimated that 90% of these ODS solvent uses (136,080 metric tonnes CFC-113 and 706,700 metric tonnes of 1,1,1 TCA in 1989) have been eliminated by no clean flux, aqueous or semi-aqueous not-in-kind alternative technologies. The organic solvent option captures about 10% of the original solvent market and consists of several types of solvents:

- Chlorocarbons
- Hydrocarbons/alcohols
- PFCs
- HCFCs
- HFCs
- HFEs

Chlorocarbons and hydrocarbons are primarily used for metal cleaning. Alcohols and the mixtures of alcohols with hydrocarbons and/or chlorocarbons are sometimes used for electronic cleaning. HCFCs, PFCs, HFCs and HFEs are serving some limited and unique applications where other suitable alternatives have not been identified, including:

- Cleaning delicate materials such as cultural heritage and archival property
- Cleaning assemblies or components with sensitive materials or particular soils
- Cleaning certain oxygen systems
- Cleaning where explosive or flammable conditions are possible
- Serving as a carrier of oil in precision applications
- Finger print solvent, rain repellent for aerospace and such speciality applications

Analysis of the *Inventory of Approved Projects* under the Multilateral Fund indicates that the use of HFCs in phasing out ODS in the solvent sector by the Article 5(1) countries is so far insignificant. Most projects adopted aqueous cleaning, semi-aqueous cleaning or hydrocarbons.

Work is underway to develop processes that do not require solvents with ozone depletion potential or high global warming potential. Where HFCs, PFCs, and HFEs are used, the emission is minimised by improved containment and by recycle and reuse.

11 FOAMS EXECUTIVE SUMMARY

It is technically and economically demonstrated that refrigerators using HC insulating foam can achieve current European energy efficiency ratings. Typically, energy consumption of these appliances could be further reduced with HFC or HCFC foam or other technologies such as vacuum insulation panels. Manufacturers have not yet produced refrigerators using HC foam in the United States because of concerns over energy efficiency, VOC abatement and process safety costs. Hydrocarbons have been selected for foam blowing in large-scale appliance manufacturing operations where necessary safety systems can be installed and maintained to meet local regulatory requirements cost-effectively. These plants are often entirely new facilities because it can be extremely expensive to retrofit an existing plant. Hydrocarbons are often less suitable in small- and medium-sized enterprises (SMEs), especially those located within residential districts.

It is technically and economically feasible to phaseout some applications of CFC and HCFC blown foam without using HFC-blown foam while maintaining energy efficiency. These applications include roofing insulation and other applications where adequate space is available to accommodate thicker insulation. However, use of additional material thicknesses can carry a financial and embodied energy cost in terms of both the insulation itself and the supporting structure. Moreover, in applications where space is limited, such as appliance insulation and insulation of building walls, selected HFC foams have the potential to provide improved insulation characteristics compared to other available alternatives.

Of the currently identified alternatives, HFC-245fa (100-year GWP 820) and HFC-365mfc (100-year GWP 840) and, to a lesser extent, HFC-134a (100-year GWP 1300) have the most promising physical and chemical properties as replacements for HCFC-141b and HCFC-22/HCFC-142b blends. Both HFCs have zero ODP, and GWPs comparable to those of HCFC-141b (100-year GWP 700) they could replace.¹⁹ These HFCs are particularly necessary for the HCFC phaseout by small- and medium-sized enterprises (SMEs) in developed, CEIT, and Article 5(1) countries, and in other situations where hydrocarbons are dangerous and/or uneconomic to implement or where energy efficiency is critical.

¹⁹The GWP (accounting for ozone depletion effects) of HCFC-141b is around 300 while the GWP of HFC-245fa is around 800. GWPs for HFC 365mfe are not yet published. HCFC-124 (ODP 0.022, lifetime 6 years, GWP 480) is a potential interim replacement for HCFC-141b in applications where economy and foam properties could be achieved.

HFC-134a is used in some extruded polystyrene and polyurethane rigid foams. There are specialised uses of polyurethane and phenolic foam that currently require HFCs to maintain current energy efficiency and other product standards as HCFCs are phased out. These product standards can encompass both the fire safety and durability of products. In 1995, the building sector accounted for approximately 34% of global energy consumption, equating to 31% of global CO₂ emissions. There is already a 5-7%/annum growth in demand for insulating foams that reduce energy costs and reduce emissions of carbon dioxide associated with the burning of fossil fuels and this is expected to grow still further. HFCs are already replacing HCFCs in rigid insulating foam uses in extruded polystyrene boards, polyurethane and phenolics and will continue to do so in the future. HFCs (and HCFCs before them) are not necessary in non-insulating foam applications such as extruded polystyrene sheet or flexible polyurethane foams except under exceptional circumstances for SMEs. HFCs may also be necessary to replace HCFCs for integral-skin flexible foam in some applications, but it is too early to estimate potential use. HFC blends, HFC/HC blends, and HC blends used as blowing agents are becoming more prevalent as the industry seeks to optimise the technical, safety, and economic benefits.

The current quantity of CFC-11 contained in existing foam products is substantial – with climate impact equivalent to 100-200 Mtonnes CO₂/year until 2010 and a total of 500,000 tonnes remaining in foam in 2010.²⁰ Recovery of CFC-11 from foam is technically demonstrated but is only likely to be economic in the context of comprehensive national recycling programs. Current efforts to design consumer products for disassembly should reduce the cost of recovering HFCs and HCFCs from foam.

Analysis of the *Inventory of Approved Projects* under the Multilateral Fund indicates that the use of HFCs in phasing out ODS in the foam sector by the Article 5(1) Parties is so far insignificant. The most common alternatives include hydrocarbons, HCFC-141b, methylene chloride and water/carbon dioxide. The use of CFCs to blow foam in CEIT and Article 5(1) countries results in manufacturing emissions of up to 25% due to higher ambient temperatures, manual operations and unskilled labour. HFC emissions could be even higher if best practices are not implemented.

12 MILITARY APPLICATIONS EXECUTIVE SUMMARY

It is not technically or economically feasible to phaseout ODSs from mission-critical military applications without the use of HFCs.

Mission-critical applications include:

- air conditioning and refrigerated equipment in ships, aircraft, armoured vehicles, and military command and control stations

²⁰The Alternative Fluorocarbon Environmental Acceptability Study (AFEAS) is refining these estimates and will soon report more precise estimates for each reporting region.

- fire and explosion protection in aircraft, tactical vehicles and ships

Flammable and toxic refrigerants are not suitable for use in occupied spaces that must be sealed against chemical and biological weapons and from which evacuation is not an option. CO₂ may be a feasible alternative but has not been thoroughly investigated. HFCs are also necessary alternatives to halon used on board ships, in tactical vehicles, and in aircraft.

13 SECTION II: HFCS AND PFCS

HFCs were introduced in the early 1990s as substitutes for CFCs with almost no use before 1990. The only significant emissions of HFCs and PFCs in 1990 resulted from unintended co-product production. Thus, emissions grew from a very small base.

Unlike most greenhouse gas emissions where release to the atmosphere occurs at the time of production (e.g. the release of carbon dioxide during 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. Thus, there is a delay between consumption of the HFC or PFC and emission to the atmosphere. The delay time varies from less than a year for applications such as use as an aerosol propellant to over a decade for some refrigeration applications, and to many decades for some insulating foam applications.

Use of HFCs has allowed the rapid phaseout of CFCs and halons in developed countries for applications where other alternatives were not available. HFCs are still important to the safe and cost-effective phaseout of CFCs and (to a lesser extent) halons in countries with economies in transition and developing countries. In developed countries, 8% of ODS was replaced by HFCs, 12% with HCFCs and 80% by reducing emissions and by non-fluorocarbon technologies. The table below shows replacement rates by application and technology. HFCs typically have lower global warming potentials (GWPs) than the ODSs they replace and have generally been selected for applications where they provide superior technical or safety performance. However, substitution rates and alternatives varied widely by application as shown in the table. Remaining uses of HCFCs and HFCs are primarily in those applications considered to be of higher societal value where their unique properties are required. In addition, emission rates have been drastically reduced in applications such as air conditioning and refrigeration through better containment, servicing practices and recovery at end of the product life. The global use pattern of fluorocarbon gases has changed dramatically as a result of these changes in technologies and practices as shown in the following pie charts.

Replacements for CFCs and halons in developed countries

APPLICATION	REPLACEMENT RATE of HCFCs and HFCs for CFCs and HALONS	DOMINANT ALTERNATIVE FLUID or TECHNOLOGY
Refrigeration and Air Conditioning	30%	Emission reductions (containment, recycle, recovery), hydrocarbons and ammonia
Closed Cell Foam	<45-50%	Hydrocarbons and Carbon dioxide
Open Cell Foam	15%	Water and Hydrocarbons
Aerosol Propellant	3%	Hydrocarbons and Alternative dispensing technologies
Fire extinguishants	<5%	Conservation, water mist, sprinklers, foam, carbon dioxide, inert gases
Other (Primarily Solvents)	3%	“No-clean technologies,” Water based systems and Chlorocarbons
All Applications	HCFCs 12% HFCs 8%	

Figure 13.1

**Estimated Global Consumption of CFCs, halons,
HCFCs and HFCs by Application**

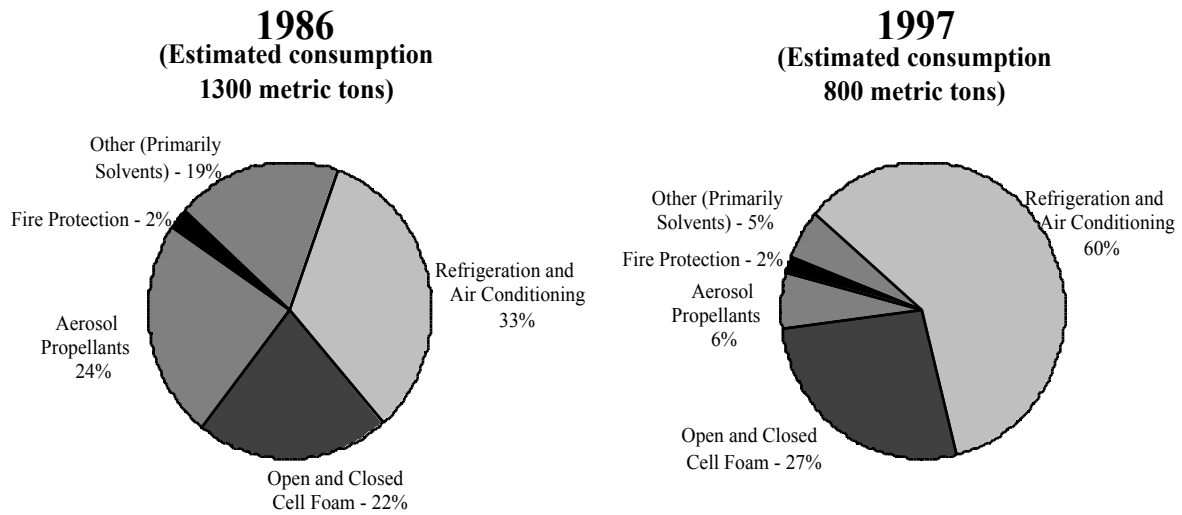
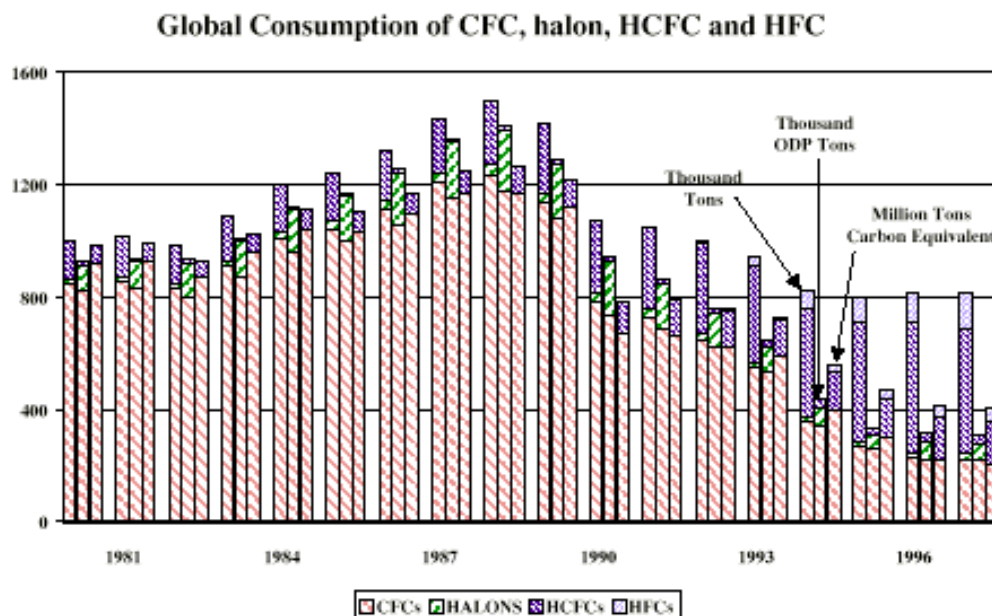


Figure 13.2



The bar chart in Figure 13.2 shows the large environmental gains in both ozone protection and climate protection 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 and the importance of ensuring that climate change activities do not interfere with the ODS phaseout. Note that the carbon equivalent values shown in the bar chart are calculated using mid-point estimates of the cooling effect of ozone depletion, which is highly uncertain. Under any assumption, significant reductions in contributions to global warming have been achieved by the phaseout of ODSs.

HFC use is also technically and economically necessary for the phaseout of HCFCs in both developed and developing countries in applications where other alternatives are not available. HFCs are expected to replace no more than half of HCFC demand for insulating foams with non-fluorocarbon gases replacing the other half. HFCs are expected to replace two-thirds of the demand for HCFCs in refrigeration, air conditioning, and heat pumps with non-fluorocarbon gases, containment, and recycling replacing the other one third. An increasing portion of new air conditioning equipment serves markets in developing countries.

14 LIFE-CYCLE CLIMATE PERFORMANCE (LCCP)

Decision V/8 requests each Party "...to give consideration in selecting alternatives and substitutes...to:

- a) Environmental aspects;
- b) Human health and safety aspects

14 LIFE-CYCLE CLIMATE PERFORMANCE (LCCP)

Decision V/8 requests each Party "...to give consideration in selecting alternatives and substitutes...to:

- a) Environmental aspects;
- b) Human health and safety aspects
- c) The technical feasibility, the commercial availability and performance of the alternative;
- d) Economic aspects, including cost comparisons among different technology options, taking into account:
 - i) all interim steps leading to final ODS elimination,
 - ii) social costs;
 - iii) dislocation costs;
- e) Country-specific circumstances and due local expertise.”

The Life-Cycle Climate Performance (LCCP), which evolved from the earlier concept of “Total Equivalent Warming Impact (TEWI),”²¹ calculates the cradle-to-grave climate impact of direct and indirect greenhouse gas emissions including inadvertent emissions from chemical manufacture, energy embodied in components, operating energy, and emissions at the time of disposal or recycle. The calculated LCCP must be tailored to account for location specific electrical generation efficiency and power mix and is sensitive to assumptions of the system lifetime, emission losses, and the integration time interval used in the calculation of the global warming potential (GWP) of greenhouse gases. Energy efficiency is often the most important strategy for reducing primary energy demand and its emissions.

The concept of Life-Cycle Climate Performance (LCCP) is intended to provide a rational way of assessing only those environmental aspects affecting climate (i.e. only a sub-segment of item (a)) The aim of LCCP is to provide a reproducible methodology for climate impact assessment. LCCP relates to a defined system and provides a comparative measure rather than one that has any absolute significance.

Use of HFC technology within an application (e.g. HFC-based foam in a refrigerator) can reduce LCCP greenhouse gas emissions where the technology has an energy efficiency advantage. The total impact on climate of any technology results from a combination of the “direct” emissions of greenhouse gases from the system throughout its life cycle and the “indirect” emissions of greenhouse gases associated with the energy used or saved by the system. The following table illustrates some examples:

²¹The Total Equivalent Warming Impact (TEWI) is less comprehensive because it did not include the emissions of feedstocks and side-stream chemical emissions in the calculation.

Direct Emissions	<ul style="list-style-type: none"> Leakage of refrigerant from a system over its life
	<ul style="list-style-type: none"> Emissions of blowing agent during foam manufacture
	<ul style="list-style-type: none"> Emissions from MDIs during normal use
	<ul style="list-style-type: none"> Emissions from foam at end-of-life
Indirect Emissions	<ul style="list-style-type: none"> Emissions of HFC-23 during HCFC-22 manufacture
(harmful)	<ul style="list-style-type: none"> Emissions of CO₂ created by manufacture of the system
Indirect Emissions	<ul style="list-style-type: none"> CO₂ emissions saved by avoidance of electricity generation
(beneficial)	<ul style="list-style-type: none"> CO₂ emissions avoided by less direct carbon fuel use

Where the use of a specific technology creates an incremental energy saving, the reduction in CO₂ emissions from the energy use can far outweigh the direct emissions over the expected life of the product.

Comparisons of the use of alternative technologies in a given system are often simplified under either LCCP calculations with reasonable assumptions that energy embodied in equipment and liberated at disposal will be similar and therefore only direct emissions and energy consumption will vary. Of course, equipment using flammable or toxic materials may have involved additional embodied energy to manufacture and additional investment and operating caution may also be necessary to satisfactorily mitigate safety concerns.

In the final analysis, the added cost of a technology will be compared with the net LCCP advantage to determine if the climate investment is economically justified.

15 CLEAR & COMPLETE TECHNICAL & ENVIRONMENTAL IMPACT

A number of projects using HFCs as alternatives to ODSs have been and continue to be approved under the Multilateral Fund for Article 5(1) Countries and under the Global Environment Facility for CEIT. When economically justified and financing is available, CEIT and Article 5(1) countries can avoid some uses of HCFCs and HFCs that were previously necessary as substitutes for CFCs, halon, and methyl chloroform and avoid a second step conversion by moving directly to non-fluorocarbons alternatives.

The momentum and the ongoing technical changes due to the Montreal Protocol could complement climate protection. The institutional structure created under the Montreal Protocol could be utilised to initiate action. UNEP TIE's OzonAction Programme in Paris has been mandated under the Montreal Protocol to facilitate bilateral and multilateral co-operation. This programme can continue to play a significant role in creating awareness on this issue and in collecting and distributing up-to-date information and in helping expand the scope of OzonAction Program to a ClimateAction Program.

16 TWO CATEGORIES OF TECHNICAL AND ECONOMIC FEASIBILITY

The Task Force identified two critical categories that distinguish the current importance of HFCs as substitutes for ODSs. The Task Force also finds that PFCs and SF₆ are unnecessary in all but low-volume specialised uses.

Critical Category 1

HFCs are currently essential substitutes for some highly important uses of ODSs.

- HFC-134a and HFC-227ea to replace CFCs in MDIs
- HFC-227ea, HFC-236fa and HFC-23 to replace halon 1301 in specialised uses where space or weight constraints apply
- HFC-43-10 to replace CFC-113 in limited cleaning and drying applications, in fingerprinting, and as solvent carriers for fluorinated lubricants
- HFCs for foam blowing as necessary for safety or economic feasibility, particularly for SMEs in all countries

Critical Category 2

HFCs are currently the only energy efficient substitutes for ODSs.

- HFC-134a for use in vehicle air conditioners
- HFCs to replace CFCs and HCFCs as refrigerants in certain refrigeration and air conditioning applications
- HFCs to replace HCFC-141b in some foam blowing applications
- HFC-236fa to replace CFC-114 in submarines and nuclear facilities

In replacing CFC-11 use in insulating foams in the refrigeration sector, around 66% of the ODSs were replaced by hydrocarbons in investment projects approved by the Multilateral Fund. In non-refrigeration uses, 31% of the ODSs were replaced by HC, 24% by HCFC and 45% by zero ODP/zero GWP technologies. The next step toward a long-term solution for some uses that use HCFC-141b is most likely to be HFCs. Since enterprises are allowed to receive financing only once under the Multilateral Fund, they have to use their own resources to convert to more long-term solutions in this situation. Therefore, any impediments on HFC uses will delay private sector investment in the implementation of ODS phaseout.

In some circumstances, the capital cost and rate-of-return on energy cost savings will be much more attractive for HFC technology than for technology based on other substitutes for ODSs. Parties may wish to consider that cost-attractive HFC technology can accelerate ozone and climate protection.

HFCs are currently technically and economically necessary to phaseout ODSs in certain important uses. In these critical applications, HFCs have a lower impact on the climate than the ODS they replace. Thus, any delay in ODS replacement slows the rate of recovery of the ozone layer and accelerates climate change.²²

17 PFCs AS ALTERNATIVES TO ODSs

PFCs are compounds with atmospheric lifetimes measured in thousands of years and with high GWPs. Except for some specialised, low volume applications, PFCs are rarely considered as substitutes for ODSs by Article 5(1) countries and no PFC project has been approved by the Multilateral Fund.²³ PFCs are not technically or economically necessary for the phaseout of ODS. However, substantial unnecessary use and emissions could result from aggressive marketing and misinformation, particularly into CEIT and Article 5(1) countries.

PFCs are marketed as refrigerants (e.g. R-14 and R-508 which are used for ultra low temperature medical refrigeration applications), fire extinguishing agents and solvents where more environmentally acceptable alternatives are available.²⁴ Aggressive marketing and misinformation includes incomplete disclosure of GWP, overstatement of efficacy, and possible regulatory controls and attempts to authorise or mandate use as part of national or international regulations. For example, PFC/SF₆ blends are promoted as new and retrofit refrigerants in Russia.²⁵

Responsible use criteria can be applied prior to the introduction of new PFC uses and periodically to existing uses. Such voluntary action could be helpful in reducing unnecessary uses and emissions.

Awareness campaigns and institutional capacity building for their customers could help limit unnecessary PFC use.

18 AEROSOL PRODUCTS

For aerosol products, other than metered dose inhalers (MDIs), there are no technical barriers to global transition to alternatives including non-HFCs.

²²The substitution of HFC-227ea for halon reduces ozone depletion and offsets positive forcing due to increases in well-mixed greenhouse gases.

²³ There are a few speciality, high value uses of PFCs such as in the manufacture of semiconductors (where programs are underway to reduce emissions during use) that are not considered here because PFCs are not replacing ODSs in these applications.

²⁴ SF₆ is marketed for use in the pressurised soles of sports shoes and tennis balls and for inflation of high performance tires where more environmentally acceptable alternatives are available.

²⁵ For example, the binary blend of 95% PFC C₃F₈ and 5% SF₆.

18.1 Metered Dose Inhalers

HFC Metered-dose inhalers (MDIs) are essential for the near-term CFC phaseout because other available options including dry powder inhalers (DPIs), nebulizers, and oral and injectable drugs cannot currently replace CFC products for all patients. DPIs are, however, an alternative inhalation product acceptable for a large proportion of patients. Development of new respiratory delivery technology continues at an impressive pace, but at least ten years is required for commercialisation and implementation.

CFC-containing metered dose inhalers (MDIs) are reliable and effective therapy for asthma and chronic obstructive pulmonary disease (COPD). MDIs historically used CFC-12 as a propellant and most used CFC-11 and CFC-114 either alone or in a mixture to suspend or dissolve medication. CFC propellants are being replaced with HFC-134a and HFC-227ea (both zero-ODP gases). Both have been approved by health authorities as acceptable propellants for use in MDIs.

The prevalence of asthma and COPD is increasing worldwide. There are estimated to be 300 million patients with asthma and COPD worldwide. Evidence now confirms that asthma prevalence is increasing as urbanisation of developing countries continues. Currently, approximately 450-500 million MDIs are used annually worldwide, requiring approximately 10,000 metric tonnes of CFC. Non-Article 5(1) Parties that requested essential use nominations for MDIs are estimated to have used 8,254 tonnes of CFCs in 1998.

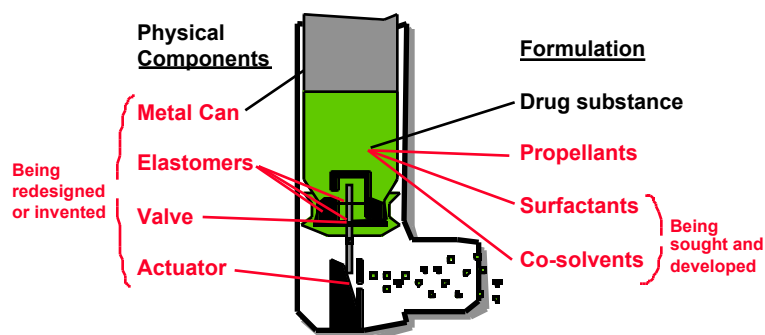
Overall use of inhaled medication is increasing because of increased disease prevalence. World Health Organisation/US National Heart, Lung and Blood Institute (WHO/NHLBI-GINA) guidelines in asthma management also encourage the inhaled route as the preferred method of administering medicine. The mainstay of therapy for asthma/COPD is likely to remain administered by the inhaled route.

The use per capita of MDIs is low in Article 5(1) Parties reflecting availability, cost, and health professional practice rather than a reduced need. Recent international studies have reported that asthma is a very significant health problem in many of the large population countries such as India and Pakistan, with slightly lower rates in China. In all of these countries the rapidly increasing use of tobacco products has also led to an increasing prevalence of COPD.

The inhaled route permits fast and efficient delivery of treatment to the airways, with minimal risk of adverse reactions. Therapy necessitates regular treatment, often with more than one drug. Although there are other inhaled delivery systems, MDIs remain the most commonly used in most countries and for all categories of drugs.

An MDI is a device designed to provide a fine mist of medicament for inhalation directly to the lungs for the treatment of respiratory diseases such as asthma and COPD. The active ingredient may be dissolved in the propellant but is more often presented as a suspension of particles, the majority of which are less than 5 micrometers in diameter. A surface-active agent may be

included to ensure that the drug is well suspended and to help lubricate the metering valve. When a patient uses an MDI, the drug/propellant mixture in the metering chamber of the valve is expelled by the vapour pressure of the propellant through the exit orifice in the actuator. As droplets of drug in propellant leave the spray nozzle the propellant gases expand, with very rapid evaporation, resulting in a fine aerosol cloud of drug particles.



An extensive search for CFC replacements over a decade identified HFC-134a and HFC-227ea as the most suitable substances for propellants for MDIs. During the initial investigations, many compounds were evaluated and only these two were deemed suitable to meet the stringent requirements for a pharmaceutical excipient. Following the selection of the HFC gases, the pharmaceutical industry has undertaken a huge reformulation program involving investments over \$1.5 billion to date, including new manufacturing plants. This research, development and commercialisation effort is not yet complete.

All the HFC MDIs under development contain the same basic components as the CFC products, but the different physical properties of the HFC propellants have meant that significant changes have had to be made and new formulations had to be developed. HFC MDIs will contain the new propellants HFC-134a or HFC-227ea, and some products may contain both. The HFC MDI looks the same as the CFC MDI but has a slightly different taste and mouth feel that is obvious to the user.

18.1.1 Currently available alternatives to HFC MDIs

Currently available alternatives to MDIs not using CFCs or HFCs are primarily dry powder inhalers (DPIs) (single or multi-dose), nebulizers (hand held or stationary), orally administered drugs (tablets, capsules or oral liquids) and injectable drugs.

DPIs have been formulated successfully for many anti-asthma drugs. DPIs are lightweight and portable like MDIs, they require less co-ordination to use than most MDIs, and they have the

potential to use pure drug without additives. DPI inhalers are an immediately available CFC-free alternative, however, they are not a satisfactory alternative to the pressurised MDIs for all patients or for all drugs. DPIs are difficult for some patients with very low inspiratory flow – e.g. small children and the elderly. The cost compared with MDIs varies between products and countries; patient acceptability is generally good, but not uniform. There is an increasing use of the multi-dose dry powder inhaler (MDPIs). Use is likely to accelerate as new multi-dose devices are produced, particularly as they may be more suitable for young children than older DPIs.

DPI usage globally as a percentage of all inhaled medication is estimated to be around 17%. This figure varies considerably from country to country, e.g. currently 85% in Sweden to less than 2% in the USA where MDPIs were only introduced in 1998.

Oral medications include tablets, capsules, and oral liquids and have been the standard form of therapy for most diseases for many years. For existing products such as steroids and bronchodilators, tablet therapies involve higher doses and greater risk of side effects, when compared to inhaled therapy. Regulatory authorities in some countries have recently approved several novel oral compounds (leukotriene modifiers) for the treatment of asthma, which may be of value to some asthma patients.

Several drugs used for the treatment of asthma and COPD are also available in injectable form. However, this is not practical for general use in ambulatory patients and is therefore reserved for the treatment of hospitalised patients.

In the future, additional CFC-free alternatives are likely to include new DPIs, new nebulizers, novel non-inhaled treatments, and new propellant-free inhalation devices. Some of these are already in the market. Others are in the late stage of development or under regulatory evaluation and will reach the market place in the next few years. There is likely to be an evolution of inhaled therapy away from propellant MDIs over the next 10-20 years to a broad range of alternatives, giving patients many options. The rate of change will be determined by several factors including the product development cycle (approximately 10 years), manufacturing capacity, and affordability—especially in CEIT and developing countries.

18.1.2 HFC MDI Introductions

A number of pharmaceutical companies have introduced or plan to introduce a range of HFC MDIs. The first introduction was in 1995. The most recent information for each of the major manufacturers is listed below.

3M Pharmaceuticals has approvals for and is currently marketing salbutamol (a bronchodilator) HFC MDI in over 40 countries. In the USA, salbutamol HFC MDI has been licensed to Schering Plough. 3M's beclomethasone (an anti-inflammatory steroid) HFC MDI has been approved in several countries with the first introduction in the United Kingdom in 1998. Under a further

licence agreement, Hoechst Marion Roussell and 3M Pharmaceuticals have entered into a strategic marketing alliance to co-promote some of 3M's HFC MDI products.

Glaxo Wellcome has filed registration applications for both salbutamol HFC MDI and fluticasone propionate (an anti-inflammatory steroid) HFC MDI in over 30 countries worldwide. Products have been approved in a number of countries and first launches occurred in 1997. To date products are available in a number of European countries, Australia, New Zealand and Japan. Further product launches are anticipated in the coming year.

Rhone-Poulenc Rorer has filed applications for triamcinolone (an anti-inflammatory steroid) HFC MDI in the USA and Canada. Filings for di-sodium cromoglycate (a non-steroidal anti-inflammatory) HFC MDI have been made in 21 European countries and in Japan. Boehringer Ingelheim's first submissions for reformulated products (Fenoterol) occurred in late 1998. Ivax (Norton Healthcare) launched its first HFC MDI, beclomethasone dipropionate (an anti-inflammatory steroid) in Ireland in January 1998. The same product range is also approved in France and further international approvals are pending.

It is likely that a wide range of reformulated products will be available in many developed countries and transition will be making good progress by the year 2000. It is estimated that approximately 25 million HFC MDIs were produced in 1998 with 60-75 million planned for 1999. Minimal need for CFCs for MDIs is envisaged by the year 2005 in non-Article 5(1) Parties. However remaining technical, patent, safety and regulatory issues for some commonly used drugs still make it difficult to predict with precision the schedule for full phaseout. Successful phaseout can be achieved, provided that a number of interacting factors are met.

These include:

1. A global transition framework – this will ensure coherence and support discrete national strategies. It will need to be flexible but at a minimum contain some guiding principles including:
 - a target date of 2005 for transition to be complete in non-Article 5(1) Parties
 - a strategy to discourage new CFC MDI approvals
 - guidance on CFC reserves
 - making CFC essential use allowances conditional on sustained research and development on CFC alternatives
 - encouraging rapid introduction of alternative technologies in Article 5(1) Parties and CEIT.
2. National transition strategies in which individual Parties control the rate of phaseout of CFC MDIs in relation to availability of alternatives whilst ensuring patient safety.
3. Education and training – with detailed information to health professionals and patients about the need for CFC phaseout and the switch to alternatives.

The threat of a restriction on HFC use would jeopardise the successful transition from CFC MDIs.

18.1.3 Environmental Impact

A range of alternatives will ultimately replace CFC MDIs and eliminate the use of ozone-depleting substances. Of these, the alternative that provides the fastest replacement of CFC MDIs is the use of HFC MDIs. A change from CFCs to HFCs alone would lead to an 80% reduction in GWP on a tonne for tonne basis due to the lower GWP of HFCs. Much of the transition is anticipated to be complete in the non-Article 5(1) Parties by 2005 and this will account for approximately 80% of CFC consumption in MDIs.

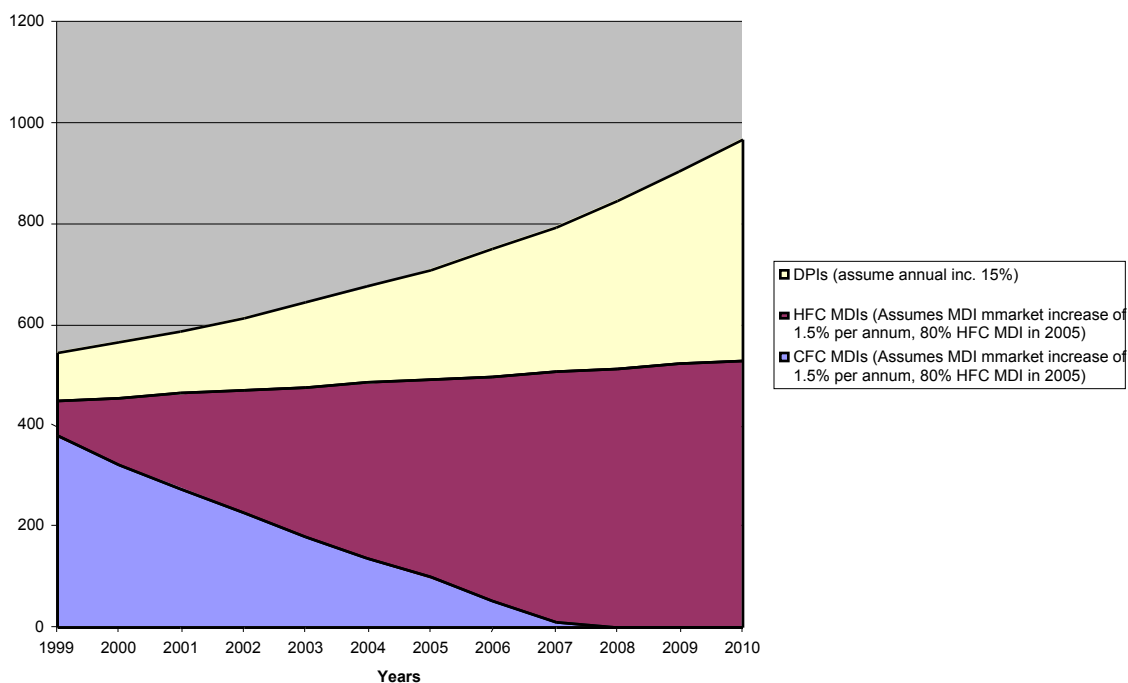
Preliminary projections indicate that worldwide emissions of HFCs from MDIs in the year 2010 will be approximately 7,500 metric tonnes, which translates into approximately 11 million metric tonnes CO₂ equivalent. These projections were derived from a 1999 survey of the member companies of the International Pharmaceutical Aerosol Consortium (IPAC). Each IPAC company reported the total units they manufactured worldwide and provided information on the amount and type of HFCs used in the MDIs. Projections for the sales in year 2010 were calculated assuming (i) all CFC MDIs will be converted to HFC MDIs by 2010 and (ii) a 1.5% annual MDI market growth rate. HFC emissions were calculated by multiplying the projected sales data for 2010 by the average amount of HFC contained in each MDI unit. Weighted GWPs for HFCs used in MDIs were calculated by taking into account each company's use of HFC-134a versus 227ea. Finally, non-IPAC member company data was added to the IPAC totals.

If a growth rate for MDIs is 3% rather than 1.5%, IPAC member companies project that approximately 8,800 metric tonnes of HFC will be used in 2010. Even with anticipated strong market growth, DPI use will still be less than MDI use (combined HFC and CFC) in 2005²⁶.

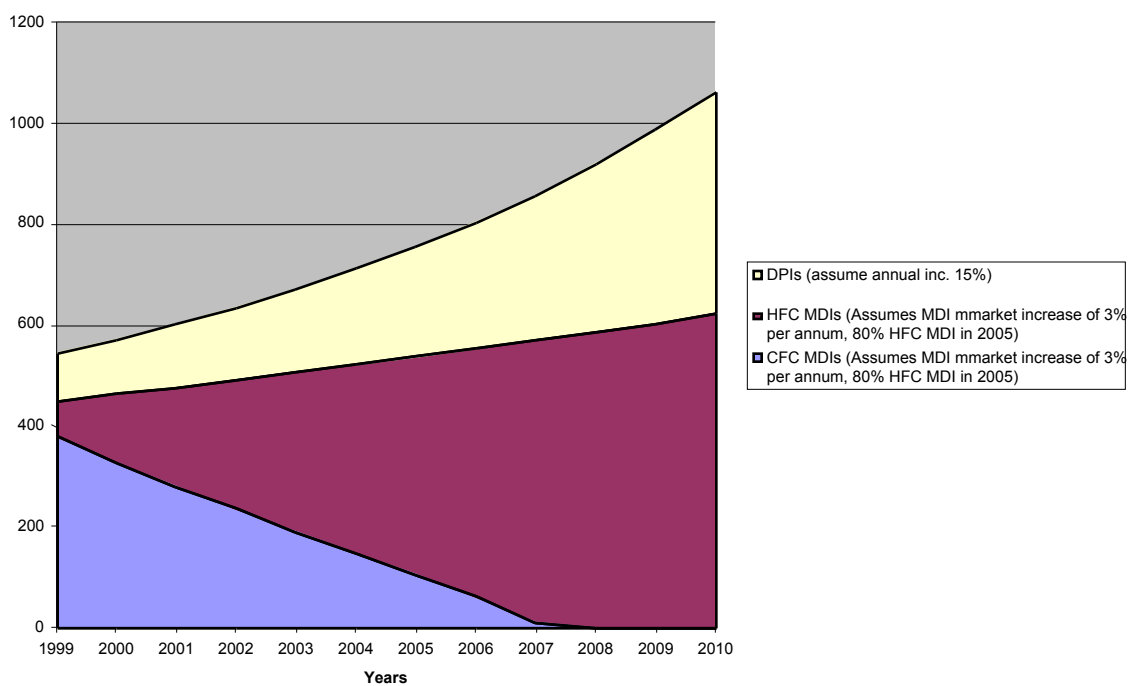
²⁶ Taking into account continued overall increasing inhaler use, global DPI versus MDI market dynamics, DPI availability, manufacturing capacity and patient uptake, and assuming the current growth in DPI use of 15% per annum continues.

Figure 18.1

Estimated asthma inhaler market (1999-2010)



Estimated asthma inhaler market (1999-2010)



Transition in Article 5(1) Parties will proceed assuming successful technology transfer and the uptake of HFC MDIs (although some transition lag is expected relative to non-Article 5(1) countries). This is likely to take until 2010 in Article 5(1) Parties.

Any threat to HFCs could impede transition from CFC MDIs and patient and health care professional confidence in the new inhaler will be undermined. Further product development would require an additional cycle (up to 10 years), and would prolong CFC usage unnecessarily.

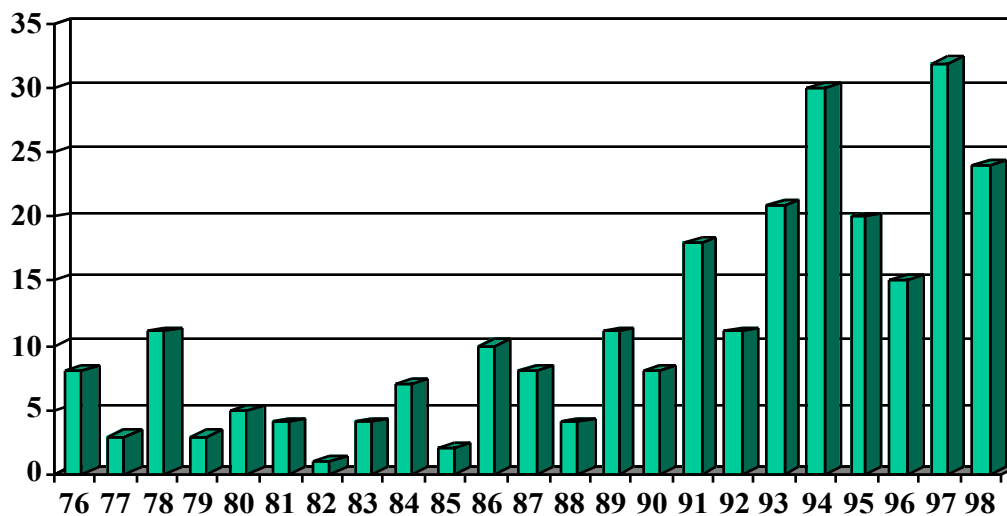
New technology is commercialised over the ten years plus development cycle described in Figure 18.3. By 2010 Parties may anticipate full phaseout of CFCs and decreasing dependence on HFCs as DPIs further penetrate the market and as HFC-free new respiratory drug delivery systems enter the market.

18.1.4 New Inhalation Technologies

The Montreal Protocol and CFC phaseout process has been largely responsible for stimulating a significant development of a number of new portable products for aerosol delivery. In addition to the development of HFC MDIs, in excess of 150 patents have been filed in the last 10 years for novel approaches to dry powder technology as well as new hand-held inhalers that utilise liquid formulations of drugs. The increase in issued patents in the United States illustrates this point.

Figure 18.2

Granted US inhaler patents



These products, which are being developed both for asthma and COPD, may serve as valuable additional options to MDIs. These approaches do not utilise propellants. Many of these products however are still early in development and may not be available as viable alternatives for MDIs until well into the next century.

Several examples of technologies under active development which utilise liquid formulation are as follows:

A spring-loaded liquid inhaler that forces the drug solution through two small channels to generate an aerosol spray when the streams merge. Promising results for this type of inhaler have been reported for beta agonists, anticholinergics, inhaled corticosteroids and combination bronchodilators.

“Piezoelectric” nebulizers use an electric current to vibrate a crystal to generate a fine droplet mist.

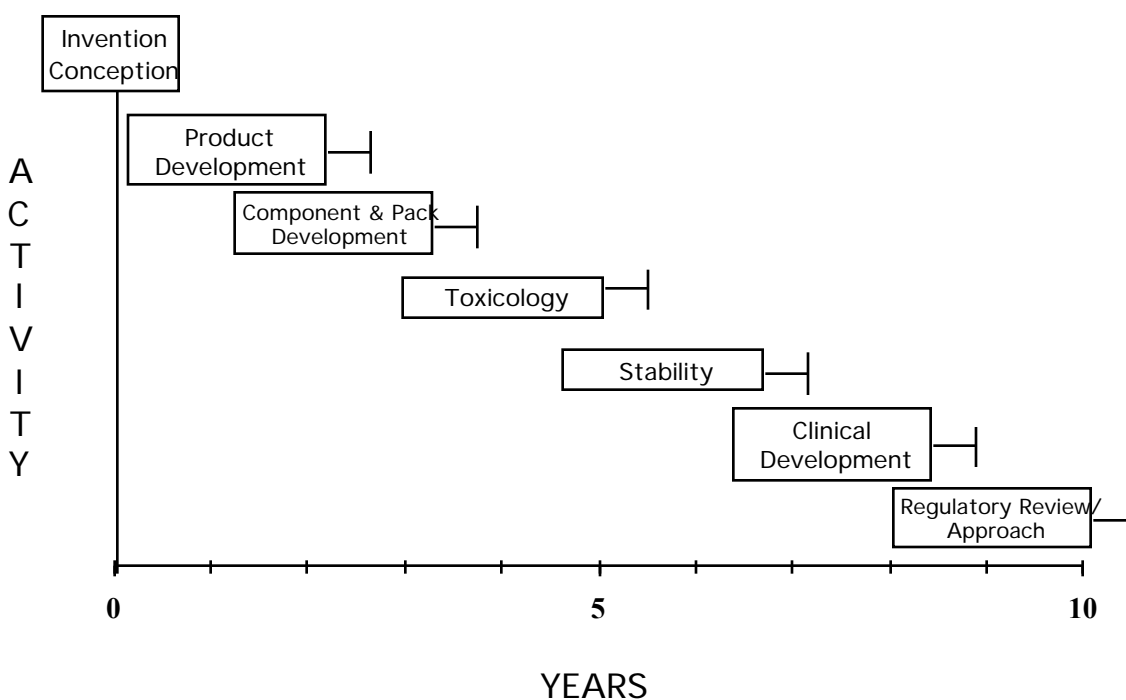
Other devices force liquid through a break-up plate, mesh cap, or open-cell foam, resulting in droplets slightly larger than the size of the holes.

An ultrasonic horn can be used to generate an aerosol cloud by capillary wave action.

Other possible future initiatives include use of microelectronics in breath-actuated devices to improve dosing accuracy and allow compliance monitoring, as well as further enhancements in dry powder inhalers.

18.1.5 New Inhaler Development

Figure 18.3: Timescale for the Development of New Inhalers



The development of a new inhaler is a complex scientific and engineering task, which requires a multidisciplinary approach. It takes approximately seven years from the development of the first prototypes to the start of commercialisation (see chart above). This time interval will depend on the novelty of the technology and the complexity of the device.

Currently there are approximately 50 different drug/formulation/dose combinations given by oral inhalation and it is unlikely that all will be developed with new technologies. Newly developed technologies will require a two-year program of toxicology testing on the final product. In addition, full clinical evaluation will need to be carried out. Once the new inhaler has been developed it will require regulatory approval globally and it is likely to take several years until the product is introduced in all countries. In parallel, the scale up of manufacture will need to be

phased so that potentially high volume demands can be met. Therefore, it is commonly assumed that it takes about a decade to fully commercialise a new inhaler.

18.1.6 Conclusions on Medical Aerosol Products

The use of MDIs is likely to continue to grow, although the introduction of new DPIs and new technology will also continue. It is anticipated that MDIs will continue to dominate inhaled delivery in the next decade.

HFCs are necessary for use in metered dose inhalers to enable a CFC phaseout that:

- ensures safety of asthma and COPD patients
- achieves minimal use of CFCs by 2005 in non-Article 5(1) Parties
- provides essential medication for patients that cannot use DPIs, either due to the patient's condition or due to the current global availability or acceptance of DPIs
- guarantees that asthma and COPD patients will still receive these cost effective inhaled medicines

There are no suitable alternatives to propellants HFC-134a and HFC-227 for use in MDIs. DPIs have been formulated successfully for most anti-asthma drugs and are an alternative inhalation product acceptable for a large proportion of patients. Any further advances in the technology to deliver inhaled medication to the lung will still take many years to fully commercialise and implement.

18.2 Technical, Pesticide, Cosmetic, Convenience, and Novelty Aerosol Products

Hydrocarbon, dimethyl ether (DME), carbon dioxide (CO₂), and nitrogen are satisfactory propellants for virtually all non-medical aerosol products with important exceptions where HFCs are necessary to comply with safety or environmental regulations. The aerosol product industry has every incentive to responsibly use HFCs. HFCs cost more than other propellants and unnecessary HFC use has the potential to re-ignite consumer boycotts. Consumer boycotts could threaten sales of all aerosol products because consumers may not be able to distinguish HFC products from acceptable HC products.

Non-medical aerosol products typically use six aerosol propellants: hydrocarbons (hydrocarbon aerosol propellants) dimethyl ether (DME), and to a lesser extent carbon dioxide (CO₂), nitrogen, HFC-134a, and HFC-152a. Virtually all aerosol consumer products can be manufactured without HFCs. For most products, hydrocarbon aerosol propellants are more economical and satisfy safety and environmental criteria. Because HFCs are much more expensive than common hydrocarbon aerosol propellants and dimethyl ether, they are only used where a unique HFC property is needed or to comply with safety and/or VOC regulations.²⁷

²⁷DME is a medium pressure, flammable, liquefied propellant with solvent properties that are desirable in some aerosol product formulations. It can be blended with other solvents and

HFC-134a is the propellant of choice for products that must be completely non-flammable²⁸ for use in airplanes and in some industrial environments, such as aerosol insecticide use on electrically energised equipment.²⁹ These uses represent a very small percentage of all aerosol applications.

HFC-134a and HFC-152a are the propellant of choice for miscellaneous uses such as laboratory, analytical, and experimental uses where chemical properties are important and flammability may be a concern.

HFC-152a is the propellant of choice in the United States for products that must meet regulations that specify maximum U.S. VOC content. In large cities with poor atmospheric dispersion conditions, such as Los Angeles and Sao Paulo, unhealthy levels of photochemical smog can be generated when VOCs react in the presence of NO_x. However, in many locations, limiting VOC emissions is not as critical and hydrocarbon aerosol propellants or DME propellants can be used.

In Southern California, some manufacturers are using HFC-152a to replace hydrocarbon aerosol propellants that have been prohibited as VOCs and it is conceivable that other highly polluted cities may follow suit, although as yet there have been no such indications. In Europe, HFCs are replacing hydrocarbon aerosol propellants in response to several well-publicised consumer accidents. “Backfilling”³⁰ of HFCs and PFCs into applications where other options have replaced ODSs could significantly increase the relative contribution of HFCs to global climate change. For example, more HFCs are currently emitted from non-medical cosmetic and convenience products in Europe than from MDIs. Such a trend could continue. Updated technical information and promotion of voluntary responsible use campaigns could further reduce unnecessary HFC and PFC uses and associated emissions.

18.2.1 HFCs in Portable Compressed Gas Dusters

Compressed gas is a non-contact method to clean surfaces and hard-to-reach areas of loose debris such as dust and other particulate matter.

In some cases, compressed gas is used for convenience when other cleaning methods would be satisfactory. Compressed gas cleaning can be accomplished with stationary or portable

propellants. Use of DME requires the same safety practices employed with hydrocarbons.

²⁸ HFC-152a can be used in some applications where flammability is less critical because it is less flammable than hydrocarbon aerosol propellants and dimethyl ether.

²⁹ This product instantly immobilises wasps and hornets by the action of “fast knock down” insecticides and chilling action. The HFC propellant product provides a long reaching jet that allows the insect to be killed from a safe distance. Repair of high-voltage power lines and transformers requires work in confined spaces or high on power poles where it is impossible to escape from wasps and hornets and where a misstep can be fatal.

³⁰ “Backfilling” refers to the substitution of a substance controlled by the Montreal or listed in the Kyoto Protocol for substances that had replaced CFCs not controlled by either protocol. For example, HFCs or CFCs replacing hydrocarbon aerosol propellants.

compressors or with portable dusters. Compressors are suitable when electricity is available and necessary moisture and purity standards can be maintained.

Where portable dusters are needed, HFC-134a, compressed air and carbon dioxide are non-flammable candidates. Compressed air and carbon dioxide have the disadvantage of providing fewer blasts per can and carbon dioxide products require expensive, high-pressure canisters. In many other applications that do not require a strictly non-flammable propellant, the use of HFC-152a is safe and effective.³¹

HFC dusters are marketed in disposable or reusable products utilising liquefied HFC-134a or HFC-152a as the active and only ingredient. These low boiling-point compounds produce a large volume of expanded vapour.

Common uses of HFC dusters include computer & office equipment cleaning, imaging equipment cleaning (cameras, enlargers, scanners, graphical reproductions, etc.), sensitive materials that should not be touched (films, storage media, etc.), and scientific equipment cleaning (laboratory equipment, electron microscopy, laser equipment, etc.). Duster users include office employees, people in home offices/businesses, scientists, technicians, photographers and hobbyists.

HFC-152a and HFC-134a have been used in dusters since 1993. Criteria for selecting HFC-152a versus HFC-134a include product safety (flammability), warehousing and storage, transportation, cost, and environmental impact. The cleaning properties of HFC-152a and 134a are similar; both are effective when used in dusters.

The current retail HFC duster market size is comprised of approximately 25% HFC-152a and 75% HFC-134a. Use is growing at approximately 2% annually. It is technically and economically feasible to replace a portion of this use with non-HFC alternatives and to shift at least 60% of applications currently using HFC-134a products to HFC-152a for a final split of 90% HFC-152a and 10% 134a. This would reduce the contribution to climate change by 40% or more.

³¹ Compressed gas dusters were exempt from the 1979 U.S. EPA ban on CFCs in aerosols and exempted from the non-essential product ban set forth in the Clean Air Act in 1990 due to critical uses and the flammability concerns of the alternatives available.

Not-in-Kind Alternatives

<u>Cleaning Method</u>	<u>Comments</u>
Surface wiping with cloth, swab, squeeze balls or other mechanical method	Not suitable for easily damaged surfaces (media storage, film) Corners and tight places difficult to reach
Compressed air	Must be clean & dry Air compressors require electricity Limited blasts per can of compressed air
Carbon Dioxide, nitrogen	High pressure gas, thick-walled containers required Limited blasts per can
Hydrocarbon propellants	Highly flammable (lower explosion limits 1.8% in air) Low ignition temperature Low molecular weight/density reduce the effectiveness

18.2.2 HFC Use in Signalling Horns

Signalling horns are used as common noisemakers and for critical use in boating and industrial safety.³² Non-flammability is a critical characteristic for safety applications necessitating the use of HFC-134a. Applications that are not sensitive to flammability concerns can use products with hydrocarbon propellants.

Gas-powered signalling horns are generally comprised of injection moulded horns that are used in conjunction with an aerosol can filled with a liquefied gas. When the horn is activated, the sound of a vibrating steel or plastic diaphragm is then amplified through the horn. The most common uses are:

Market/Use	How Used
Marine boat horns	Used to meet marine safety regulations and as back-up signalling devices on boats during power outage
Industrial safety	Used to meet occupational health and safety standards for signalling during power outage and in remote plant locations Used by railroad crews for signalling
Sports horns and noise-makers	Used by referees and coaches for signals Used by sports fans, hikers, bicyclists, etc.

³²Signalling horns were exempted from the U.S. EPA 1979 ban on CFCs in aerosols and then exempted from the non-essential product ban set forth in the Clean Air Act in 1990 due to their critical use and the flammability concerns of the alternates available.

Aerosol signalling horns are portable (no alternate energy source required), loud (decibel level of 110+), and efficient (duration of noise produced from small signalling device).

HFC-134a and hydrocarbons have been used in signalling horns since 1993. In marine and industrial safety applications, where flammability is a critical concern, HFC-134a is used as the propellant. The choice of HFC-134a versus HFC-152a or hydrocarbon propellants depends on product function, product safety (flammability), warehousing and storage, transportation, cost, and environmental effects. HFC-134a, HFC-152a, and hydrocarbons all work effectively in the standard-sized safety horns, however, hydrocarbons are less effective in very small horns due to the lower molecular weight and density of the gas.

Signal horns are marketed which depend on pressurised air supplied by a small hand pump. These have similar sound levels as HFC products, but they have to be recharged by hand several times to produce the same number and duration of blasts as HFC horns.

The current horn market is comprised of approximately 15% hydrocarbon and 85% HFC-134a and growing at approximately 1% annually.

18.2.3 Not-in-Kind Alternatives

Other alternative signalling methods and their inherent deficiencies include:

<u>Signalling Method</u>	<u>Deficiencies</u>
Electric horns	Most portable battery devices unable to produce sound level required by marine regulations (approx. 80 decibels). Compressed gas more reliable than batteries for lifeboats.
Whistle (human activated)	Poor sound level Does not satisfy marine safety regulations Not easy to use
Carbon dioxide, nitrogen	High pressure, thick-walled, containers and pressure equalising valve required. Significantly less sound produced per kg propelled
Hydrocarbon propellants	Flammable gas Not safe where an ignition source is present
HFC-152a	Flammable gas Not safe where an ignition source is present

18.2.4 Use Trends

Most non-Article 5(1) countries and some CEIT and Article 5(1) countries use HFC-134a and HFC-152a as a propellant for safety pesticides, speciality aerosol solvent, and marine safety products. CEIT and Article 5(1) countries use very little HFC for tyre inflators, dust blowers, and noisemakers because these products are more expensive than non-in-kind alternatives or are accessories to luxury products that are less common. Projects approved under the Multilateral Fund for the aerosol sector have utilised hydrocarbon aerosol propellants, dimethyl ether or carbon dioxide because of the economic and environmental advantages. CFCs are still used for aerosol products in several CEIT and Article 5(1) countries when hydrocarbon aerosol propellants are not available at competitive prices. If hydrocarbon aerosol propellants remain unavailable, HFCs could replace CFCs in some aerosol products, particularly if consumers demand ozone-safe products.

Total use of HFCs in non-medical aerosol products is difficult to estimate, but it is unlikely that it exceeds 15,000 metric tonnes per year. Assuming CFC use in non-medical aerosol products will be almost entirely replaced by alternatives, and if non-critical uses are constrained, HFC use is unlikely to exceed 20,000 metric tonnes by 2010. Consumption is expected to be relatively stable unless more stringent air quality regulations shift more products to HFC-152a for VOC control.

When scientists first warned of stratospheric ozone depletion in the early 1970s, CFC aerosol cosmetic and convenience products were the subjects of the first public boycotts and national product prohibitions. Unnecessary use of HFC aerosol propellants could re-ignite that public debate with the potential that consumers will boycott all aerosol cosmetic and convenience products, including products using hydrocarbon propellants that are ozone-safe and are not controlled as greenhouse gases by the Kyoto Protocol. Therefore, there are strong incentives for corporate and industry leadership in demonstrating responsible use of HFCs in aerosol products.

“Responsible use” of HFCs for aerosol products can be guided by the following principles:

- 1) use HFCs only in applications where they provide technical, safety, energy, or environmental advantage that are not achieved by not-in-kind alternatives; and
- 2) select the HFC compound with the smallest GWP that still meets the application requirements.

Application of these principals justifies the use of HFCs for some products in some circumstances such as hornet and wasp sprays used on energised electric equipment, horns required for marine safety, and aerosol dusters used for scientific and laboratory applications. These “responsible use” criteria are not satisfied when not-in-kind alternatives are technically and economically suitable such as replacement personal deodorants, shaving creams, and room fresheners. It is particularly challenging to enforce voluntary “responsible use” when HFC products are critical for specific applications but may be unnecessarily used in other applications.

For example, HFC aerosol horns are required by many national authorities on small boats where electric horns are unreliable and hydrocarbon propellants would be an unacceptable risk of fire during boating emergencies. However, these same horns are purchased for use at sporting events and other uses where alternatives would be acceptable.

ILLUSTRATED EXAMPLES OF THE “RESPONSIBLE USE” CRITERIA

Aerosol Product	Not-in-kind are unsuitable (HFCs technically justified)	Not-in-kind are suitable alternatives (HFCs not technically justified)	HFC compound with the smaller GWP
insecticides used to stun and kill wasps and hornets	on energised electric circuits	where pesticide alone is sufficient	HFC-134a
aerosol foam used to caulk and insulate	where hydrocarbons unsafe/incompatible	ordinary caulk	HFC-134a
cosmetic products	In locations where VOC propellants are unacceptable and equivalent non-aerosol formulations are not available	body deodorant, shaving cream, room fresheners	HFC-152a
dust blowers	technical applications (lasers, electron microscopes, some electronics service)	convenience applications (home office, photography, and hobby)	HFC-152a or HFC-134a if product must be non-flammable
horns	boat horns, attack deterrence, and industrial alarms	sports, carnival, other amusements ³³	HFC-134a
novelty products	none identified	aerosol foam party streamers ³⁴	none identified
sports devices	none identified	pneumatic pellet guns and bait guns ³⁵	none identified
tyre inflators	none identified	manual and electric tire pumps, spare tires, emergency road service ³⁶	none identified

³³ Operation of air horns can damage hearing.

³⁴ Hydrocarbon aerosol foam party streamers are hazardous near flame.

³⁵ Bait guns propel food into areas to be sport fished.

³⁶ Tyres inflated with hydrocarbons are hazardous to repair.

18.2.5 “SELF-CHILLING BEVERAGE CANS”

The HFC-134a and HFC-152a “self-chilling beverage cans” achieve refrigeration through the physics of expanding pressurised and liquefied gas that is directly emitted to the atmosphere. The self-chilling beverage can is arguably an alternative to previous uses of ODS or it may be considered as an entirely new and unique HFC use.³⁷ The advantage of the product is that cold drinks can be dispensed without access to ice or refrigerators. The disadvantage is that approximately 35-75 grams of HFC-134a or HFC-152a is directly emitted to the atmosphere for every beverage can chilled. U.S. EPA has estimated that “...even a small market penetration could substantially increase U.S. emissions of greenhouse gases. One scenario, a 5% market penetration of cans using HFC-134a, resulted in greenhouse gas emissions of 96 million metric tonnes of carbon equivalent (MMTCE), which would be 25% higher than the 76 MMTCE of total expected reductions in greenhouse gas emissions currently estimated in the year 2000...At 30% market penetration of cans using HFC-134a, emissions would be 575 MMTCE, more than total CO₂ emissions from all U.S. electric utilities’ burning of fossil fuels.”³⁸

Fortunately, the company that invented and was about to commercialise the self-chilling can decided that it was environmentally unacceptable and switched to an alternative cooling system. This company pledged in writing to not manufacture or license the technology and to discourage its use. And the United States government has banned the use of HFCs in self-chilling beverage cans.³⁹

However, the corporate leadership of the inventing company may not be sufficient to prevent other companies from supplying the product to highly profitable markets. With manufacturing costs reported to be less than one US\$ dollar per can, self-chilling beverages could compete in price with traditional beverages dispensed from vending machines and hotel mini-bars and for tourist, sporting, and convenience situations where cold drinks are currently not available or are very expensive. Whilst a number of HFC producers have stated publicly that they will not supply such an application, HFC supplies might be available from other companies not pledging to supply. If the international community allows the use of self-chilling cans, the significant emissions of HFC will not meet the criteria of “responsible use” as detailed above. Awareness campaigns and institutional capacity building for their customers could help limit unnecessary HFC use.

³⁷CFCs have been used for a wide variety of similar cooling products. For example, CFC-12 sprays have been used to chill and “frost” beverage glasses, to freeze water in pipes (to stop flow during repair), to “freeze” electric circuits to reveal loose connectors or cracked solder joints, to chill skin of burn victims, and to cool locks to such a low temperature that they can be cracked open.

³⁸*Federal Register*, Volume 64, Number 41, March 3, 1999.

³⁹*Ibid.*

19 REFRIGERATION AND AIR CONDITIONING SECTOR TECHNOLOGY

The energy efficiency and emissions of refrigeration and air conditioning equipment depends on the choice of refrigerant, the quality of the components, and on proper maintenance. Use of flammable and toxic refrigerants typically requires more expensive manufacturing facilities and equipment safety features and requires greater care in operation and service. In some cases, systems using flammable and toxic refrigerants provide the highest life-cycle climate performance (LCCP). In other cases, equivalent investment using HFC refrigerants would provide better LCCP.

19.1 Introduction

Refrigeration, air conditioning and heat pump applications are the largest consumer of CFCs, HCFCs and HFCs and also one of the largest energy using sectors. It is estimated developed countries refrigeration and air-conditioning systems use between 10 and 25 % of the electricity consumption. The portion of national energy use depends on specific country circumstances.

Refrigeration and air conditioning applications vary enormously in size and temperature requirements. A domestic refrigerator keeps food frozen or chilled, has an electrical input between 60-140 W and contains less than 100-150 g of refrigerant. Industrial refrigeration and cold storage is characterised by temperatures between $-10\text{ }^{\circ}\text{C}$ and $-40\text{ }^{\circ}\text{C}$, electrical inputs up to several MW and refrigerant charges ranging from hundreds of kilograms to several tonnes. Air conditioning and heat pumps may show evaporation temperatures between $0\text{ }^{\circ}\text{C}$ and $+10\text{ }^{\circ}\text{C}$, significantly different from refrigeration applications, and vary enormously in size and input as well as refrigerant charge.

There are four main refrigeration and air conditioning subsectors: (i) the food chain in all its aspects, from cold storage to transport to domestic refrigeration, (ii) industrial refrigeration, (iii) comfort air conditioning, including reversible and non-reversible heat pumps, and (iv) mobile air conditioning.

Refrigerants for the vapour compression cycle deserve most attention, since it is unlikely that during the next 10-20 years other refrigeration cycles will take over a substantial part of the market. The vapour compression cycle provides the most simple, economic and efficient refrigeration using ammonia, fluorocarbons and hydrocarbons.

The Montreal Protocol triggered a worldwide search for alternative refrigerants that has systematically identified and evaluated every chemical that is likely to be commercially available in the near future. There is an extremely small likelihood that additional chemicals will be identified and commercialised within the next decade. Thus, there is little advantage in delaying the selection of refrigerants.

A substantial inventory of CFC and HCFC refrigeration and air-conditioning equipment still exists. In developed countries, regulatory and market incentives influence the timing of

investments in replacement or retrofit technology. In CEIT and Article 5(1) countries, information, technology, and financing are necessary, as well as non-investment activities such as training and a network of experts for information sharing. The availability of cost-attractive HFC technology as replacement for existing CFC or HCFC equipment can accelerate ozone and climate protection.

Each alternative to ODS refrigerants has advantages and disadvantages that depend on the particular refrigeration and air conditioning application. Refrigeration and air conditioning appliances often must satisfy national, regional, and local requirements for energy efficiency, safety (operation, repair, and disposal), and environmental acceptability.

The choice of refrigerant is dealt with in section 2; the different non-ODP refrigerants are described in section 5.2. Safety issues are discussed in section 4.

19.2 Choice of Refrigerant

The efficiency of any refrigeration / heat pump system depends greatly on the design of the system and less on the choice of refrigerant. The most important factor that determines the energy efficiency is the design of the system and the quality of the components. The choice of refrigerant should be tailored to the application and thus consider the level of cooling temperature, the climate conditions, safety, availability, price and level of education among technicians. Moreover, when refrigerant blends are used, the glide of temperature during the phase change has to be integrated in the heat exchanger design. The choice of a refrigerant capable of high efficiency, such as ammonia, does not ensure that the system will be high efficiency, since the design of the system and the quality of components will have great influence on the actual performance.

The ambient temperature and the desired cooling temperature may favour the use of different refrigerants for the same equipment in different temperature applications, but most manufacturers compromise energy efficiency and use the same refrigerant with different compressor and/or heat exchanger designs.

Refrigerants can be classified according to physical and performance characteristics as follows:

1. normal boiling point (i.e. boiling temperature at atmospheric pressure) and density
2. toxicity
3. flammability
4. materials compatibility, including oil solubility
5. global environmental impacts (ozone depletion, global warming contribution)
6. technical performance in the refrigeration / heat pump system:
 - compressor discharge temperature
 - heat transfer coefficient
 - pressure drops
 - latent heat

- other factors

Single component fluids in the two-phase-region are used for constant temperature applications. Multi-component fluids (e.g. zeotrope refrigerant mixtures such as iso-butane/propane or HFC-134a/HFC-125 – components to be tailored according to the temperature glide needed) may be used for applications with changing temperatures of the heat sink / source. There are also applications where there is an advantage to having a constant temperature on one side of the refrigeration / heat pump process and a gliding temperature at the other. In such a case a refrigerant with distinct temperature change on, e.g. the high temperature side of the cycle and a constant temperature on the low temperature side is preferred, such as in the trans-critical carbon dioxide cycle. The choice of refrigerant does not automatically ensure high performance because the system has to be carefully engineered, built, operated and serviced according to the design to maintain efficiency and limit emissions.

The use of flammable or toxic refrigerants in particular applications may require secondary loop systems e.g. for ammonia or hydrocarbons in supermarket applications. In such secondary loop systems the design and the temperature difference across the primary heat exchanger are very important. Secondary heat transfer fluids must be selected using the same criteria as for refrigerants, i.e. flammability, toxicity, water and ground pollution.

CFC and HCFC will be phased out more rapidly if replacement technology is safe, affordable, and offers users additional savings from reduced energy use. Ammonia and HC air conditioners have the advantage that emissions have very low direct effect on climate and the additional advantage that the potential energy efficiency is as good or better than HFC systems. For example, in calorimeter studies propane has demonstrated higher potential efficiencies than HCFC-22, R-404A and R-407A, but R-410a has demonstrated higher efficiency than propane in actual equipment. HCFC-123 air conditioning chillers have demonstrated higher energy efficiency than HFC-134a chillers. However, ammonia and HC air conditioners may lose the potential advantage of higher energy efficiency if necessary safety systems include secondary fluids for heat transfer instead of the direct expansion option or may be so expensive that customers choose to delay replacement of existing CFC and HCFC equipment.⁴⁰

The potential advantage of low GWP “natural refrigerants” is lost if HFC systems are made leak-tight and if industry implements servicing and disposal programs to minimise emissions. Of course some leakage is unavoidable from the fracture of tubes and components failure and because recovery never will be 100% efficient.

⁴⁰For example, ammonia systems can cost up to 30% more than HFC systems. The added cost are due to features that better assure containment of toxic ammonia and because copper is not compatible with ammonia. High efficiency electric motors with aluminium windings are more expensive to produce than high-efficiency motors with copper windings. If the additional 30% cost were invested in further improving an HFC system, the HFC system might have a better LCCP than the HC system.

The safe use of flammable or toxic refrigerants is accomplished with combinations of three strategies:

1. Minimising the quantity of refrigerant that can leak (extra containment, small refrigeration charge)
2. Isolating the refrigerant from occupied spaces (remote refrigeration equipment locations with secondary loops), and ensuring that the hydrocarbon cannot leak into or accumulate in the secondary loop which would breach the isolation
3. Reducing the risk from ignition or inhalation (explosion-proofing electric controls, leak detectors and alarms, active and passive ventilation)
4. Provide appropriate training and procedures for the maintenance and repair of the system ensuring that the risks of maintenance have been fully evaluated

There has been much controversy surrounding the use of flammable and toxic refrigerants, largely the result of competing commercial interests. The main debates centre around efficiency, safety and liability. Prior to August 1998, approximately 25 to 30 million hydrocarbon refrigerators had been sold worldwide with no reported fires.⁴¹ However, a more recent highly publicised accident in Australia is indicative of the types of accidents that can occur during maintenance of systems with HC charges larger than domestic appliances. The accident in Australia occurred when a refrigerated food case developed a leak, emitting between 500 to 1000 grams of hydrocarbon refrigerant into a café located in a shopping mall. A service technician pulled an electric plug from a wall socket, igniting the hydrocarbon. The technician was severely burned, the café owner was moderately burned and the shopping mall was evacuated.⁴²

19.3 Progress in Containment

19.3.1 Limiting emissions

Limiting emissions by reducing refrigerant charge is an effective method that is also very cost-effective. In some applications the charge has also been significantly reduced due to changes in the equipment design. The most relevant examples can be taken from the commercial field. A U.S. company has developed a new concept to eliminate machinery rooms in supermarkets by locating compressors in soundproof boxes in the sales area, removing heat from condensers by water. This reduces the charge of refrigerant by more than 70%, minimising the possibility of large emissions. Another design strategy that also dramatically reduces charge is to replace shell and tubes heat exchangers with plate heat exchangers. These strategies are strongly application dependant, however there is a general trend to reduce refrigerant charge in new equipment designs.

⁴¹ Chemical & Engineering News, August 3, 1998; page 33.

⁴² The Adelaide Advertiser and news reports, 6th July, 1999.

19.3.2 Better leak tightness design and control

Better leak tightness design and control are related issues for emissions reduction. Welded junctions can replace a number of mechanical fittings. The quality of leak-prone devices like valves and flanges can be specified and assembly and service practices can be improved. The Refrigeration Sector is making good progress in all these areas.

19.3.3 Containment during the life time of equipment

The main stakeholders of installed equipment are service organisations and owners. Service contractors need to be educated on the importance of recovery and leak tightness control to protect their customers' investment and the global environment. Involvement of end-users and owners is also essential for implementing new specifications and including these important features in service contracts. Regulations for recovery and leak tightness control must be issued and clearly enforced by regulatory agencies and trade associations.

19.3.4 Refrigerant recovery at equipment disposal, recycling or destruction

Refrigerant is usually recovered during servicing but not at end of equipment life. Recovery from domestic appliances (refrigerators, small air conditioners, and dehumidifiers) at disposal is often poorly done. Large quantities of refrigerants are released because no incentive enables recovery. Regulation and enforcement play key roles and incentives are necessary to make refrigerant recovery viable. Campaigns to raise awareness and educate the end-users and owners are also important.

19.4 Safety Issues related to the use of refrigerants

Safety requirements for refrigeration equipment using flammable and/or toxic refrigerants are established in mechanical and electrical safety standards. Significant work is ongoing for the update of those standards due to the rapid change in refrigerants due to the ban on CFCs and the phaseout of HCFCs. The important mechanical safety standards (ISO 5149, Pr EN-378, and ASHRAE 15) use the same structure to address safety issues. Three classifications define the limits of use of a given refrigerant in a given refrigeration system located in a given building.

- **The refrigerant classification** is now based on one of two measures. The Refrigerant Quantity Limit (RQL), expressed in ppm(v) or in g/m³, limits the maximum quantity of refrigerant that can be released into an enclosed space. The Refrigeration Concentration Limit (RCL) varies depending on flammability, toxicity, or breathability of refrigerants.
- **The refrigerating system classification** defines whether a direct or an indirect design may be used for a given application. In direct systems, the refrigerant is circulating through a heat exchanger located in the occupied space. Indirect systems use a heat transfer fluid, which is cooled in a primary heat exchanger by the refrigerant, then circulated to the space to be cooled.

- **The building classification** distinguishes between 3 principal categories: 1) industrial occupancy where personnel are aware of danger and trained for emergencies, 2) a general occupancy which covers most public buildings, and 3) buildings where people are restricted in their movements (hospitals, jails, etc.)

Electrical standards limit the maximum allowable charge of flammable refrigerants for domestic appliances (refrigerators, air-conditioners, dehumidifiers) assuming that some appliances will be used in small rooms. A general agreement has been reached in defining 150g of flammable refrigerants as the maximum charge for refrigerators (IEC 335-2-24). In the case of air conditioning systems, agreement is much more difficult to reach, because refrigerant charges are usually much higher than in case of refrigerators (ranging from 150g to several kilograms). As a result, discussions are still ongoing in the combined ISO/IEC working group and the IEC 335-2-40.

In larger refrigerating systems (e.g. supermarkets, building air conditioning, etc.) indirect system design is required to prevent flammable or toxic refrigerants from being released into occupied spaces. The unresolved issue is how to assure a safe design of a machinery room built in general occupancy buildings. Know-how on the use of toxic or flammable refrigerants is limited to industrial facilities because there is no historical use of these refrigerants in general occupancy buildings. The main design uncertainties are the achievable leak tightness of the machinery room relative to the rest of the building, the reliability of normal and emergency ventilation, the adequacy of emergency exits and the specification of safe electrical switches necessary to make systems safe for machinery room design inside general occupancy buildings. Pressure relief and blast zone direction in the vent of an explosion are important considerations for the design of machinery rooms containing hydrocarbons.

The European standard Pr-EN 378 should be ratified by the end of 1999 and be published in early 2000, limiting the use of flammable refrigerant in general occupancy applications (with machinery rooms) to 10 kg, without any limitations for ammonia, and an informative Annex C contains clause 2.3.1. In general, group L3 refrigerants (which include hydrocarbons) are highly flammable and explosive. Direct, indirect open and indirect vented open systems shall not be permitted for air-conditioning and for human comfort. This standard is different than other safety standards such as ASHRAE 15 (US) where the use of flammable refrigerants is only possible in industrial occupancy, or ISO 5149 (which is currently under revision).

Beyond the safety standard specification, it is important to stress that equipment manufacturers, installers and owners remain responsible for the safe design, operation and maintenance of the equipment. The risk of accidents and possible moral, financial or criminal liabilities are the main “barriers” to extensive use of toxic or flammable refrigerants when the equipment refrigerant charge is high. If manufacturers, installers or owners accept those risks (particularly with the support of government and environmental organisations) the shift away from HFCs may be accelerated. This has been clearly demonstrated in the case of the German domestic refrigerator

industry, which converted away from HFC-134a in only a few years, but is clearly more challenging for equipment with larger charges. The service of refrigeration is generally done by highly trained technicians affiliated with the equipment manufacturer. Risks in service and maintenance have not been fully explored for larger systems or in regions where training and skills of technicians are relatively poor.

19.5 Refrigerant Options in Different Sub-sectors

Table 19.1 presents the non-HFC options, which can be applied in each type of refrigeration equipment. Some of these options have been commercialised and some are in demonstration (on-site constructed specific designs), or in prototype phase which are still being evaluated for performance.

Table 19.1: Applications/sub-sectors and refrigerant options

Refrigeration Applications	NH₃	CO₂	H₂O	HCs HC-blend	HCFC-22	H₂O-LiBr (absorption)¹	NH₃-H₂O (absorption)	HFC	HFC-blend	Air
Domestic	None	None	None	Mass-produced	None	None	Mass-produced	Mass-produced	None	None
Commercial.										
- unitary	None	Prototype	None	Mass-produced	Mass-produced	None	None	Mass-produced	Mass-produced	None
- split	Mass-produced	Experimental	None	Custom Application	Mass-produced	None	None	Mass-produced	Mass-produced	None
- secondary loop	Mass-produced	Custom Application/ Prototype ²	None	Mass-produced	None		Mass-produced		Mass-produced	None
Ice, cold storage, and frozen food production, ice rinks, etc.	Mass-produced and custom applications	Custom Application	Prototype	None	Mass-produced	Experimental	Custom Application	None	Mass-produced	Custom Application
Industrial	Mass-produced	Prototype ³	Prototype	Mass-produced	Mass-produced	None	Custom Application	Prototype	Mass-produced	None
MP controlled	No	No	No	No	Yes	No		No	No	No
In Kyoto basket of gases	No	Yes ⁴	No	No	No	No		Yes	Yes	No

Mass-produced: large-scale commercial production at competitive prices

Custom Application: small-scale, made-to-order or fabricated on site

Prototype: pre-production model sold or otherwise placed in service for final testing and design adjusted

Experimental: equipment intended for laboratory or field testing of engineering concepts or design features but not expected to be produced in its current form

¹ Li-Br is used as the absorber for water as a refrigerant.

² 40 supermarkets in Sweden and 2 in supermarkets in Switzerland

³ 2 installations in Europe

⁴ The quantity of carbon dioxide refrigerant is inconsequential to national obligations under the FCCC and its Kyoto Protocol.

A/C Applications	NH₃	CO₂	H₂O	HCs HC-blend	HCFC-22	H₂O-LiBr (absorption)	NH₃-H₂O (absorption)	HFC	HFC-blend	Air
Unitary A/C	None	Prototype	None	Custom Application	Mass-produced	Custom Application	None	Mass-produced	Mass-produced	None
Central A/C / chillers	Custom Application	None	Experimental, Prototype, and Custom Application	Custom Application	Mass-produced	None	Mass-produced	Mass-produced	Custom Application	None
Transport	None	Prototype	Prototype	Custom Application	Mass-produced	None	None	Mass-produced	Mass-produced	Mass-produced
Mobile A/C	None	Prototype	None	Prototype	None	None	None	Mass-produced	None	Prototype
Heat pumps heating	Experimental	Prototype	Prototype	Custom Application	Mass-produced	None		Mass-produced	Mass-produced	None
MP controlled	No	No	No	No	Yes	No		No	No	No
In Kyoto basket of gases	No	Yes ⁵	No	No	No	No		Yes	Yes	No

Mass-produced: large-scale commercial production at competitive prices

Custom Application: small-scale, made-to-order or fabricated on site

Prototype: pre-production model sold or otherwise placed in service for final testing and design adjusted

Experimental: equipment intended for laboratory or field testing of engineering concepts or design features but not expected to be produced in its current form

⁵ The quantity of carbon dioxide refrigerant is inconsequential to national obligations under the FCCC and its Kyoto Protocol.

19.5.1 Overview of refrigeration and AC sub-sectors

19.5.1.1 Domestic

Domestic refrigeration covers a wide range of categories: refrigerator only, freezer only (upright or chest), refrigerator-freezer with two compartments. Different technical options are country dependent: automatic ice-makers, no frost systems, water coolers, automatic defrosts. The size of the typical cabinet is also very different. Refrigerators in Asia are typically the smallest (<300 litres), in Europe they are medium sized (300-400 litres), and in Australia, Canada, and the United States they are the largest (400-500 litres). Due to the significant energy consumption (in the range of 2 to 4% of the country power consumption), Minimum Energy Standard Requirements are enforced in Europe, Japan, the United States, and several other countries.

Energy efficiency depends on the global design of the appliance: insulation material properties, insulation thickness, energy efficiency of the compressor, heat exchanger surfaces, control system and the refrigerant of choice. It has been clearly demonstrated that existing European energy efficiency requirements can be achieved with either HFC-134a or HC- 600a.

19.5.1.2 Commercial

Commercial refrigeration includes a wide range of equipment. The refrigeration capacity of centralised systems in supermarkets varies typically from 20 kW to 1000 kW, but for stand-alone equipment small capacities are in the same range as domestic equipment.

Commercial refrigeration is composed of 3 different families of equipment:

- **Stand-alone equipment** where all the components are integrated: wine coolers, beer machines, ice cream machines, all kind of display cases sold as stand-alone equipment. Sometimes they are called plug-in systems or self-contained systems.
- **Condensing units** separated from the cooling (evaporator) equipment, which can be a small cold room, process equipment or a vending machine. A condensing unit is composed of one (or two) compressor(s), a condenser and a receiver and it may be in a remote location or a machinery room.
- **Central systems** where compressors are located in a machinery room. Two systems are typical: direct and indirect systems.
 - * **Direct systems** are widespread and simple. The refrigerant circulates from the machinery room to the sales area, where it evaporates in display cases. Then it returns in gas phase to the suction port of compressors.

- * **Indirect systems** are composed of primary heat exchangers where a heat transfer fluid is cooled down, pumped towards the display cases where it recovers heat and then comes back in the primary heat exchanger.
- **Distributed systems** that are composed of several systems with compression located in the sales area, the heat being removed from condensers by water and the refrigerant charge is reduced by more than 70%.

19.5.1.3 Industrial Refrigeration

Industrial refrigeration covers a wide range of uses and operating conditions within the chemical industry (including petrochemical and pharmaceutical), the oil and gas industry, the metallurgical industry, plastic moulding, large cold stores and various other uses. System capacities span from some 20 kW up to several MW of cooling, while the temperature range goes from below -100°C (approximately -90°C in conventional systems) to above ambient. Some types of small units for special purposes, e.g. ultra low temperature freezers, may also be classified as industrial refrigeration.

All refrigerants are used – with HCFCs and ammonia currently representing the majority of refrigerant volume. Hydrocarbons cover a significant market proportion within sectors handling flammable fluids. Industrial refrigeration systems are normally situated in industrial areas with very limited public access. For this reason toxic or flammable fluids like ammonia and hydrocarbons may be applied with minimal additional costs.

19.5.1.4 Air Conditioning (unitary and centralised)

On a global basis, air-cooled air conditioners and heat pumps ranging in size from 2.0 kW to 420 kW comprise the vast majority of the air conditioning market. Nearly all of these units use HCFC-22 as the working fluid. There has been significant progress made in developing HCFC-22 alternatives for this category of products since 1994.

The results of current research programs and recent new product introductions indicate that two HFC blends R-410A and R-407C are the leading candidates to replace HCFC-22 in these products. Unitary equipment using either R-410A or R-407C is already commercially available in some regions of the world such as the EU. Commercialisation has already begun in Japan and widespread commercial availability of systems using HFC refrigerants in developed countries is very likely to occur between 2000 and 2005. HFC-134a will likely be commercialised in larger capacity (>100 kW) unitary products.

Hydrocarbon refrigerants may also be suitable replacements for HCFC-22 in some categories of products: air-to-water heat pumps and possibly air-to-air systems with very low charge. In addition, R-744 (CO_2) is the focus of significant research activities that might result in the commercialisation of trans-critical cycle products within the next 5-10 years.

A continuously growing number of water chillers for air conditioning, in service around the world, use refrigerants including fluorocarbons (CFCs, HCFCs, HFCs), ammonia and hydrocarbons (HCs). Chillers employing fluorocarbons dominate the installed base and new production due to relatively low initial costs and high energy efficiency. Because the HCFCs and HFCs are relatively similar to the CFCs physically and chemically, they can often replace the CFCs in new and existing chillers with less extensive modifications of chillers and equipment rooms than are required for other replacement refrigerants. However, ammonia and hydrocarbon chillers (and to some extent water) are emerging, particularly in Northern Europe where short cooling seasons and modest summer temperatures make energy efficiency less important than Asian, African, Australian, and North and South American locations.

19.5.1.5 Transport

Transport refrigeration includes refrigeration in ships, railcars, containers, swap bodies and road transport equipment. It also includes refrigeration and air conditioning on merchant ships, and in buses and railcars. In all segments of transport refrigeration, emission rates can be significant, due to the rough operating conditions; therefore containment and maintenance are very important together with system design improvement.

Most systems in ships use HCFC-22, though R-407C and R-404A are options. In the future, R-410A is expected to become the dominant refrigerant in this sector. HFC-134a predominates in new refrigerated containers.

Most current production refrigerated road vehicles use HFC-134a, R-404A, or HCFC-22. Some R-410A units are also available. Hydrocarbon refrigerants and solar and cryogenic systems are being researched.

Bus and railcar air conditioning is moving from HCFC-22 to HFC-134a, and is so far characterised by relatively high leakage rates.

HFCs are the currently preferred option for buses, though there is limited work on alternatives including hydrocarbons, ammonia, air cycle and CO₂. HCFC, HFC and HC retrofits options exist for systems currently in use.

19.5.1.6 Mobile Air Conditioning (MAC)

All new vehicles produced since 1995 have been equipped with HFC-134a air conditioning systems (with the exception of very limited production of CFC-12 systems in China, India and Korea). Thus, HFC-134a is clearly the globally accepted mobile air conditioning refrigerant.

New vehicles are expected to continue to be equipped with HFC-134a air conditioning systems until an alternative is identified, developed, and commercialised that offers an economically viable

environmental advantage with respect to global climate change. Efforts to identify alternatives are underway. Hydrocarbons, HFC-152a, and carbon dioxide are candidates and hydrocarbons and carbon dioxide are the most likely candidates.

MAC could use flammable refrigerants, such as hydrocarbons or HFC-152a, in a secondary loop system. It is expected that cooling performance with a secondary loop system will be comparable to direct expansion HFC-134a systems. Furthermore, preliminary risk analysis of MAC systems with flammable refrigerants and secondary loops show no significant increase in risk for the consumer. However, energy consumption of HC systems with secondary loops is expected to be higher by 10% or more.

Retrofit of existing MAC is almost exclusively with HFC-134a, although HCs are used in rare situations. The United States and most states in Australia have prohibited the use of hydrocarbons to retrofit CFC-12 mobile air conditioners because the equipment is not designed for safe use of flammable gases. Leaks frequently occur during normal operation or during accidents and there are multiple sources of ignition in the engine and passenger compartment and in repair shops.

19.5.1.7 Heating-only Heat Pumps

Heating-only heat pumps are used for space and water heating in residential, commercial/-institutional and industrial buildings.

The vast majority of heating-only heat pumps in buildings are located in Western Europe and most heat pump installations in Japan, USA and Canada are reversible to provide both heating and air-conditioning. Heating-only heat pumps are used for space and water heating in residential, commercial/institutional and industrial buildings. In industry heat pumps are used for heating of process streams, heat recovery and hot water/steam production. They are often an integrated part of industrial processes, such as drying, evaporative concentration and distillation. Virtually all heating-only heat pumps are electric closed-cycle compression type systems.

Refrigerants currently used in heat pumps are CFCs, HCFCs, HFCs, ammonia and HCs. A few prototype systems use water as a refrigerant.

19.5.2 Overview of Long-Term Refrigerant Options

For the long term there are currently only five important refrigerant options for the vapour compression cycle:

- ammonia (NH₃, R-717);
- carbon dioxide (CO₂, R-744);
- hydrocarbons and blends of them (HCs, HC-290, HC-600a, HC-1270 etc.);
- hydrofluorocarbons and blends of them (HFCs, HFC-134a, R-400 series, R-500 series);

- water (H₂O, R-718).

Non-vapour compression options, such as absorption, adsorption, air cycle, and Stirling cycles may use other refrigerants. Thermoelectric cooling does not require refrigerants but is thus far drastically less energy efficient than vapour compression cycles.

19.5.2.1 Ammonia

The lower the molecular weight and the higher the latent heat of evaporation and heat capacity of a refrigerant, the better the energy performance in correctly designed refrigeration systems. Ammonia has the lowest molecular weight of all commercialised refrigerants, a large heat of evaporation, and very good heat transfer properties. Unfortunately ammonia is toxic and flammable. But it has a very distinct odour, which can warn people before the concentration becomes dangerous. Ammonia is also lighter than air, allowing venting to the outside air in locations where adequate dispersion can occur down-wind of the release.

Ammonia, which has long been used for industrial refrigeration plants, is now being used in other applications, such as supermarket refrigeration systems or water chillers for centralised air conditioning systems. The number of systems installed in Denmark has increased from an annual rate of 3-5 new installations in 1990 to over 30 new systems installed annually as of 1997. The energy consumption of ammonia systems with water secondary loops can be up to 10% lower than that of HCFC- or HFC-system using secondary water loops. In other situations, such as supermarket refrigeration, the energy consumption of the indirect ammonia plant with conventional single-phase brines may be up to 10-15% higher than direct expansion HCFC- or HFC-systems using evaporating carbon dioxide for the low temperature. One supermarket in Norway and 3 in Switzerland use melt ice slurry for the chilling range. These indirect ammonia systems have 10% less energy consumption compared to most HCFC- or HFC-direct expansion systems.

Engineers in Germany and Denmark are investigating the use of ammonia in refrigeration systems with small capacity (below 50 kW or 16 tons). Suitable components, materials (ammonia cannot be used with copper and zinc) and component joining methods are being developed. Ammonia is not suitable for very small systems, i.e. household appliances, because the hermetic compressor would have to be so small that energy efficiency would be lower than for HC and HFC alternatives.

It is important to note that ammonia technology differs significantly from HCFC and HFC technology. For example, ammonia is immiscible with mineral oil (like HFCs), it is toxic and flammable, and it cannot be used in contact with copper. Therefore proper training service is required. Also in many countries safety standards and service checks required are more stringent than for HFC plants.

19.5.2.2 Carbon Dioxide

The use of carbon dioxide is currently being revived. In the early 1990s, Lorentzen and Pettersen conducted experimental work on mobile air conditioning applications. Work is also underway on supermarket systems in Sweden, Switzerland and Norway; and on transport refrigeration systems and hot water heat pumps. When used below its critical point (31.8°C) carbon dioxide works just like any other vapour compression refrigerant, with the only difference that it has a much higher specific refrigeration capacity (i.e. 5 times that of ammonia) and much better compression efficiency. If used in hot water heat pumps or air conditioning systems, carbon dioxide cannot be condensed, but will be cooled in a gas cooler on the high-pressure side. This results in a gliding temperature on the refrigerant side, which in the case of a heat pump can be used beneficially, resulting in higher efficiency. In other cases, the energy efficiency of the transcritical CO₂-cycle is normally lower than other refrigerants. Carbon dioxide can also be used as very efficient phase-changing secondary refrigerant. Approximately 40 systems have been installed in Sweden and at least 2 in Switzerland using evaporating carbon dioxide at low temperature. Carbon dioxide is simply pumped through the system evaporating and condensing at the appropriate places. This application gives a constant temperature brine with much higher heat capacity than any known single phase brine.

Carbon dioxide is toxic at concentrations above 10% (100,000 ppm) in air (LC₁₀). In addition, as the concentration of CO₂ or other gases such as HFC increases, oxygen concentrations decline and can cause asphyxiation. Chemical toxicity occurs at about 30% for CO₂. The IDHL (Immediate Dangerous to Health or Life concentration) of carbon dioxide has been set at 4% (40,000 ppm). The IDHL concentration represents the maximum concentration in air to which a healthy worker could be exposed for 30 minutes without suffering permanent or escape-impairing health effects and represents a maximum limit. Normally much lower concentrations are defined for longer exposure, i.e. work environment. Germany, for example, defines the maximum concentration for the work environment (the MAK value based on safe 8 hour exposure) at 5,000 – 9,000 ppm (0.5 – 0.9%). Other countries use similar values.

19.5.2.3 Hydrocarbon Refrigerants

Hydrocarbon refrigeration technology was first marketed in the 1920s before being replaced by CFCs and has only recently been re-commercialised. Hydrocarbon refrigerants are preferred over fluorocarbons by some manufacturers, environmental NGOs, government environmental authorities and many customers due to their negligible GWP, high thermodynamic efficiency, favourable material compatibility and oil solubility. The HC refrigerants currently used are HC-600a, HC-290, HC-1270 and blends of HC-600a/HC-290. These refrigerants are primarily used in domestic and commercial refrigeration appliances. Some uses are in unitary air conditioning, heat pumps, centralised indirect commercial refrigeration equipment, and some large capacity cooling systems in the chemical industry have been using HCs for decades.

Hydrocarbons are flammable and proper safety measures must be used during handling, manufacturing, servicing and disposal of the appliance or equipment. HC-600a, for example has a

lower flammability limit of 1.8% in dry air and requires ventilation and appropriate electrical equipment standards. The flammability introduces incremental product design requirements to reduce explosion risks. This is done by sealing electrical components that may be exposed to leaking refrigerant; and by providing more robust protection of refrigeration system components from mechanical damage, which could result in refrigerant leakage. Hydrocarbon refrigerants have low liquid density, which result in a relatively low refrigerant charge.

Flammability is an important aspect in the consideration of the quantity of charge. The size of HC refrigerant charge allowed depends on specific standards and national regulations.

Domestic refrigerator manufacturers currently use 97.5 – 99.5% pure HC-600a. This high purity provides both high thermodynamic performance and added protection against toxicity of probable impurities such as benzene, a carcinogen and n-hexane, a neurotoxin. In many countries it is illegal to sell hydrocarbons containing benzene and n-hexane.

Domestic refrigerator/freezer manufacturers have narrowed the choice of refrigerant to HFC-134a and HC-600a. Both can provide safe, reliable and energy efficient domestic refrigerators/freezers. The current global market share of HC-600a domestic refrigerators is estimated to be 8%, with great regional differences, e.g. 45% in Europe and 98% in Germany alone, and virtually zero in the United States, Canada, and Japan.

Commercial refrigeration equipment using hydrocarbon refrigerants are in use in some European countries, such as Austria, Denmark, Germany, Sweden and the UK. HC-290, HC-600a, HC-1270 and blends of HC600a/HC-290 are the main refrigerant choices. The hydrocarbons are also used for new non-reversible heat pumps for heating only in Europe and may be used as an emerging viable alternative in low charge residential and commercial systems for replacement of CFCs and HCFCs. In addition, some large capacity cooling systems are built with hydrocarbons. In such applications a secondary loop system is being used due to safety considerations (large quantities of hydrocarbons to be handled). The secondary loop system reduces energy efficiency depending on the choice of secondary fluid. Traditional liquid, single-phase fluids increase energy consumption by 10-15%. The use of phase changing secondary fluids, such as evaporating carbon dioxide or melting ice slurry, may significantly improve energy efficiency of such systems.

While small hydrocarbon air conditioners have been marketed in Europe for several years, these small and medium-sized unitary equipment typically have very low energy efficiency, are not widely available and have captured only a very small part of the market. Consequently, there has been little necessity for servicing and disposal of used equipment. Over time, the actual costs and safety risks of servicing and disposing equipment using “natural refrigerants” will be determined and the economic and environmental performance will be documented.

19.5.2.4 Hydrofluorocarbons (HFCs)

Historically almost all refrigeration equipment used CFCs. After the Montreal Protocol, the common quest was for new high efficiency, low toxicity, stable, non-flammable chemicals. HFCs were the chemicals well suited to satisfy these requirements since chlorine was removed to eliminate the ozone depletion effect. An important feature for any refrigerant is that it be chemically stable to withstand constant use inside the refrigeration equipment for up to 30 years, and sometimes even longer. Unfortunately, the chemical stability of HFCs results in relatively high GWP.

When used as refrigerants HFCs have several advantages, similar to those of CFCs:

- they are non toxic, or of very low toxicity
- several of them are non-flammable
- with the proper system design, good efficiency can be obtained
- they are compatible with many commonly available materials.

Unlike CFCs, they are not miscible with mineral oil and they do not have the self-lubricating effect of the chlorine containing CFCs. Although technically resolved, these aspects make lubrication more challenging.

During the last fifteen years a number of developments have enabled broad commercialisation of HFCs. For example the toxicity of R-134a was thoroughly studied for seven years and has become the new reference for toxicity studies. Tens of refrigerant blends were initially proposed for the replacement of CFCs, then for replacement of HCFCs, in different applications. Because it proved impossible to directly replace a single refrigerant with another, new non-ODP blends have been developed in order to match the thermodynamic properties of the previous CFCs and HCFCs. New blends of HFCs and other low GWP molecules will be proposed in the future in order to maintain safety requirements and improve thermodynamic properties.

It is technically feasible, but currently neither economical, beneficial to the climate, nor acceptable due to safety considerations to phase out HFC refrigerants in air conditioning and commercial and industrial refrigeration. This is because in some applications HFCs provide the highest energy efficiency. Without HFC, phaseout of ODSs would make some products expensive to purchase or operate in developed countries and unaffordable in developing countries. If HFCs were not available, contributions to the Multilateral Fund would need to increase to offset the added cost for new equipment.

19.5.2.5 Water and heat transfer fluids

Water was used in large low-pressure vapour compression systems in the beginning of the 20th century. It is increasingly used in lithium-bromide / water absorption plants for large heat driven air conditioning plants especially in the USA and Japan. It is also used in mechanical vapour compression systems. In South Africa and Denmark (built by Danish, German and Israeli

companies) it is used for ice making in the low temperature stage of large mechanical vapour compression systems.

Since 1995 water has also been used in industrial chillers and industrial heat pumps. Water chiller systems have proven extremely efficient due to the fact that the process water to be cooled or heated is used as refrigerant thus eliminating the use of heat exchangers. Consequently these systems use 30-40% less energy than the best available HFC or ammonia technology. Due to the very low density of the water vapour, centrifugal compressors are usually employed. In Germany, such a compressor was especially designed for an air conditioning chiller with 500 kW capacity and is now commercially available.

Water is also used as a heat transfer fluid, pure or in mix with other substances, in secondary loops, e.g. centralised air conditioning plants or supermarket systems with ammonia or hydrocarbons as primary refrigerant. Especially for supermarket refrigeration systems, water mixed with salts or alcohols is sometimes used to temperatures as low as -40°C . Non-aqueous heat transfer fluids are also used at low temperatures. Great care has to be taken when selecting the appropriate heat transfer fluid in order not to increase the energy consumption of secondary loop systems unnecessarily. Phase-changing materials like evaporating carbon dioxide or melting ice slurry can offer great energy efficiency advantages, but the systems have to be engineered properly.

19.5.2.6 Other options (absorption, air cycle, Stirling etc.)

The two commercially available absorption systems are ammonia/water with ammonia as the refrigerant and water as the absorbent and water lithium-bromide with water as the refrigerant and lithium bromide as the absorbent. Both systems are heat driven. Water lithium-bromide is especially used for large AC chillers, whereas ammonia/water probably is best known for its use in boating, motor homes, cabins, and hotel refrigerators. For chiller applications, gas fired absorption systems show a lower overall efficiency than the very high efficiency of centrifugal chillers. Absorption systems are environmentally efficient when making productive use of rejected heat. Different calculations show that the coefficient-of-performance (COP) has to be higher than 1.4 for absorption systems to be competitive with electrical centrifugal chillers in terms of CO_2 emissions. Absorption systems are generally more expensive than mechanical vapour compression systems and require more space.

Air cycle refrigeration is used in aircraft air conditioning systems, due to its simplicity, its low weight and good reliability. Nonetheless, the efficiency of air cycle equipment at cooling temperatures above -40°C is generally far lower than that of mechanical vapour compression systems. The advantage of air cycles is that air used as a refrigerant has neither a direct ODP nor GWP. Of course, energy use may be so much greater. In high emission applications, like transport refrigeration and air conditioning, the benefit of a zero GWP refrigerant may outweigh the indirect CO_2 emissions resulting from low efficiency. So far, air systems have not proven cost effective in climate protection.

Air conditioning in some 200 German high-speed trains is one example for this. Air cycle refrigeration equipment can be used with higher efficiencies than mechanical vapour compression systems at temperatures below -40°C , which is the case in for example blast freezers.

The Stirling cycle is a gas cycle where expansion and compression creates a flow from hot to cold via a regenerator. The piston is normally connected to a (linear) electric motor, which largely determines the efficiency of the cycle. Cold is produced at one side and heat is removed from another side. The critical part of the refrigeration cycle connected to a Stirling machine is the transport from the cold side to the cold room and heat to the surroundings (when used as a cold producing cycle). The secondary loops connected to the Stirling machine may seriously affect its efficiency. The usual application of the Stirling cycle is for cryogenic purposes where the cold spot on the machine (at a temperature level of 100 K) can be directly used in laboratory equipment.

19.6 Application of Life-Cycle Climate Performance (LCCP) in the Refrigeration and Air Conditioning Sector

LCCP is the total quantity of GWP units emitted to the atmosphere from the time it is installed through disposal at the end of its useful life. The two components of this calculation are a) the direct emissions of the refrigerant and / or insulating foam and b) the indirect emissions from the energy produced to power the system throughout its lifetime. The difference between Total Equivalent Warming Impact (TEWI) and LCCP is that LCCP does not include economic discounting and does include the HFC or other gas emissions that occur from the chemical manufacturing process. Both approaches include direct emissions from the end system, energy used to power the system, and energy used to manufacture the refrigerant gas. Neither method is an absolute measure, but rather a tool for comparing specific options for specific applications.

The Technology Review Panel of the Montreal Protocol (currently called the Technology and Economics Assessment Panel) in its first report to the Parties in 1989, emphasised the importance of preserving energy efficiency in insulating foams and refrigeration when seeking alternatives to ODS.⁴⁸ In its 1991 report, the Technology and Economics Assessment Panel, stated “the selection of technologies...should be made to minimise energy consumption as well as ozone depletion.”⁴⁹ The concept of TEWI was first introduced in 1989, and has been used to evaluate the climate performance of ODS alternatives. The Alternative Fluorocarbon Environmental Acceptability Studies (AFEAS), a consortium of fluorocarbon manufacturers, and the U.S. Department of Energy have used TEWI to assess the relative performance of refrigerant and refrigeration systems since their first report in 1991. The first AFEAS study compared the global warming impacts of then-available CFC alternatives using the 500 year time horizon. The second study added new alternatives and based the assessment on the 100 year time horizon.

⁴⁸ Synthesis Report (UNEP/OzL.Pro.WG.II (I)/4*), 6 December 1989, Page 21 and Report of the Technology Review Panel, June 30, 1989, pages 4-5.

⁴⁹ Synthesis Report (UNEP/OzL.Pro.WG.1/6/3/, 9 December 1991, page 12.

The rationale for changing the time horizon was that continued high release rates of greenhouse gases could affect the rate of climate change in the next several decades, and policy decisions should be based on shorter time horizons. The third study assessed the significant developments in new HFC blends and “natural refrigerants”, and studied the regional differences in the design and use of refrigeration equipment and their impact on TEWI.

The energy efficiency and emissions of refrigeration and air conditioning equipment depends on the choice of refrigerant, the quality of components, the level of maintenance and refrigerant handling procedures. The use of flammable refrigerants typically requires more expensive manufacturing facilities, more safety equipment and features, and greater care in operation and maintenance. In some cases, systems using flammable and toxic refrigerants provide the best LCCP. In other cases equivalent investment in systems using HFCs could result in improved efficiency and better LCCP. The most acceptable climate impact results from an optimum combination of refrigerant, equipment design, quality of components, controls, proper maintenance and proper refrigerant handling. Better energy efficiency can often be achieved at higher cost using additional components cycle modifications, etc.

The direct effect of chemical emissions depends on the GWP of the refrigerant or foam-blowing agent and the quantity emitted. The quantity emitted depends on product engineering, manufacturing practices, and servicing and disposal procedures. The indirect impact of emissions from the generation of energy depends on the technology used for energy production (nuclear, hydraulic, wind, thermal plant, etc), and in the case of thermal plants on the fuel source and combustion and/or generating efficiency.⁵⁰ Thus, the environmental choice depends on the particular situation in the location where the activity will occur. For example, consider the case of two systems; one an indirect system using a natural refrigerant and the other a direct HFC system with 10% greater efficiency than the indirect system. The LCCP of the indirect system used in an area with hydro power could be better than the HFC system used in an area with inefficient coal fired power plants.⁵¹ However, cross-region comparisons are difficult to interpret.

The prevailing industry view is that mandatory worldwide recovery, reclamation, and recycling of HFCs would reduce emissions to very low levels and would provide a better LCCP than would be possible with “natural refrigerants.” On the other hand, the prevailing view of environmental groups is that “natural refrigerants” have not enjoyed equal time or developmental resources as HFCs, and could satisfy a much greater proportion of the world’s refrigeration needs with better environmental performance if intensive engineering efforts were undertaken. It is ironic that environmental organisations are advocating flammable and toxic refrigerants but industry is reluctant to accept the health and safety risks.

⁵⁰The climate impact of electric generation and direct heating depends on the fuels used in particular geographical locations and the changes that will occur in those systems in the years ahead. For example, the climate impact from electricity generation from nuclear, wind, hydroelectric, tidal and photovoltaic is less than the impact from coal, oil, or gas systems.

⁵¹ Analysis of Alternative Technology Options in the Residential Sector, March 1999, Commercial Chemicals Branch, Environment Canada, pages 67-69.

Based on the current state of technology there is no single refrigerant or class of refrigerants that are able to satisfy the wide range of refrigeration needs in the world. It is important that the wide range of refrigerants available continue to be available to meet the wide range of refrigerant applications.

19.6.1 LCCP of Refrigerant Manufacturing

The Life-Cycle Climate Impact of the manufacture of refrigerant fluids includes calculations of energy use, energy embodied in production inputs, and direct emissions of greenhouse gases. Additional energy is used in transporting refrigerant from the production facility to the location where it is used. An example of direct greenhouse gas emissions from refrigerant manufacture is HFC-23 released from the manufacture of HCFC-22. Unintended emissions occur at point sources such as flanges and joints on the production facilities and from losses during the loading and transport of the final product. Some emissions are from intentional process venting to dispose chemicals that are difficult to separate technically and where collection and destruction is not profitable on the facility. Unintended emissions are minimised for economic reasons and all emissions (both unintended and intended) are controlled under national pollution control regulations.

Estimates of the HFC emissions during manufacture are available from producers and in some cases, from local pollution control authorities. Estimates from the three largest global producers of HFC-134a indicate that production losses are approximately 0.2% of the production levels plus a further 0.2-0.3% during loading and transport.

An estimate of the production energy requirements for common refrigerants, HFC-134a, and CFC-12, HCFC-22, ammonia and hydrocarbons, has demonstrated that the implications for climate change are often relatively insignificant in comparison with other stages in the total lifecycle of a finished product (e.g. a refrigeration system or an insulating foam). For example, the CO₂-equivalent of production energy to manufacture HFC-134a, is 6-9 kilograms of CO₂ per kilogram refrigerant compared to the global warming potential of HFC-134a of 1300.⁵² The emissions of HFC-23 from the manufacture of HCFC-22 is more significant but still less important than energy efficiency.

19.7 Developing Country Issues

Developing countries often depend on information from developed countries regarding available technology. This is particularly true in the case of ODS substitutes because the developed country phaseout is virtually complete, and is only now beginning in developing countries. Industry in CEIT and developing countries usually select the most favourable technology that is available at the time of the investment. For example, HFCs are widely used as alternative

⁵² Campbell and McCulloch, *Trans I. Chem E.*, Vol. 76, Part B, August 1998, pp 239-244.

refrigerants in developed countries and a similar trend is occurring in CEIT under the GEF and in developing (Article 5(1)) countries under the Multilateral Fund. According to the November 1998 *Inventory of Approved Projects* under the Multilateral Fund, approximately 70% of refrigeration sector investment projects are based on HFCs. Most of these projects assist manufacturing companies to replace CFC-12 with HFC-134a in the domestic and the commercial refrigeration sector. HFC emissions from these products can be minimised by manufacturing and servicing practices and by recovery and reuse or disposal at the time of product disposal.

Although there is strong interest among Article 5(1) and some developed countries, it is not yet clear what equipment can be safely retrofitted to use flammable or toxic refrigerants such as ammonia. Safe use of flammable or toxic refrigerants depends on equipment design, manufacturing safety, clear labelling, and the availability of trained technicians with proper tools and working environments. Projects demonstrating retrofit of CFC refrigeration equipment to hydrocarbons are underway in several developing countries under the sponsorship of organisations from developed countries where such retrofit has not substantially occurred, e.g., Australia. UNEP TIE has published a book, "*Study Potential for Hydrocarbon Replacements in Existing Domestic and Small Commercial Refrigeration Appliances*," that provides a good overview of the safety and performance concerns and the current global experience.

19.8 Concluding Remarks for R and A/C

Future systems must satisfy the Montreal Protocol and have a high LCCP in order to be successful long-term solutions. In addition to low GWP refrigerants, future systems will be characterised by very low emissions, since reduced emissions will favour the use of a variety of refrigerants, including HFCs and other non-ODP solutions. HFC-134a and other HFCs have become well-established solutions for many refrigerant applications.

Hydrocarbons are expected to dominate domestic and small plug-in commercial systems in some regions. Carbon dioxide may have a future where flammability is a problem (e.g. direct exchange supermarket systems). Ammonia is being used in new applications such as water chillers and commercial refrigeration systems in Northern Europe. Secondary loop systems with more efficient heat transfer fluids may be used not only with ammonia and hydrocarbons, but also with HFCs in order to minimise the primary charge. Distributed systems will be used more widely with HFC systems in order to reduce emissions, reduce the primary charge and minimise energy consumption.

At the time the Montreal Protocol developed its phaseout strategy, it was not technically or economically possible to contain CFC and HCFC emissions and little effort was made to recover and recycle. Furthermore, it was believed that zero-ODP refrigerants and insulation foam blowing agents would provide equal or better energy efficiency. At a future date, Parties to the Montreal and Kyoto Protocols may wish to revisit the HCFC phaseout decision mindful of the condition of the ozone layer and the need to protect the climate. At that time, a technical assessment could present the relative environmental performance of all available options.

20 HALON SECTOR TECHNOLOGY

20.1 Use Patterns

Halon production was phased out in non-Article 5(1)-countries in 1994 based on three main assumptions:

- the existing halon inventory (also called the halon bank) can be used for critical applications for which there are no alternatives
- not-in-kind fire protection technologies (both existing and newly developed) are readily available for most halon applications
- new fluorinated gases (HFCs and PFCs) are available as replacements for applications where not-in-kind alternatives are not technically feasible.

Over the last few years a clearer picture has emerged about the new fire protection strategies used to phase out halon.

20.1.1 Portable extinguishers

Halon 1211 in portable extinguishers is being replaced almost entirely by other extinguishants (e.g. water, foam, dry chemical and carbon dioxide). Only a few specialised applications require HFCs, such as passenger cabins of aircraft. PFCs are not required for portable extinguishers.

20.1.2 Fixed systems

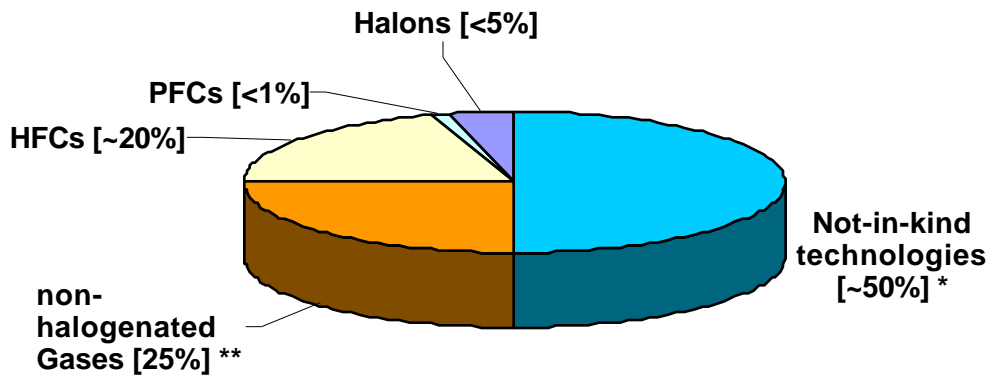
For fixed fire extinguishing systems where halon 1301 would have been used,

- approximately 50% use on not-in-kind alternatives. These include water mist, portables, dry chemical, sprinkler and improved detection and alarm systems without active suppression,
- approximately 25% use non-halogenated gases, e.g., carbon dioxide or inert gases. The market for these systems is limited by their higher cost, greater space/weight requirements, and longer discharge time.
- approximately 20% use fluorocarbons. HFCs (HFC-23, HFC-125, HFC-227ea, and HFC-236fa) represent the majority of the gases, and PFCs (FC-2-1-8, FC3-1-10) account for less than 1%. Fluorocarbon-systems cost significantly more than the halon systems they replace.

For a small number of critical applications (< 5%), halon remains the only technically feasible option. These critical uses include civil and military aircraft, military vehicles, oil production facilities, and other specialised, high-risk situations. The critical use of halons in military is further discussed in the military section.

Forced early decommissioning of existing halon systems will likely result in a greater use of HFCs in situations where a different fire protection solution would have been chosen. This in turn could yield a greater installed base of HFCs and result in accelerated growth in the use of HFC in the future.

Figure 20.1: Distribution of fire protection alternatives in new applications



*) "Not-in-kind" technologies consist of water mist, sprinklers, foam, dry powder or improved-detection systems

***) "non-halogenated gases are CO₂ or inert gas mixtures

20.2 Selection of an Alternative Fire Protection System

There are a number of technical issues that determine the most appropriate solution to a fire protection situation.

- First is the adequacy of a system to counter the fire threat. System considerations include design concentration, adequate storage space and weight, discharge time, and ventilation requirements, among others.
- The second consideration is whether the space to be protected is occupied or not. The toxicity of the agent and design concentration necessary to extinguish the fire threat determine whether a specific agent and system design can be used safely. If the LOAEL (lowest observable adverse effect level) approaches the concentration necessary to extinguish the fire, the system is inappropriate for occupied spaces. This is not as significant an issue for unoccupied spaces.

- The third consideration is the environmental impact of the system. These include ozone depletion potential, global warming potential, atmospheric lifetime and ultimate environmental fate of the agent.

Other considerations that influence the final system selection include availability of hardware and support, economics, and acceptance by insurance carriers and authorities having jurisdiction.

Despite the wide variety of new alternatives available and the significant effort being expended to develop new alternatives, there remain a small number of critical applications for which halons are the only technically feasible solution. The bulk of these applications are in aviation, marine, oil and gas production, and the military. Recycled halons are used to satisfy these applications.

20.3 Contribution to the Basket of Gases to be Controlled under the Kyoto Protocol

Fire fighting applications represent a very small share of the total production and consumption of HFCs and PFCs (less than 2%). Conservation techniques introduced to reduce halon emissions following passage of the Montreal Protocol have become standard industry practice for all halocarbon systems in many places. These practices include improved maintenance and service procedures, non-emissive testing and training procedures, recovery and recycling, among others. As a result, halocarbon emissions have declined from 25% of installed base before the Montreal Protocol to around 4-6% today. As HFCs unlike halons can easily be chemically transformed it is possible to establish a reclamation program to gather and re-use the chemical once it is no longer used for fire fighting.

Despite the relatively high cost of fluorocarbon based systems, their market growth appears to be very strong in some Article 5(1) countries and CEITs. This may be due to intense marketing efforts that have resulted in fluorocarbons being used in applications for which other alternatives with lower environmental impact are more appropriate. Awareness campaigns involving fire protection experts and users of fire protection equipment could to help restrict the use of HFCs to those few applications where their use is necessary.

21 SOLVENT SECTOR TECHNOLOGY

21.1 Replacement of CFC-113 and 1,1,1 Trichloroethane in non-Article 5(1) Countries

CFC-113 and 1,1,1 Trichloroethane uses have been primarily replaced in non-Article 5(1) countries by three alternative technologies. They are:

- No Clean
- Aqueous or Semi-Aqueous cleaning
- Organic Solvents

It is estimated that 90% of these ODS solvent uses (136,080 metric tonnes CFC-113 and 706,700 metric tonnes of 1,1,1 TCA in 1989) have been eliminated by No Clean, Aqueous or Semi-aqueous not-in-kind alternative technologies. The organic solvent option captures about 10% of the original solvent market and consists of several types of solvents:

- Chlorocarbons/Hydrocarbons/Alcohols
- PFCs
- HCFCs
- Brominated Solvents
- HFCs
- HFEs

21.2 Replacement of CFC-113 and 1,1,1 Trichloroethane in Article 5(1) Countries

Most of the solvents sector projects approved by the Multilateral Fund for the replacement of CFC-113 and 1,1,1, TCA used not-in-kind technologies such as aqueous, semi-aqueous and hydrocarbons. However, a small number of projects were approved using HCFC-141b and HCFC-225 (ca and cb). To date no projects based on HFCs or HFEs have been approved.

21.3 Chlorocarbon, Hydrocarbon, and Alcohol Solvents

Chlorocarbons and hydrocarbons are primarily used for metal and general cleaning requiring good solvency. Alcohols and hydrocarbons are used for electronics cleaning.

21.4 Perfluorocarbon Solvents

Perfluorocarbons (PFCs) such as C_5F_{12} , C_6F_{14} , C_7F_{16} and C_8F_{18} were introduced as substitutes for ODS in early 1990s, and are also used in some applications where ODS solvents were never used. PFCs are used as a carrier fluid for fluorolubricants for computer hard disk drives; as a flush fluid for particulate removal in precision cleaning; as a coolant in other electronic components; and as a rinsing agent in a co-solvent process for cleaning printed circuit boards and mechanical components containing oil, grease and other soils.

Perfluorocarbon solvents production is estimated to be around 3000-4000 metric tonnes consisting of 2500 tonnes for C_6F_{14} and 500-1000 metric tonnes for other PFCs. PFCs are being replaced in many of these applications by HFCs and HFEs.

21.5 HCFC Solvents

HCFCs are serving some limited and unique applications where other suitable alternatives have not been identified, including:

- Cleaning delicate materials such as cultural heritage and archival property
- Cleaning assemblies or components with sensitive materials or particular soils
- Cleaning certain oxygen systems
- Cleaning where explosive or flammable conditions are possible
- Serving as a carrier of oil in precision applications

HCFCs are used in precision and electronic cleaning where compatibility of the solvent with the substrate to be cleaned is critical. The two HCFCs currently used in this application are HCFC-225 ca/cb and HCFC-141b. Use of HCFC-141b is already restricted and may be phased out in most developed countries by 2004. All HCFCs, including HCFC-225, are subject to additional reductions in production and consumption with a phaseout in non-Article 5(1) countries in 2020 (except refrigerant uses in 2030). Article 5(1) countries phase out in 2040.

The Solvent Technical Options Committee estimates that HCFC-141b and HCFC-225 uses as solvents are about 14000-16000 metric tonnes in 1998. Both HCFCs are considered as transitional substitutes for ODSs.

21.6 Brominated Solvents

Some manufacturers and suppliers are marketing two brominated solvents—chlorobromomethane (CBM) and n-propyl bromide (nPB)—as replacements for CFC-113, 1,1,1, TCA, chlorocarbons and the HCFCs (HCFC-141b and HCFC-225). The ozone depletion potential of CBM is 0.12. nPB has an ODP of .026 calculated using a 2D model. However, because nPB has a very short atmospheric life of only 11 days, the ODP will depend on where it is emitted and the time of the year. It will take 1-2 years to develop a 3D model to more reliably estimate the ODP of short-lived compounds.

Both CBM and nPB have relatively high toxicity. CBM has unacceptably high ODP and toxicity, and the U.S. EPA has not approved its use as a solvent under the SNAP regulation. nPB is heavily promoted as a substitute for 1,1,1, TCA and chlorocarbons in both the developed and Article 5(1) countries despite the ODP and full toxicity information not yet being available. The United States EPA, under the SNAP regulation, has not approved nPB as a substitute for ozone depleting substances pending the availability of ODP and toxicity data. However, its use in the rest of the world is rapidly increasing and could reach several thousand tonnes per annum.

21.7 HFC Solvents

In mid 1990s, an HFC (HFC-43-10mee, C₅F₁₀H₂) was introduced to replace CFC-113 and PFCs in many applications. It has better solvent properties than PFCs and has desirable environmental properties such as zero ozone depletion potential and very short atmospheric life compared to PFCs and CFC-113. HFC 43-10mee and several new compositions with some additives such as alcohol, hydro- chlorocarbons and hydrocarbons in azeotropic proportions were introduced to

meet critical cleaning needs to replace CFC-113 in electronics defluxing, ionic impurities removal and precision cleaning applications.

HFC-43-10mee is used as a solvent, mostly for electronic contact cleaners. HFCs and PFCs are also used to dry electronics and precision parts after aqueous cleaning and in some circumstances may have a lower climate effect than thermal drying.⁵³

HFC-43-10mee has also replaced some uses of PFC and CFC-113 as a carrier fluid for lubricant applied to computer hard disks, in some precision bearing lubrication applications, for displacement drying of minute electronic and optical components, and as a flush fluid for removal of particulate in precision cleaning.

The Police Scientific Development Branch of Scotland Yard (UK) has tested and qualified HFC-43-10 as an acceptable solvent alternatives to CFC-113 for dissolving Ninhydrin reagent for developing latent fingerprints off porous material (such as paper). In addition, federal and some state forensic laboratories in the United States and prefecture authorities in Japan have also qualified HFC-43-10 for these uses. Forensic uses of CFC solvents are currently allowed under terms of the global laboratory and analytical essential use exemption.

HFC-43-10mee has also replaced CFC-113 in a rain water repellent formulation for the aircraft windshield.

Although the HFC solvent is used in many applications, the total use in solvents and coatings is very small and estimated to be less than 1000-2000 tonnes, which equals to less than 1% of CFC-113 uses in 1989.

21.8 HFE Solvents

A family of fluorinated ethers (HFEs)⁵⁴ was also developed during the mid-1990s as replacements for CFC and PFC solvents. HFEs have successfully replaced PFCs, HFCs, CFC-113, 1,1,1-trichloroethane and HCFCs in certain precision cleaning operations as well as in industrial aerosol solvent formulations.

21.9 HFEs as Replacements to PFCs and ODSs

There are two commercially available HFEs that have not yet been included in the Kyoto Protocol.⁵⁵ These HFEs and the various azeotropic formulations are the newest substitutes and are used in critical cleaning applications where compatibility with substrate to be cleaned is critical. HFE are also being utilised as replacements for some of the HCFC-141b and HCFC-225

⁵³ Precision Cleaning, June 1999.

⁵⁴ See definition of segregated ether in Appendix B.

⁵⁵ GWP of HFEs had not been reported in the scientific literature at the time the IPCC SAR report was prepared.

solvents scheduled for phaseout. These HFEs have no ozone depletion potential, low toxicity, are non-flammable, and they have exempted from the U.S. EPA definition of VOC. The GWP of commercially available HFE-7100 and HFE-7200 are 390 and 55, respectively. HFC-43-10mee has a GWP of 1300, a factor of 4 to 30 times higher. However, these HFEs will not always be substitutes for HFC-43-10mee due to application-specific requirements.

HFEs are also being considered as a replacement for extremely high global warming PFCs in many applications such as computer disk lubrication, and particulate cleaning.

21.10 Containment Technology for Fluorosolvents

Because HFEs and HFCs are expensive to manufacture, the cost and sale price of these alternatives are going to be quite high compared to the CFC-113 and HCFC-141b they are replacing. This high cost has resulted in significant improvement in the containment technology of the new degreaser, defluxers, and dryers. Most cleaning machines using HFC and HFE have been retrofitted with higher free-board and a low temperature secondary cooling coils. Also, in some cases other improvement have been made to reduce drag-out losses. The result of these containment technologies has reduced the losses of solvent from these systems to a very low level. In cases where HFCs, PFCs or HFEs are essential solvents, it is possible to reduce emissions to a minimal fraction of the volume required by implementing good handling practices.

If the health, safety, and performance requirements of a fluorochemical are necessary for an end-use application, the end-user should select the fluorochemical with the smaller climate impact that satisfies the application requirements.

21.11 VOC Regulations

Commercially, HFCs and HFEs (HFC-43-10 and HFE-7100 and HFE-7200) are considered negligibly photo-chemically reactive in the lower atmosphere; hence, the United States EPA exempts them from VOC regulations. However, the VOC regulations in European Common Market are different from that of the USA. The EU defines an organic substance as VOC if it has vapour pressure of 0.01 kPa at 293 Kelvin (20.0C) (equal to .075 mmHg at 20.0C).⁵⁶ Under the EU definition, most organic liquids are VOCs and must comply with the directives.

21.12 Options for limiting emissions of greenhouse gases

21.12.1 Not-in-kind Alternatives

The greenhouse gases – CFCs, PFCs and HFCs – can be replaced in many applications with not-in-kind alternatives by either modifying the process or cleaning requirements without compromising safety, performance or compatibility. These new technologies should be evaluated as they become available.

⁵⁶ Council Directive 1999/13/EC dated 11th March 1999.

21.12.2 Containment and Emission Reduction

There are several emission reduction options:

- Recovery and recycle
- Abatement Technology
- Airless degreaser
- Upgrading of the old degreasers for better containment

21.12.3 Alternative Fluorinated Solvents

PFCs are being replaced in some applications by lower GWP solvents such as HFCs and HFEs. Research continues to develop new low GWP solvents to replace PFC. New HFEs are now being developed with boiling points necessary to replace PFCs in additional applications.

21.13 Emission Scenario over the next 10-20 years

It is expected that PFCs will be replaced in most applications by the lower GWP HFC and HFE alternatives over the next 10 years. In some cases, lower GWP alternative may replace HFCs. Growth of this market is not anticipated to be high due to high cost of these alternatives and selective solvency.

22 FOAM SECTOR

There is little current use of HFCs as blowing agent in the foam sector. Future use will be limited primarily⁵⁷ to those applications where CFCs and HCFCs are currently used, particularly closed cell thermal insulation foams.

22.1 Energy Efficiency, Carbon Dioxide Emission and the Role of Insulating Foams

Insulation materials save energy and reduce CO₂ emissions. Thermal insulation uses extend to buildings, building services, industrial and food preservation sectors (including domestic appliances). In 1995, the building sector accounted for approximately 34% of global energy consumption, equating to 31% of global CO₂ emissions. To put the importance of energy efficiency in the buildings sector in context, an average increase in global energy efficiency of 1% in buildings would reduce CO₂ emissions by 50-80 Mtonnes annually. A typical building energy efficiency audit identifies energy savings opportunities of around 25-35%. The role of thermal insulation in such improvements depends to a great degree on the design of the building and the application. Not-in-kind (non-foam) insulation materials such as mineral fibre have a major part to play in the saving of energy but the additional efficiency arising from the use of foams may, in

⁵⁷ Switching to HFCs from non- ODS blowing agents will only occur where pressing energy efficiency or safety standards need to be met.

some cases, enable higher energy efficiency standards to be reached than would otherwise have been possible. As a consequence, insulating foams already account for at least 30% of the overall global insulation market despite their higher cost per unit volume. This percentage is expected to grow with increasing demand for energy efficiency.

Insulation foams are also integral to domestic refrigerators and freezers. Since these appliances typically account for 30% of household electricity usage, they are the focus of increasingly stringent energy efficiency requirements. The insulation performance of the foam therefore continues to be a critical factor in appliance design. In some areas there is increasing interest in the use of vacuum insulation panels for the same reason.

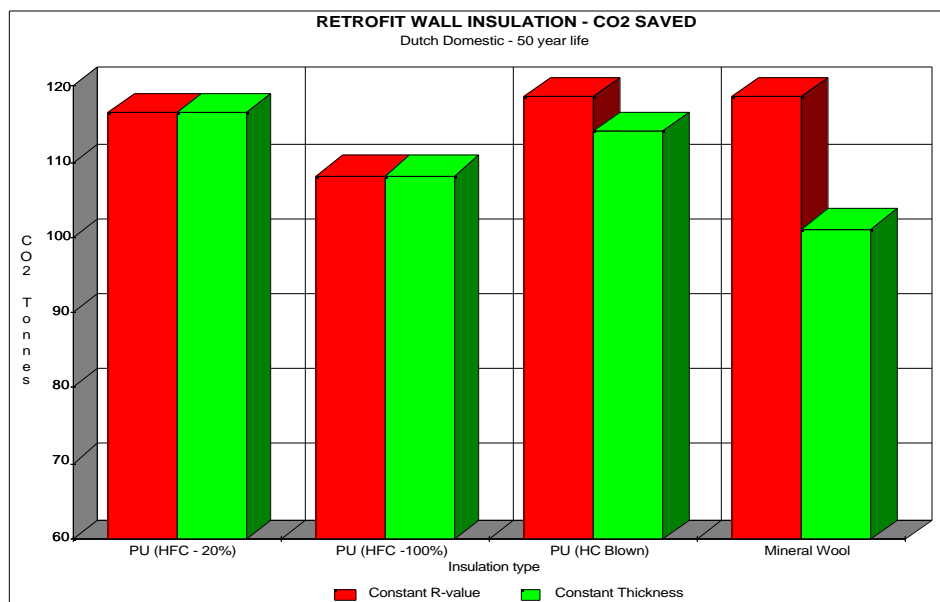
The energy efficiency of foam is influenced by the choice of blowing agent, and HFCs currently produce the most efficient foams. Efficiencies also vary depending on product type and application. Energy efficiency considerations will promote the use of HFCs in some applications. However, approximately 15-20% of all insulating foams in the polyurethane (PU) sector are currently based on hydrocarbon blowing agents despite the widespread availability of HCFCs. In some regions this has been driven more by regulatory pressure than by technical imperatives. It is possible that this hydrocarbon use will grow further proportionately as HCFCs are phased-out. However, the relative cost effectiveness of HFC and hydrocarbon options is still unclear, particularly in the appliance sector where energy standards are increasing globally and other energy efficiency measures are often less competitive.

22.2 Energy Efficiency and Blowing Agent Selection

The cost-effectiveness of insulation solutions is a key factor which will dictate their importance in CO₂ emission reductions (see Appendix C). The methodology for assessing cost effectiveness substantially affects the outcome and there is a critical need to move from traditional pay-back costing methodologies to lifetime based assessments. Given their inherent higher thermal efficiency, HFC blown foams could play a significant role in optimising CO₂ emission reduction. In addition to consideration of cost effectiveness, use of HFCs in thermal insulation foams may be preferred solely on the basis of climate protection. A typical example would be those applications where the thickness of insulation is constrained by the space available. Figure 22.1 shows the comparative CO₂ saving of different insulation options when used as domestic wall insulation in a Dutch dwelling. This evaluation takes into account the following characteristics:

- CO₂ emissions avoided from life-time energy savings
- potential direct impact of HFC emissions (with allowance for containment)
- energy required to manufacture the insulation material (embodied energy)

Figure 22.1



Where thickness is constrained, use of HFC blown polyurethane (PU) foam is preferred where emissions can be limited to 20%. If emissions cannot be controlled, hydrocarbon blown PU foam would be the preferred option. Where there are no thickness constraints, both hydrocarbon blown PU foam and mineral wool would have a lower climate impact. The choice would then depend on the physical requirements of the insulation and the comparative costs. As indicated in Figure 22.1 the direct impact on the net CO₂ saved is around 5-6%. This is quite typical for many thermal insulation applications and reflects the relative importance of thermal performance over other factors. Embodied energy has even less of an effect and is typically less than 1%. Figure 22.2 illustrates the fact that to justify HFC use on environmental grounds, the reduction in CO₂ emission provided by the additional HFC thermal efficiency must exceed the direct impact and embodied energy of the HFC.

Product ageing is another factor in the lifetime thermal performance of foam. There is limited data for HC and HFC-blown foams but the ageing phenomenon needs to be considered carefully in order to make optimal choices of insulation. Recent published studies suggest that HFC blown foams may have some advantages in this area⁵⁸.

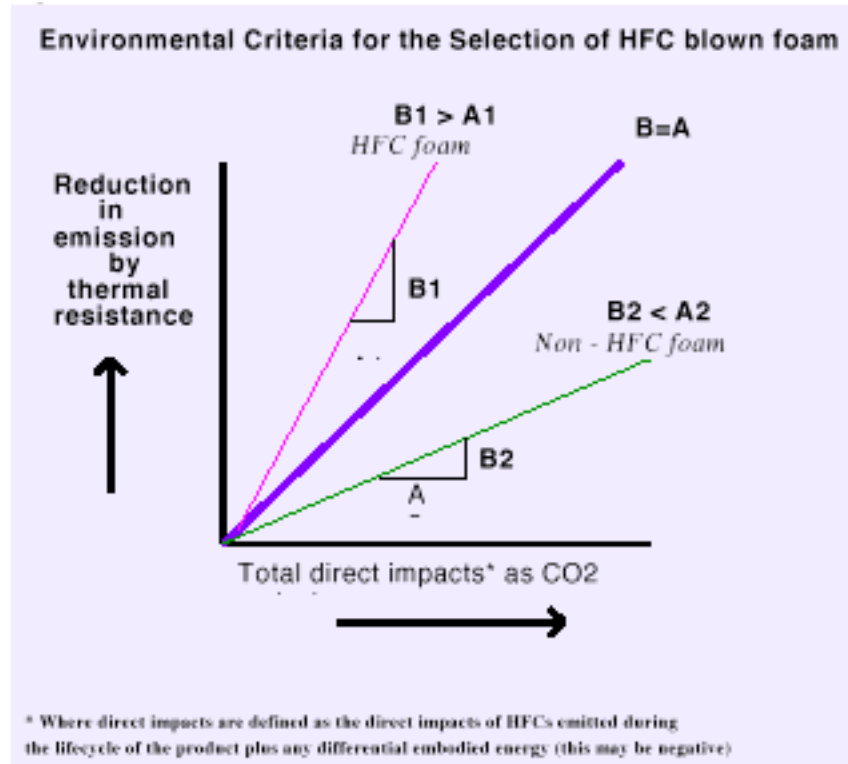
Parties may wish to consider the benefits of regulatory incentives to promote use of the most efficient insulation options or standards establishing minimum acceptable levels.

The growth of insulation markets at 5-7% globally over the decade is predicted to continue over the next ten years. Much of the future growth is expected to be in non-HFC based foams. Currently approximately 15-20% of all PU foams produced globally are based on hydrocarbon

⁵⁸ Association of Home Appliance Manufacturers (AHAM) reference

blowing agents. For reasons described above, HCFC replacement with HFCs is likely to be on less than a 1:1 basis. New emerging insulation technologies are also expected to begin to replace some portion of HFC-blown foams in the period from 2015-2020.

Figure 22.2



In summary, the economic and/or environmental justification for HFC foam on energy efficiency grounds will depend on the:

- application fulfilled by the insulation solutions
- difference in the thermal resistance of the alternative insulants
- relative cost of HFC blown foams versus alternatives (including the cost of HFCs as well as the costs of changes in foam density and thickness)
- carbon intensity of energy in the region
- direct impact of the HFC (a combination of GWP and quantity used)
- difference in embodied energies of the alternative insulation materials (including the embodied energy of additional support materials which may be needed for thicker and/or heavier alternatives)
- methods which may be used to control emissions

The selection process is not simple but illustrates why there is no single preferred blowing agent to replace CFCs in thermal insulating foams.

22.3 Other Issues in Blowing Agent Selection

22.3.1 Product Performance

22.3.1.1 Safety

Product safety in the foam sector depends on the application and regional circumstances. The impact of the choice of blowing agent on the safety of a product is therefore even more difficult to define.

Safety considerations include:

- Fire, smoke and the toxicity of fire products
- Explosion risk (especially with polyethylene foam during distribution)
- Human health effects caused by the form or composition of the insulation material during manufacture, installation, use or disposal.

The most common technical justification for use of HFCs is based on problems associated with using flammable blowing agents and the flammability of those products that are currently used in fire sensitive applications. An example would be the case of polyisocyanurate (PIR) and phenolic foams. This matter is dealt with further under the Regulation section.

There are also concerns about using hydrocarbons in polyethylene foam insulation, where changes in foam storage and distribution practices have been introduced to avoid explosions. Several incidents have occurred when concentrations of blowing agent have accumulated in enclosed areas such as transport vehicles (particularly in North America where rigid sided vehicles are used). An additional consequence of these changes has been a reduction in the maximum thickness of insulation board achievable because of the need to ensure that cell gases have fully equilibrated.

22.3.1.2 Physical Properties

Blowing agent selection has been found to influence the cell structure and hence physical properties of foams. In some instances, the solubility of the blowing agent in the matrix has been a particular problem whilst in others the partial pressure of gases within the cells have also contributed. In most cases, technologies have been optimised to minimise these impacts and the likelihood of such issues affecting the uptake on HFCs in the polyurethane sector is low with the exception of some flexible integral skin formulations for transport safety applications where surface finish criteria are critical.

22.3.2 Manufacturing

22.3.2.1 Safety & Cost

The use of hydrocarbons and other flammable materials as blowing agents has created the need to reassess most foam blowing manufacturing processes. Highly robust, but in many cases costly, engineering solutions have resulted in the introduction of hydrocarbon polyurethane and

packaging foams in most regions outside North America. The Multilateral Fund provided added assistance for HC projects in Article 5(1) countries. However, concern still exists over the safety of some thermoplastic packaging foam installations in developing countries following the loss of several plants through fire.

Other areas of concern exist where foams are applied in non-factory environments. In particular, hydrocarbon blown polyurethane spray foams may pose a problem, particularly where they are applied in poorly ventilated areas. Some applications will almost certainly require HFCs as a major part of their HCFC replacement strategy.

In general, discontinuous processes have been harder to re-engineer than continuous processes. SME producers are more likely to be engaged in discontinuous processes and have not been able to justify the cost conversion to hydrocarbon. They have therefore selected HCFCs as their alternative. This situation will persist during the phaseout of HCFCs, and HFCs will remain an important part in future solutions.

HCFCs are often selected under the MLF on projects for SMEs. These projects select HCFCs because conversion costs to hydrocarbons cannot be justified under current investment rules. This situation is, however, currently under review by the TEAP Replenishment Task Force. Use of HFCs would allow a continuing move away from CFCs and HCFCs if hydrocarbon investments cannot be justified.

Cost and local air quality requirements are a critical part of the decision process for North American appliance manufacturers. Local regulatory demands restricting VOC emissions can result in investment costs that are substantially higher than those experienced in Western Europe. The proportion of these costs associated with VOC abatement vary widely but the costs of process safety are usually higher than environmental compliance.

22.3.3 Regulation and Other Regional Factors

Regional or country variations can include cultural, political factors or reflect how markets have developed and how products are used. Several situations exist globally in selecting blowing agent options, and the most relevant are described below:

22.3.3.1 Volatile Organic Compounds

Use of hydrocarbons has been inhibited in some regions by the need to limit emissions of VOCs. This is particularly the case in North America and has significantly influenced US appliance manufacturers. Where hydrocarbons are used in sensitive areas (for example for polyethylene foam in Switzerland), the cost of installing emission control equipment has been substantial and new technology has been necessary. The forthcoming EU legislation may also result in costly abatement measures.

As noted previously, the domestic appliance sector is already being impacted by stringent energy efficiency regulations in some regions of the world. The European producers have achieved current energy efficiency targets using hydrocarbons as both blowing agents and refrigerants while the North American producers have used HCFCs and, after them, HFCs to meet their more stringent energy standards. Use of HFCs may be a cost-effective way for hydrocarbon users to meet any future increased efficiency requirements and thereby avoid future VOC concerns.

22.3.3.2 Health & Safety

The control of health and safety matters within factories is the domain of local government and flammable blowing agents are not universally acceptable. In a recent instance, a foam plant in Latin America where a Multilateral Fund hydrocarbon project was prevented from being completed because of local fire regulations. There are several other such instances.

22.3.3.3 Product Flammability Standards

While fire and flammability are a concern to all users of foam products globally, it is particularly so in Japan. The country is very densely populated, with concentrations around major cities in which industry is inter-mixed with residential areas. Fire performance along with residential and commercial building codes is therefore highly regulated. Accordingly, hydrocarbons (or other highly flammable blowing agents) are not likely to find ready acceptance in this society.

In Western Europe, European Union and national governments and major insurance companies are increasing requirements for the flammability performance of buildings. The harmonised test methods and classifications developed as part of the Construction Products Directive (89/106/EEC) in the European Union will enter into force in 2000 and will run in parallel with the existing national regulations for five years. The new test methods are more demanding for several categories of cellular plastics. Insurance losses are increasing as the result of several recent fires. For example, there have been fires in food processing applications involving panels with foamed plastic cores. New, very stringent, standards are being set such as the UK Loss Prevention Council test LPC 1181.

In the USA, there are additional concerns over product liability resulting from the use of flammable blowing agents because of the litigious nature of the society.

22.3.3.4 Regional Extruded Polystyrene Density Requirements

Development work is underway on the technical and economic feasibility of using CO₂ as a blowing agent. There has been some success in Europe but it is not yet possible to meet the technical needs of the North American market at this time. CO₂ technology requires that the foam be of higher density to meet minimum product property requirements. There is therefore a technical barrier to producing the North American product mix, which on average is about 20% lower in density. Step-change improvements are required to overcome this barrier.

22.3.3.5 Chemical Supply

For the foam industry there are several supply issues which are particularly severe for developing countries.

There is uncertainty about the supply of HCFC 141b in the medium term as the demand for this product disappears in the major developed country markets due to legislative phaseout in 2003/2004. All full-scale production units are currently in the USA, Japan or Europe with minor but growing production in China. This may require more rapid implementation of alternatives than is currently envisaged.

The commercial production of the two “liquid” blowing agents, HFC 245fa and HFC 365mfc, is not expected before 2002 and, at best, they will be available just before the phaseout of HCFC 141b in the major developed countries and the EU. Based on current market predictions, there is unlikely to be more than one or two manufacturers of either product and these will be in developed countries.

HFC-134a is currently readily available for foam applications. Recent tightness in the market has stimulated further investment and supply/demand is likely to drive future capacity. The volumes for foam, now or in the future, are likely to be significantly less than for refrigeration and mobile air conditioning applications unless “liquid” HFCs are not commercialised.

22.4 SME and Developing Country Issues

For SMEs in both developed and developing countries the costs of conversion are very significant. The costs include the capital costs of replacing manufacturing equipment, the need for trials and re-qualification of the end product, the training of staff, the production downtime and the changes in operating costs.

These considerations have driven the search for a mythical “drop-in” replacement for CFCs. For polyurethane rigid foams HCFC-141b has become the nearest to meeting this goal although its higher unit cost and technical features have often entailed some conversion costs. Another such technology uses pre-blended HFC-134a, although it has some performance deficiencies compared to CFC- 11.

Many manufacturers would choose a hydrocarbon route since this offers a “permanent” replacement strategy without the penalty of a further technology change when HCFCs are phased out – provided that VOC regulations do not become prohibitively stringent and provided that the insulation value is adequate. However, the investment cost is high for small enterprises and for those operating discontinuous processes. This is unfortunate since there is the possibility of reduced operating costs.

These considerations apply to producers in both developed and developing countries. A guide to economic levels of CFC 11 replacement is provided by the thresholds developed in the

Multilateral Fund process of the Montreal Protocol for Article 5(1) countries. This data has been built up from the data of several years and is shown in the table.

22.4.1 Multilateral Fund Thresholds for CFC Replacement in Rigid Polyurethane Foams

APPLICATION	THRESHOLD (\$/KG ODP/YEAR)
Rigid Foam (general)	7.83
Domestic Refrigeration	13.76
Commercial Refrigeration	15.21

The data collected by refrigeration sectors applies to the replacement of CFCs in both the foam insulation and in the cooling circuits. Taking the general rigid foam threshold the maximum grant for a medium-sized enterprise using 50 tonnes per year of CFC 11 (about 500 tonnes of foam) would be \$392,000 which is near the borderline for hydrocarbon technology (estimated to be \$400,000). For a smaller enterprise using 20 tonnes per year of CFC 11 (about 200 tonnes of foam) the maximum grant is \$157,000 which is far below the minimum investment required for hydrocarbon technology. Many of the smaller enterprises must bear a part of the costs themselves.

These cost considerations must be taken into account when considering realistic CFC phaseout options. The cost implications are even broader than these. In developing countries there has been a considerable price difference between the replacements and CFC 11. However, prices are now increasing as the freeze comes into effect.

22.5 Summary of Potential Uses and Projected Amounts of Use

The TEAP Task Force has assessed the case for HFC use in each sector of the foam industry originally covered under the Montreal Protocol (i.e. as original CFC use) and has estimated future HFC use. This table is categorised as follows:

- Category 1 No HFC use of significance expected
- Category 2 HFCs unlikely to be used as the primary blowing agent technology
- Category 3 HFCs likely to be used as primary blowing agent technology
- Category 4 HFCs virtually certain to be used as primary blowing agent technology

Category	Application	Region	Reason for choice	
1) <i>No HFC use of significance Expected</i>	<i>Flexible PU processes</i>			
	- <i>Block</i>	<i>Global</i>	<i>Suitable CO₂ technology (except for Box Foam)</i>	
	- <i>Moulded</i>	<i>Global</i>	<i>Suitable CO₂ technology</i>	
2) <i>HFCs unlikely to be used as primary blowing agent</i>	<i>Domestic Appliances</i>	<i>Global (except in countries where strong energy regulations dictate otherwise)</i>	<i>Good HC technologies</i>	
	<i>Rigid Integral Skin</i>	<i>Global (except for some decorative applications)</i>	<i>Viable H₂O technology</i>	
	<i>Polyethylene & Polystyrene packaging foams</i>	<i>Global</i>	<i>HC technology (although some safety concern in developing countries)</i>	
3) <i>HFCs likely to be used as primary blowing agent</i>	<i>Domestic Appliances</i>	<i>Japan</i>	<i>Regulation (Energy)</i>	
	<i>Discontinuous Rigid PU processes</i>			
	- <i>Panels</i>	<i>Global</i>	<i>Process (Safety)</i>	
	- <i>Block</i>	<i>Global</i>	<i>Process (Safety); Product Performance (Energy and Safety)</i>	
	- <i>Pipe-in-pipe</i>	<i>Global</i>	<i>Product Performance (Energy)</i>	
	- <i>Water heaters</i>	<i>Global</i>	<i>Process (Safety)</i>	
	- <i>Refrigerated transport/reefers</i>	<i>Global</i>	<i>Product Performance (Energy)</i>	
	- <i>Commercial Appliances</i>	<i>Global</i>	<i>Process (Safety)</i>	
	<i>One Component Foams</i>	<i>Global</i>	<i>Product Performance (Fire); Process (safety)</i>	
	<i>Continuous RigidPU processes</i>			
	- <i>block</i>	<i>Global</i>	<i>Process (Safety); Product Performance (Energy and Safety)</i>	
	- <i>boardstock (incl. PIR)</i>	<i>Global</i>	<i>Product Performance (Energy and Safety)</i>	
	<i>Flex. Integral Skin</i>	<i>Global</i>	<i>Product Performance (surface finish) better than otherwise viable H₂O technologies</i>	
	4) <i>HFCs virtually certain for use</i>	<i>Domestic Appliances</i>	<i>North America</i>	<i>Regulation (Energy) Process (Cost)</i>
		<i>Spray</i>	<i>Global</i>	<i>Process (Safety)</i>
<i>Phenolic</i>		<i>Global</i>	<i>Process (Safety) Product Performance (Energy and Safety)</i>	
<i>Extruded Polystyrene</i>		<i>Global</i>	<i>Product Performance (Energy) ; Regulation (VOC)</i>	

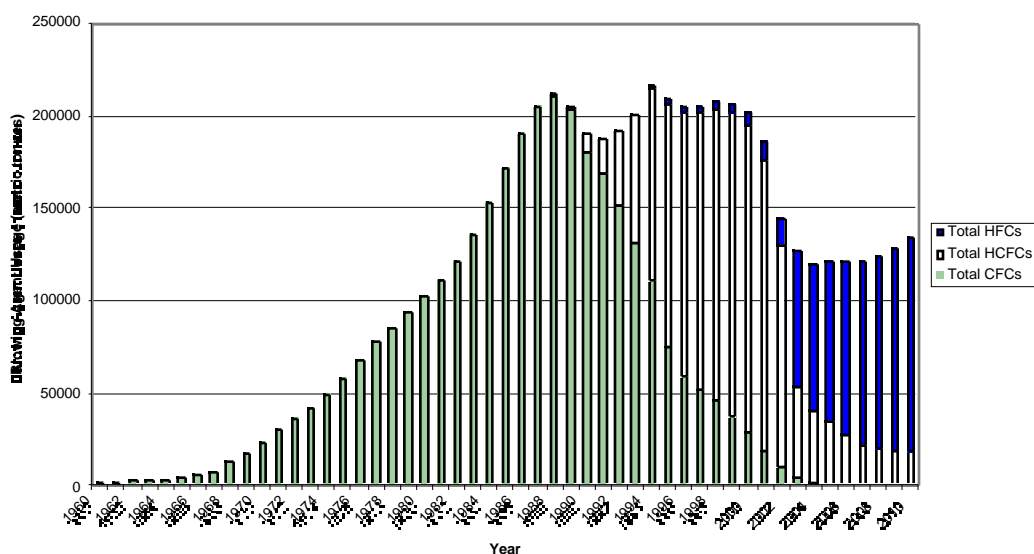
The classifications used in these tables indicate primary technology choices. These forecasts do not preclude the use of HFCs in any category where their use may be fully justified by specific product and process requirements or other local regulatory considerations.

The numerous factors already identified have led to the adoption of varying strategies for blowing agent selection in different sectors. In some cases, such as polyurethane spray foam process safety is an issue. In other areas, such as polyisocyanurate and phenolic foams, the fire behaviour of the product is the key determinant. In a recently developed model, it has been assumed that 50% of projected HCFC use in extruded polystyrene will switch to HFC blowing agents in the 2002-2010 time frame. This reflects the fact that the use of HCFC-142b will be permitted in North America until 2015. In addition, those applications in the polyurethane sector which have not switched to hydrocarbons or CO₂ by 2004 in developed countries will need to switch to HFCs, such as HFC-134a, HFC-245fa and HFC-365mfc, despite their projected higher cost on a 1:1 basis. Similarly most polyisocyanurate and phenolic foams will also switch directly to HFCs. Although, there will be a switch from HCFCs to HFCs in developing countries based on current technology and conversion costs, its impact in global terms may not be large. An allowance for this has been made.

With these assumptions in place, 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. However, there may be some gradual reduction in HFC use within the extruded polystyrene sector and elsewhere which may offset this growth to some extent. At worst, this could leave HFC use in foams at a level of between 150,000 and 200,000 tonnes in 2020. The situation is summarised for the period to 2010 in Figure 22.3.

Figure 22.3

CFC/HCFC/HFC Blowing Agents in use globally in Rigid Foams



Replacement of HCFCs by HFCs is expected to be on a less than ‘one for one’ basis by 2010 and reflects less than a 50% replacement level when corrected for market growth (see table above). The situation would change further if neither of the liquid HFCs became available, a scenario yet to be modelled.

22.6 Assessment and Control of Emissions

The long lifetime of insulation foam applications (15-50 years) makes emission modelling a complex issue. Because of the uncertainty of the mix in HFCs likely to be used in some sectors and the emission functions resulting, it is not possible to finalise emission scenarios, particularly with respect to the liquid HFCs. Preliminary analysis, which has been carried out so far on the use of HFC-134a in extruded polystyrene, projects emissions of around 12,000 tonnes (15.6 M tonnes of CO₂ 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 when the model is upgraded is expected to less than double the annual emissions in 2010. Accordingly emissions of around 25-30 M tonnes equivalent are expected in 2010 if no emission abatement occurs. With on-going optimisation of HFC use and some further blowing agent substitution continuing after 2010 it is viewed as unlikely that HFCs will ever exceed a 50 M tonne CO₂ equivalent emission level from closed cell insulation foams. These preliminary estimates require further validation.

22.6.1 Emission reduction options

The emission reduction options available to this sector have been identified as follows:

- Use of alternative blowing agents where issues of thermal efficiency, product performance or process safety are less critical.
- Use of alternative not-in-kind insulation materials including new technologies such as vacuum insulation.
- Minimise HFC blowing agent use per unit of foam by using co-blowing agents or minimising the molecular weight of the HFC (this increases blowing efficiency)
- Where HFCs are used, the following areas are also opportunities for reducing emissions:
 - during manufacture
 - during product use
 - at decommissioning

The following table summarises the advantages and potential disadvantages of each of these approaches:

	Option	Advantages	Disadvantages
1	Flammable blowing agent	Zero GWP	Possible VOC emissions
		➤ Long term alternative	➤ Flammability (process)
		➤ Lower material costs	➤ Flammability (product)
			➤ Investment costs (SME)
			➤ Investment costs (Dev. C.)
			➤ Potential Insulation loss
			➤ Density increase
			➤ Greater use of associated materials
2	Not-in-kind insulation	Zero GWP	Potential insulation loss
			➤ Decrease in structural strength leading to increased weight and use of support materials
			➤ Lower moisture resistance
			➤ Fibre concerns
3	Minimising HFC blowing agent through use of blends or higher blowing efficiency	➤ Less HFC emissions	➤ Potential insulation loss
		➤ Lower cost	➤ Flammability
4	Reduction of emission on manufacture through changes in processing practice	➤ Less HFC emissions	➤ Unproven technical and economic feasibility
		➤ Cleaner factory environment	➤ Investment costs
		➤ Cost gain	
5	Reduction of emission in use through facing changes	➤ Better retention of insulation value	➤ Increased cost
			➤ Uncertain market acceptance
6	Reduction of emission on de-commissioning through use of municipal incineration	➤ Major savings in HFC	➤ Needs development of separation technology and practice
			➤ Requires investment in incineration and collection infrastructure
			➤ May require regulation
			➤ Requires consistency of policy

A net effect of the long lifetime of insulating foam applications is that emissions are spread over long periods. The impact of reduction measures will therefore equally be spread over significant periods and reductions may be achieved many years after the consumption of blowing agent. One assessment indicated that up to 57,000 tonnes (49%) of potential 2010 emissions of 115,000 tonnes could be abated by introducing of reduction measures 4, 5 and 6 above. 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 to accomplish this is well understood (e.g. the European TAMARA study), the practical efficacy and economic viability are not. 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. Another study in Sweden estimated sorting costs alone at above \$300 per metric tonne of carbon emission abated. The situation may be eased somewhat in 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. This may reduce the cost by as much as 50%. Indeed, it is only the more traditional boardstock and spray applications that present real separation problems. However, boardstock currently accounts for nearly 20,000 tonnes of the potential savings based on current market splits.

The environmental benefits of early action to implement are significant as there is an opportunity to destroy a large quantity of CFCs and HCFCs contained in installed 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 M tonnes of CO₂ equivalent could be abated. This is over double the projected maximum annual emissions arising from the use of HFCs in rigid insulating foams.

22.6.2 The Pace of Technology Change

None of the current technologies are expected to be permanent options. It seems unlikely that reliance on existing technologies will extend beyond 2030. Consequently, predictions of growing consumption beyond this date are currently believed to be unreliable.

23 MILITARY APPLICATIONS

23.1 Background

Perfluorocarbons (PFCs), Hydrofluorocarbons (HFCs), and Sulfur Hexafluoride (SF₆) are used in many important military applications around the world. In some cases, they were adopted as alternatives to ODS and in other cases they are used in applications where ODS were never used. In many cases militaries use these chemicals for the same applications as the civilian sector.

However, in a number of applications, PFCs, HFCs, and SF₆ are used more predominately in military hardware or are unique to military applications.⁵⁹

HFCs were selected as alternatives to ODSs only after extensive research and development efforts were unable to identify more environmentally acceptable alternatives. The HFCs were selected because their unique physical properties were technically necessary. For example, the U.S. Department of Defense is conducting extensive research to qualify and implement ODS alternatives, a number of which are HFCs, PFCs, and/or SF₆ because no other alternatives are technically or economically feasible.⁶⁰ This development work includes system optimisation in order to use greenhouse gases as efficiently as possible and minimise life cycle direct and indirect greenhouse gas emissions. To phase out ODS as quickly as possible, military organisations made significant investments in the development, testing and implementation of new technology.

The unique design and operating environment of military equipment make a number of alternatives to ODSs that are available to the civilian sector inappropriate for military applications. Other systems using flammable refrigerants such as ammonia and hydrocarbons can be engineered for acceptable safety against accidental fire or explosion in civilian applications, they are not acceptable in a battlefield environment where equipment will be deliberately put in harms' way and where evacuation is not a safe option. Mindful of the importance of non-flammability in weapons platforms, research programs sought alternatives with the lowest global warming potentials as possible and overall systems designs that maximised energy efficiency. To minimise emissions of greenhouse gases, the US Department of Defense has adopted a responsible use policy to minimise emissions for HFCs, PFCs, and SF₆. For example, the U.S. Navy requires that shipboard air-conditioning and refrigeration equipment containing HFCs be immediately repaired if significant leaks are detected.⁶¹ Examples of this responsible policy can be found on the US Department of Defense web site.⁶²

23.2 Specific Applications

23.2.1 Refrigerants

HFCs are widely used as alternatives to CFC and HCFC refrigerants in military applications. Important military applications of HFC refrigerants include:

⁵⁹ Military experts from Canada, the Czech Republic, Denmark, Sweden, the United Kingdom and the United States helped prepare the preliminary first draft of this section. Findings were presented at the NATO conference on "Approaches to the Implementation of Environmental Pollution Prevention Technologies at Military Bases" held in Budapest, Hungary, May 5-7, 1999.

⁶⁰ Department of Defense Ozone-Depleting Substance Reduction Program Report to Congress, August 1995

⁶¹ U.S. Navy Environmental and Natural Resources Program Manual (OPNAVINST 5090.1B, Change 1), Chapter 19, 2 February 1998.

⁶² Department of Defense Talking Points on Climate Change and National Security, Available on-line at <http://www.denix.osd.mil/denix/Public/News/OSD/Climate/talkpts.html>

- Chilled-water air-conditioning on ships and submarines – used for cooling of combat systems, electronics, and personnel
- Food refrigeration on ships and submarines
- Medical refrigeration on ships (blood, plasma, medicine, etc.)
- Air-conditioning and refrigeration in tactical battlefield equipment – used for cooling in ambulances and mobile hospitals, tactical vehicles, battlefield shelters, etc.
- Environmental control units on aircraft
- Command, control and communications centres

One military organisation reported that a refrigerant blend with a PFC component was being considered as a drop-in replacement for CFC-12 in armoured fighting vehicles and in some shipboard refrigeration plants.

Military organisations considered factors such as direct global warming impact from chemical emissions, indirect global warming impact from energy consumption, toxicity, flammability, space, weight, cost, materials compatibility, and commercial availability (technology maturity), when selecting HFC alternatives. Hydrocarbons and ammonia were ruled out due to flammability, toxicity, space/weight, and cost reasons. Not-in-kind technologies such as thermoelectric cooling and thermoacoustic cooling were ruled out due to cost, indirect warming impacts, and lack of commercial availability.

Military systems typically involve much higher investment than commercial systems to implement, and typically have longer expected lifetimes, often on the order of 30-50+ years. The design of military HFC refrigeration systems includes features to reduce leakage, and improve the efficiency and ease of recycling refrigerant. The US and other militaries have revised their maintenance procedures to require recovery and recycling of HFC refrigerants, and the US has implemented specific maximum annual allowable leakage rates. This practice has not been implemented globally, either for military or civilian refrigeration systems.

23.2.2 Radar Waveguide Pressurisation Gases

SF₆ and PFC-116 (C₂F₆) are used in waveguides of some military radar systems found on ships, aircraft, and ground-based air-traffic control systems. These pressurisation gases are used to prevent air and moisture from entering the waveguide and to prevent waveguide arcing and corona. Without these gases, military radars would not function properly. In most cases these gases have always been used for these applications, however the survey conducted for this report revealed a few specific pieces of equipment where SF₆ is actually used as a substitute replacing CFC-12. Civil radar systems typically do not require these gases because they operate at significantly lower power settings and are not as susceptible to arcing.

Although the total installed quantity of SF₆ and PFC-116 is relatively small, emissions as a percentage of installed quantity appear to be relatively large. Some waveguides on airborne radar systems are designed to vent the gas in order to prevent overpressurisation while at altitude. In

addition, the gas is vented and replaced several times a year on most systems to prevent damage to the waveguide that may be caused by moisture and decomposition products such as SOF₂. When the performance of the radar is degraded and it is suspected that this is a result of arcing, the gas is also vented and replaced. In most cases the gas cannot be recovered by conventional recovery methods because of the design features of existing radar system designs. Specifically, most waveguides and other transmitter components are not designed to withstand high pressure, either positive or vacuum. As a result, application of conventional recovery methods using vacuum pumps/compressors would collapse and destroy the waveguide and other internal components.

It is possible to design most new radar systems without greenhouse gases, however it would take time to develop and implement new designs.

23.2.3 Fire/Explosion Suppressants

Both HFC-125 and HFC-227ea are being used to replace halon 1301 currently used aboard ships, tanks, aircraft, and in some important command and control facilities as fire/explosion suppressants. This is predominantly for new systems, however some retrofit of existing systems is taking place where alternatives are economically and technically feasible.

The following are important military applications for these HFCs:

- Crew compartment explosion suppression in tactical vehicles
- Fire suppression and explosion suppression on aircraft
- Room flooding fire suppressants on ships in machinery spaces, flammable liquid storage & issue areas, engine enclosures, and other areas
- Fire suppressants in turbine engine testing facilities
- Fire suppressants in areas of such high value or strategic importance to the military mission that damage or interruption of operations is considered to be unacceptable (remote radar sites, flight simulators, command & control areas, etc.)

New and modified weapon systems have been designed or are being designed to use these chemicals:

- Aircraft Carriers
- Amphibious Landing Craft
- Submarines
- Fighter Aircraft
- Helicopters, Utility, Transport and Attack
- Armoured Fighting Vehicles

In addition, HFC retrofits for Halon 1301 used in some applications in existing aircraft, ships, and tactical vehicles such as tanks and armoured personnel carriers are being considered.

Sweden reports it will soon complete its program to replace approximately 20 tonnes of halon, including approximately 11 tonnes considered essential, with an HFC. However, they will continue to require halons in fighter airplanes and submarines.

Non-greenhouse gas alternatives, such as fine water mist, inert gas generators, and carbon dioxide, have been implemented for a number of applications, such as ship machinery spaces. However, for a number of important military applications HFC-125 and HFC-227ea have thus far proved to be the only viable substitutes. The US reports a continuing research program called the DoD Next-Generation Fire Suppression Technology Program (NGP) designed to find new, more environmentally acceptable substitutes.⁶³

Design features and programs to reduce emission rates that have been implemented by some, military organisations include:

- Improved reliability systems to reduce the incidence of false alarm and accidental discharge.
- Improved recycling fixtures that reduce the time to recover the gas and reduce leakage while connecting and disconnecting recovery equipment.
- Systems that are monitored for leakage through periodic leak checks.
- Recovery and recycling of all gases during servicing or disposal of equipment.

Restrictions that prevented military organisations from using HFCs as alternatives to Halon 1301 fire and explosion suppressants would compromise the safety of personnel, and the survivability and performance of much military equipment to an unacceptable degree. This is especially true since greenhouse gases are used only in cases where no other suitable fire suppressant exists. Furthermore, any such restrictions would penalise militaries that have expended significant resources in order to speed the development of alternatives to protect the ozone layer. The military pioneered many of the technologies and their applications, and led the civil sector in banking halon in order to end production early. This military leadership enabled halons to go from the least controlled in 1987 to the first chemicals phased out of production under the Montreal Protocol by 1994.

23.2.4 Direct Immersion Liquid Cooling & Recirculating Coolers for Electronics

Perfluoro-compounds (C₅-C₁₈) have been used extensively since the 1960's as heat exchange fluids in military electronics equipment such as radar transmitters and klystrons, lasers, power supplies, high voltage transformers, and supercomputers. It is also used in small quantities as an antimigration coating for circuit boards. The unique chemical compatibility and stability, high dielectric strength, and favourable heat transfer characteristics permit these fluids to be used in direct contact cooling applications with electronic components. Their use enables the design of high-density equipment configurations that take up significantly less space, while still operating

⁶³ Next-Generation Fire Suppression Technology: Strategy for a National Program, available on-line at http://www.dtic.mil/ddre/fire_suppression/cover.html

at high power and increasing system reliability. Many of the most advanced combat systems use small quantities of these fluids for direct contact cooling or in recirculating coolers.

Total PFC emissions from these applications are minimal because they are closed-loop systems. Additionally, these compounds are typically liquids at room temperature so they are also normally recovered and recycled during maintenance or disposed of as a hazardous waste.

Little effort has been expended in finding alternatives for these applications because the quantities used in these applications are small, direct emissions are low, and conservation techniques are in place. Possible future alternatives for these PFCs include Hydrofluoroethers (HFEs) that have much shorter atmospheric lifetimes and lower greenhouse warming potentials (GWP).

23.2.5 Precision Cleaning/Contamination Control

PFCs and HFC 43-10mee are used in a variety of speciality precision cleaning applications to remove particulate, flotation and damping fluids, and other contaminants from precision components such as missile, spacecraft, and aircraft guidance systems. In some cases PFCs and HFC 43-10mee replaced the use of CFC-113 as a solvent in precision cleaning. Due to the high cost of these solvents, they are generally used in low-emission cleaning equipment and are recycled or disposed of when they become contaminated, resulting in very low emissions. Also they are only used in applications where other alternatives such as aqueous cleaning are not suitable. The US reported that they converted over 95% of their CFC-113 precision solvent cleaning operations (1988 annual usage = 1,250,000 kg) to aqueous processes. The remaining non-aqueous processes included alternatives such as alcohols, volatile methyl siloxanes (VMSs), supercritical fluids, and perfluorocarbons. Some military organisations reported using HFC-134a for flux removal and as an electrical cleaner, but added that replacements will soon be implemented.

While estimates of the volume usage and emissions of PFCs and HFC 43-10mee in precision cleaning applications is unavailable, the US estimated its annual emissions in these applications are only on the order of several thousand kilograms at most. Future usage is expected to decline as alternatives are implemented such as aqueous, alcohol, VMS, HFE, supercritical fluid, carbon dioxide snow, laser, and plasma cleaning.

23.2.6 Liquid Injectant Thrust Vector Control Chemical

Halon 2402 is injected into the second stage rocket motor of the Minuteman III weapon system in order to achieve thrust vector control. Since Halon 2402 is an ozone-depleting chemical, the U.S. Air Force conducted a research and development (R&D) program to identify an acceptable alternative. This R&D program spanned over five years beginning in 1991.⁶⁴ The alternative

⁶⁴ Technology Development Plan For Alternatives To Ozone-Depleting Substances For Weapon System Use, Draft Final Report, DoD Office of the Director Defense Research and Engineering,

identified is perfluorohexane (C₆F₁₄), a PFC, and will be implemented over the next several years. Although over 50,000 kg of this PFC will be installed, only a few hundred kilograms of annual emissions are expected. Because of low emissions and the high cost of qualifying alternatives, C₆F₁₄ is expected to be used for this application for the next 40+ years.

23.2.7 Other Miscellaneous Uses

PFCs and HFCs are used in a variety of other minor military applications. These include ordnance manufacturing, lubricant deposition, electronic environmental and thermal shock testing, leak testing, acoustic lens materials for sonar equipment, sound coupling applications, and others. Emissions from these applications are estimated to be small. In some cases the PFCs and HFCs used in these applications as alternatives to CFC-113, and in other cases the PFCs have always been used for these applications. Emissions from these applications are likely to decrease over the next several years as PFCs are replaced with HFCs and/or HFEs and HFCs are replaced with HFEs.

23.3 Summary

HFCs, PFCs, and SF₆ fulfil important military applications around the world. In many cases, they represent the only technically and economically feasible option for the foreseeable future. However, appreciating their environmental impact, a number of militaries have instituted policies discouraging the use of greenhouse gases, in particular PFCs and SF₆, unless there are no other acceptable alternatives. A number of military organisations also reported policies in place discouraging the use of greenhouse gases, and PFCs and SF₆ in particular, unless there are no other acceptable alternatives.

Restrictions on military uses of HFCs, PFCs, and SF₆ would also undermine the years of investment devoted to develop and implement alternatives to ODSs. In addition, the cost of qualifying alternatives for some military systems appears disproportional to the quantities of greenhouse gases involved. It is important to note that military organisations expressed technical optimism during the early days of the Montreal Protocol and invested heavily to develop and implement alternatives to ODSs. These investments and policy leadership enabled an early phaseout of halons. In a number of cases, these early alternatives proved to be HFCs, and in lesser cases, PFCs.

There are opportunities to reduce emissions by sharing recovery and recycling techniques currently used by some militaries but not others. In addition, civil sectors may benefit and learn from military recycling technology. In addition, there remain opportunities to expand and improve recycling technologies. For example, there is an opportunity to develop techniques to capture gases currently vented by airborne radar systems. While developing and implementing recycling technologies involves some investment, the high cost of some of these substances provides an economic incentive to prevent emissions and to conserve.

Containment techniques, recovery, recycling technologies and conservation policies, and new system designs rather than retrofits, are the prudent courses of action to minimise emissions of these gases.

24 CEIT AND ARTICLE 5(1) COUNTRIES

Developing countries are at the different stage of their implementation of the Montreal Protocol as compared to developed countries. Nonetheless, developing countries want to integrate and harmonise their initiatives in protecting the ozone layer and mitigating the climate change. Strategies include emission reductions, “leap-frogging” where possible, and enhancing energy efficiencies by co-ordinating assistance under MLF and GEF. The clearinghouse mechanism that has guided developing countries towards successful implementation of the Montreal Protocol could be replicated to respond to climate change.

CEIT and developing countries depend on the availability of technical and environmental information, access to technology, and affordable financing. Non-investment financing for training and capacity building is also critically important.

24.1 Implications of Technology Selection

Article 5(1) countries share the global concerns for stratospheric ozone and climate protection. The choice of technology considers a balance of maturity, availability, cost effectiveness, energy and other performance, safety and safety costs. In addition to the guidance provided through the Multilateral Fund (MLF) Executive Committee 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, access to technology at affordable price, availability of training and other market circumstances and regulatory compliance.

24.1.1 Impact of Replacement technology options in Montreal Protocol MLF projects

Tables 24.1-24.6 show the quantities of controlled substances (CFCs) that have been (or are in the process of being) phased out in developing countries, through approved projects under the Montreal Protocol’s Multilateral Fund. The corresponding quantities of replacement substances selected have been shown. For this purpose, data for projects, approved as of 31 March 1999⁶⁵, in four selected industrial sectors (aerosols, foams, refrigeration and solvents) and sub-sectors is presented.

⁶⁵ Inventory of Approved Projects, MLF Secretariat, March 1999.

Table 24.1: Aerosols

Sector/Sub-sector (# projects approved)	BASELINE TECHNOLOGY (MT ODP)		REPLACEMENT TECHNOLOGY (MT ODP)			
	ODS	IMPACT	HCFCs	HFCs	HCs	Other
Contract fillers (26 projects)						
	CFC-11	377	0	0	377	0
	CFC-12	17,986	0	0	13,919	4,067
Filling plants (58 projects)						
	CFC-11	954	0	0	954	0
	CFC-12	4,746	0	11	4,736	10
	CFC-114	9	0	0	9	0

Table 24.2: Foams

Sector/Sub-sector (# of projects approved)	BASELINE TECHNOLOGY (MT ODP)		REPLACEMENT TECHNOLOGY (MT ODP)			
	ODS	IMPACT	HCFCs	HFCs	HCs	Other
Flexible Slab-stock (159)	CFC-11	11,934	35	0	0	11,899
Flexible Moulded (12)	CFC-11	450	66	0	0	384
Integral Skin (84)	CFC-11	2,573	597	0	345	1,631
Rigid Foam (238)	CFC-11	10,938	7,144	58	3,003	733
EPE/EPS Foam (63)	CFC-11	1,204	0	0	980	224
	CFC-12	6,280	196	0	6,084	0
	CFC-114	40	0	0	40	0
Multiple Foams (32)	CFC-11	1,910	637	0	200	1,073

Table 24.3: Refrigeration

Sector/Sub-sector (# projects approved)	BASELINE TECHNOLOGY (MT ODP)		REPLACEMENT TECHNOLOGY (MT ODP)			
	ODS	IMPACT	HCFCs	HFCs	HCs	Other
Domestic Refrigeration (168 projects)						
Foam	CFC-11	16,589	4,379	0	12,188	0
Refrigerant	CFC-12	5,241	0	4,553	688	0
Commercial Refrigeration (161 projects)						
Foam	CFC-11	2,432	1,648	0	784	0
Refrigerant & chillers	CFC-12	1,136	4	1,132	0	0
	CFC-502	1	1	0	0	0
Foam insulation conversion only (34 projects)						
Foam	CFC-11	1,998	636	0	849	513
	CFC-12	8	8	0	0	0

Table 24.4: Solvents

Sector/Sub-sector: (# of projects approved)	BASELINE TECHNOLOGY (MT ODP)		REPLACEMENT TECHNOLOGY (MT ODP)			
	ODS	IMPACT	HCFCs	HFCs	Hydrocarbons	Other
Total 84 projects	CFC-11	12	0	0	0	12
	CFC-12	55	0	0	0	55
	CFC-113	944	20	0	47	877
	CTC	399	0	0	0	399
	TCA	350	13	0	152	185

Tables 24.5-24.6 show the overall impact of the selected technologies by sector and by substance.

Table 24.5: Impact of Replacement Technologies by Sector

Sector/Sub-sector (# of projects approved)	BASELINE TECHNOLOGY (MT ODP)	REPLACEMENT TECHNOLOGY (MT ODP and % of total)							
		HCFCs		HFCs		HCs		Other	
	ODS IMPACT	ODP	%	ODP	%	ODP	%	ODP	%
Aerosols (84)	24,072	0	0	11	0.01	19,995	83.05	4,077	16.94
Foams (588)	35,329	8,675	24.55	58	0.17	10,652	30.15	15,944	45.13
Refrigeration (363)	27,405	6,676	24.36	5,685	20.74	14,509	52.94	513	1.96
Solvents (84)	1,760	33	1.87	0	0	199	11.31	1,528	86.82

Table 24.6: Impact of Replacement Technologies by Substance

ALL SECTORS	BASELINE TECHNOLOGY (MT ODP)	REPLACEMENT TECHNOLOGY	
		MT ODP	%
CFCs, CTC, TCA	88,566		
HCFCs		15,384	17.31
HFCs		5,754	6.47
HCs		45,355	51.02
Other		22,402	25.20

Notes on Tables 24.1-24.6:

- The data presented does not cover the Halons Sector.

- The data presented covers individually approved investment projects only. Country-level ODS phaseout projects, where sector-level information is not available, have been excluded.
- The data for the refrigeration sector does not cover recovery and recycling projects and compressor conversion projects.
- The data for technologies presented under "other" include other zero-ODP technologies such as water and aqueous compounds, gaseous and liquid carbon dioxide and blends, methylene chloride, etc.
- The key for acronyms used is as below:
HCs - Hydrocarbons (Pentanes, butanes, hexane, etc.)
CTC - Carbon Tetrachloride
TCA - 1, 1, 1, Trichloroethane (methyl chloroform)
- The data does not reflect the impact of growth.
- Projects in sectors where uses are classified as essential, are not eligible for funding and therefore no projects were approved. This is the case of metered dose inhalers. HFCs are used as alternatives. Data are not presented in the tables since no projects were approved under the MLF.

From Tables 24.1-24.6, it is clear that HCFCs and HFCs have not been significant as an alternative technology choice for phasing out ODS in the aerosols and solvents sectors. However HCFCs and HFCs have been selected as significant alternatives to ODS in the foams and refrigeration sectors.

24.1.1.1 Foams Sector

Referring to Table 24.2 and Table 24.5, the present contribution of HFCs as a direct replacement technology for ODS is negligible (58 ODP MT or 0.17%). The contribution of hydrocarbons selected as a replacement for ODS is significant (10,652 ODP MT or 30.15%). The contribution of other zero-ODP and zero-GWP technologies is also very significant (15,944 ODP MT or 45.13%). Thus, the overall contribution of zero-ODP and zero-GWP technologies selected to replace ODS is 26,596 ODP MT or about 75.28%.

The contribution of HCFCs as a selected alternative in the foam sector amounts to about 24.55% of the total replacement (8,675 ODP MT). HCFCs have been selected as an interim replacement in all foam sub-sectors, where application of zero-ODP and zero-GWP technologies was not feasible due to availability, safety and safety related costs, or energy efficiency reasons. HCFCs are expected to be replaced by zero-ODP and zero-GWP substitutes, such as water, carbon dioxide or hydrocarbons, in the medium term, except in the rigid polyurethane foam sub-sector. While several mid-size and larger domestic and commercial refrigeration companies have switched to hydrocarbons in the rigid foam part, small and medium sized enterprises have more difficulties in this selection due to safety uncertainties and mainly safety costs. It is expected that a large part of this SME sector would convert to HFC alternatives in the medium to long term in Article 5(1) countries.

24.1.1.2 Refrigeration Sector

In the refrigeration sector, the foam part is exclusively rigid polyurethane foam. The contribution of HFCs as a direct replacement for ODS blowing agents in the foam part, is negligible in the projects approved under the MLF. In projects where suitable zero-ODP and zero-GWP alternatives meeting the availability, safety and safety related costs, and the stringent energy efficiency requirements, were available (hydrocarbons and other substances), they have been applied, contributing to 14,509 ODP MT (52.94%). HCFCs have been selected as an interim replacement technology for ODSs, where such alternatives could not be applied, contributing to 6,676 ODP MT (about 24.36% of the total replacement).

The contribution of HFCs (Table 24.3) as a direct refrigerant replacement technology, is 5,685 ODP MT per year contributing to 20.74% of the total replacement in the sector and about 89.1% of the refrigerant replacement. Conversion of the refrigeration components of the refrigeration manufacturing plants are heavily determined by market forces (compressor supply) and safety costs.

24.1.1.3 All Sectors

In the overall ODS replacement scenario for all sectors by substance, zero-ODP and zero-GWP replacement options (such as hydrocarbons and other natural substances) have been applied in 76.22% (67,757 ODP MT) of the total replacement.

HCFCs have been applied to about 17.31% (15,384 ODP MT) of the overall replacement, a large part of which would be expected to potentially convert to HFC alternatives in the medium to long term, to meet energy efficiency, availability, safety and cost-effectiveness requirements.

HFCs have been applied to about 6.74% (5,754 ODP MT per year) of the overall replacement.

24.2 Developing Countries Concerns and Opportunities

Developing countries have concerns related to the fact that the uncertainty on possible controls on HFC in developed countries may adversely affect compliance with MP obligations, in particular for R/AC and foam sectors. Another concern is on the availability of HFC to be supplied to developing countries, which have selected HFC technologies with or without MLF assistance. It is also important that enterprises have supplies of chemicals and components to guarantee maintenance and services to their customers.

Enterprises in developing countries that received MLF assistance and selected zero-GWP solutions in the rigid PU foam sub-sector are mostly large enterprises. Many small and medium enterprises have selected HCFC-141b as a transitional substance, and will have to convert from HCFCs without financial assistance from the MLF. Enterprises are uncertain on the impact on their business of the developed countries future restrictions on HFCs as well as on HCFCs. Questions on HCFC availability after 2003 has been a concern. Developing countries selected

the technology according to approved MLF decisions and to comply with Montreal Protocol national obligations as well as need to compete in a changing market.

Financial assistance is available now for agreed incremental costs for ODS phaseout through the MLF of the MP. GEF financing is available for improving energy efficiency, and other reductions of GHG emissions in general, such as HFCs (up to US\$ 10 per tonne of carbon equivalent abatement over the lifecycle of the relevant investments). CDM will also provide opportunities to reduce HFC emissions. Opportunities exist in the refrigeration sector where large uses of HFCs exist in new equipment manufactured, including mobile air conditioning, which will need maintenance. Emission reduction is possible and best practices training is necessary.

In some instances, the absence of financing for enhancements to energy efficiency may limit choice and favour HFC over other options. Furthermore, the incremental investment in energy efficiency during conversion from ODSs may be highly cost effective and institutionally efficient. CEIT and Article 5(1) countries would welcome additional funding for climate protection enhancements to GEF and Multilateral Fund ozone protection investments.

Under the Multilateral Fund, enterprises are eligible for financial assistance only once. This makes it crucial for an enterprise to choose a technology that is cost effective, environmentally acceptable, and globally sustainable. It is very important to examine opportunities for developing countries to orchestrate their strategies for integrating and harmonising their initiatives in protecting the ozone layer and mitigating the climate change. Such opportunities, inter alia, may be in the field of emission reductions, transitioning directly to non-fluorocarbon alternatives where possible, enhancing energy efficiencies and availing blend of assistance under MLF and GEF.

24.3 Information on Technology Choices

The choice of technology in CEIT and Article 5(1) countries is often influenced by local circumstances including: preferences of enterprises, their joint-venture partners and customers; access to technology at affordable prices and confidence in competitive prices for service; availability of training and other infrastructure; and other market circumstances. Therefore, national governments and their enterprises need information and access to a range of options including HFCs.

CEIT and developing countries report that there sometimes is inconsistency in the information made available to the developing countries by the manufacturers of the alternatives to CFCs and HCFCs. In some cases, information on only one alternative is available to an enterprise through dealings with a single vendor. This leads to inappropriate choice of technologies. A co-ordinated approach to the provision of unbiased information will lead to more informed selection of alternatives taking into account all the necessary factors. This could be coupled to decision trees to aid choices.

Technology is evolving at a rapid pace. A wider range of alternatives to CFCs and HCFCs has been available over the past five years for many applications. Developing countries will require access to new information and assessment of new technologies as they become available. As a result there is a requirement for an unbiased technical assessment process to continue through CFC/HCFC phaseout in order to ensure that the most appropriate overall and integrated environmental solutions are chosen.

All enterprises in both developed and developing countries will want to select technologies to protect the stratospheric ozone layer and climate protection as well as other environmental and safety concerns. However, there is concern that some developed countries may try to impose their own preferred choice of technology on developing countries. One approach is to work for fully informed choices but to respect investment decisions—regardless of which technology is selected to replace ODSs.

With various technical publications, UNEP TIE assists enterprises in developing countries to obtain information on commercially available ozone-friendly technologies and where to obtain these technologies. Those publications contain lists of technology suppliers and other contacts for additional information necessary for business owners to initiate ozone-friendly business operations. These countries would welcome more information and full access to all technology in order to choose wisely when replacing ODSs with HFCs or PFCs.

Currently, UNEP's activities under OzonAction Programme provide various types of supports including information exchange, networking, institutional strengthening, capacity building and training. Through its clearinghouse service, UNEP provides neutral and unbiased information on technology and policy options. It provides sources of technologies to expedite the technology transfer. The OzonAction is an enabling program that strengthens the capacity of governments and industry in developing countries to take informed decisions that facilitate transfer of technology to phase out ODS. UNEP TIE's OzonAction Programme in Paris has been mandated under the Montreal Protocol to facilitate bilateral and multilateral co-operation, create environmental awareness, and to collect and distribute up-to-date information. The scope of OzonAction Programme could be expanded to become a Climate Action Programme.

One of the most innovative UNEP activities is the system of regional networking of the National Ozone Units for co-operation between government officers in charge of co-ordinating and proposing ODS strategies. Regional networking provides government ODS officers with a means of sharing their knowledge with their peers in developing and developed countries. Such networking has helped the countries to set up enabling environment and policy setting for favourable technology transfer.

24.4 Trade Restrictions

Trade restrictions on HFCs could undermine efforts to phase out CFCs by discrediting national governments and consultants who have worked closely with enterprises in selecting HFCs to achieve early phaseout of CFCs. For example, in Thailand four refrigerator manufacturers dependent on one local compressor manufacturer co-operated to redesign the compressor to use HFC-134a. Import restrictions on refrigerators containing HFCs would be economically devastating to these Thai companies because over 30% of refrigerators are currently exported.

An alternative to restrictions to specific HFC use or trade would be to encourage selection of alternatives based on environmental and economic criteria and to encourage recovery and recycling.

Manufacturers in Article 5(1) countries have responded rapidly to regulations in developed countries that prohibited import of products made-with or containing ODSs when funds were available. However, current operating rules of the Multilateral Fund do not provide for the incremental costs of converting from HFC to HC, and alternative sources of funds are not yet available under the Kyoto Protocol. Any restrictions on the import of products made-with or containing HFCs would severely impact the implementation of the Montreal Protocol in CEIT and Article 5(1) countries. These countries often depend on export markets for revenue and could delay conversion from ODSs if HFCs are subject to regulatory uncertainty.

24.5 Responsible Use and Good Practices

The manufacturers of HFCs in developed countries have adopted low-emission technologies and have evolved new practices in order to minimise emissions of HFCs from their production facilities. Similarly, concepts of “responsible use” and “good practices” have been passed from manufacturers to the distributors of HFCs and on to users and the servicing sector, enabling emissions reductions during use.

HFCs production facilities are in operation and under construction in developing countries. It is vital that manufacturing practices that minimise inadvertent emissions are available for adoption at developing countries facilities. Similarly, practice of “responsible use” and “good practices” are promoted and available to all users of HFCs in developing countries.

25 REDUCING LIFE-CYCLE EMISSIONS

It is technically and economically feasible to reduce life-cycle refrigerant emissions.⁶⁶ Engineering and monitoring technology has improved containment and better training and wider use of recovery and recycling equipment can further reduce servicing losses, however, it has to be realised that refrigerant levels or reductions will never be brought to zero. With proper

⁶⁶Life-cycle refrigerant emissions include emissions that occur during refrigerant manufacturing and marketing and during operation, servicing, and disposal.

motivating, existing and emerging technology can recover refrigerants at the time that equipment is disposed. Global HFC refrigerant emissions can be reduced by at least 50% worldwide by recycling from vehicle and stationary systems and better handling procedures. Higher prices of HFCs encourage necessary investment to achieve these emission reductions.⁶⁷

Better refrigerant handling, energy efficiency and containment can reduce emissions to almost zero, allowing the use of low ODP and GWP refrigerants without significant ozone depletion or climate change. If engineered systems and mitigation can minimise the likelihood and consequence of major leaks, flammable and toxic refrigerants can be used in new applications to

⁶⁷Technology is commercially available to recover and recycle HFC refrigerants but the revenue from recovered refrigerant is often not sufficient to guarantee that recycling occurs in the absence of regulations. Some governments including Denmark, France, Germany, Iceland, Norway, the United Kingdom and the United States limit emissions of HFCs from refrigeration equipment and the Netherlands and Sweden have CFC and HCFC refrigerant conservation requirements that may also be applicable to HFCs. Australian industry associations have voluntarily implemented HFC recovery and reuse. Japanese industry associations have voluntary action plans for implementation of HFC recovery and recycle.

Life-cycle emissions from HFC vehicle air conditioning can be reduced by 50 percent with recovery and recycling during servicing and at the time the vehicle is disposed. Life-cycle emissions of stationary equipment can be reduced dramatically, with the technical feasibility of very low life-cycle emissions for hermetically sealed equipment. Japanese industry associations have voluntary action plans to reduce the release while manufacturing, installing, and serving, and to develop the small charge and/or using low GWP HFC equipment.

Refrigerant Reclaim Australia is a product stewardship organisation that is managed and financed by industry. It recovers and either reclaims or destroys all fluorocarbon refrigerants. The organisation is financed via a US\$ 0.63 per kilo levy payable on all imported ozone depleting refrigerants. Refrigerant Reclaim Australia has expanded its service to HFCs even though Australia regulations require reclaim of ozone depleting refrigerants but not HFCs. In addition, Australian Industry Codes of Practice have been revised to include HFCs, in addition to HCFCs and CFCs.

Denmark has a voluntary industry organisation called Kølebranchens Miljøordning (KMO) collects CFC, HCFC and HFC refrigerant for reclamation or disposal. Useable refrigerant sold back to customers. Refrigerants are also independently recycled on site. Expenses for the KMO secretariat and for transport, quality tests, special equipment, destruction, etc. are covered by a special fee on the price of new HCFC and HFC refrigerants. The special fee is at present US\$ 3.00 per kilogram. The wholesale dealers pay US\$ 0.85 to US\$ 1.65 per kg returned refrigerant as an economic incentive to recover the largest possible amounts of refrigerants.

France collects a US\$ 0.20/kilogram deposit on newly-produced HFC that is used to sponsor recycling centres Dehon Service buys recovered refrigerant for US\$ 3.00/kg and reclaims it for reuse.

German and Norway prohibit HFC disposal into nature. However, in Germany virtually no refrigerant is returned because owners have to pay for disposal.

Iceland requires that HFCs be recycled and re-used or disposed as decomposable waste in accordance with pollution control regulations.

The United States prohibits venting of HFCs and requires recycling or destruction.

replace ODS and HFC refrigerants. "Virtually zero emissions" technology thus provides the opportunity to reconsider in a wide variety of applications, the LCCP of low-ODP refrigerants such as HCFC-123 and zero-ODP "natural refrigerants" such as HC and ammonia.

The lack of adequate regulatory incentives in some CEIT and Article 5(1) countries is a major obstacle to phaseout. The majority of Article 5 (1) countries do not have legislation prohibiting CFC and HCFC emissions and creating the legal environment for refrigerant conservation. The Refrigeration Management Plan (RMP), which is a non-investment activity funded by the Multilateral Fund, can serve as a good example. Under the RMP, implementing agencies assist countries in setting up appropriate regulatory structures. Conservation technology, including containment, recovery, recycling and reclamation, contributes to the safe use of flammable and toxic "natural refrigerants" and could provide a basis for reconsidering the phaseout of HCFC-123 refrigerants if new refrigerants cannot match the life-cycle climate performance.

26 NEXT-GENERATION SUBSTANCES

National research organisations and private corporations are engaged in an ambitious search for safer, more environmentally acceptable, more energy efficient and economically feasible substances to replace HCFC and HFC refrigerants and foam blowing agents. "Natural refrigerants"⁶⁸ are among the most environmentally attractive options but equipment must be engineered to mitigate refrigerant flammability and toxicity concerns. New system designs are necessary for water and carbon dioxide because of the difference in pressure.

27 ADDITIONAL COMMENTS

The Montreal Protocol has been successful because environmental leadership companies were willing to make substantial investments in early technology to phaseout ODS. For example, chemical manufacturers in developed countries began construction of HFC-134a production facilities long before their customers had selected substitutes and environmental regulators had verified environmental acceptability. In developing countries, environmental authorities cooperated with industry to speed ODS phaseout. For example, in Thailand refrigerator manufacturers jointly selected HFC-134a as the refrigerant and HCFC-141b as the blowing agent to phaseout CFCs in refrigerators used in their domestic market and exported to Article 5(1) and

⁶⁸ "Natural refrigerants" are usually defined as the naturally occurring substances already circulating in large quantities in the biosphere. These chemicals include ammonia (NH₃), sulphur dioxide (SO₂), carbon dioxide (CO₂), water (H₂O), and hydrocarbons (HC). "Natural refrigerants" were used exclusively prior to the introduction of CFCs and HCFCs and are competitive with CFCs, HCFCs, and HFCs in applications where they can be safely used and provide higher energy efficiency. In the majority of cases, "natural refrigerants" are manufactured or isolated in industrial processes but in some cases they may be available without the need for purification. Although sulphur dioxide fits the definition of a natural refrigerant it is not considered due to its unacceptable health effects. An alternative definition would be "non-fluorocarbon refrigerants."

non-Article 5(1) markets. Parties may wish to consider the advantages of honouring this early leadership by avoiding the use of non-tariff trade barriers.

Restrictions on HFC technology will delay the ODS phaseout if contributions to the Multilateral Fund are not increased to finance more expensive alternatives.

HFC uncertainty could destabilise investment confidence and have unintended environmental consequences.

The use of HCFCs will soon be restricted in non-Article 5(1) countries, resulting in over-capacity and the likelihood of strong price competition in Article 5(1) markets. Any uncertainty in the market or regulatory acceptability of HFCs will reinforce decisions to prolong HCFC uses. Delay in conversion from HCFCs is more harmful to the ozone layer and climate than the early conversion to HFCs.

At the time the Montreal Protocol developed its phaseout strategy, it was not technically or economically possible to contain CFC and HCFC emissions and little effort made to recover and recycle. Furthermore, it was believed that zero-ODP refrigerants and insulation foam blowing agents would provide equal or better energy efficiency. At a future date, Parties to the Montreal and Kyoto Protocols may wish to revisit the HCFC phaseout decision mindful of the condition of the ozone layer and the need to protect the climate. At that time, a technical assessment could present the relative environmental performance of all available options.

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APPENDIX A – HALOCARBON REPLACEMENTS FOR HALON 1301 IN FIXED SYSTEMS

Alternatives to halon for fixed systems include inert gases, carbon dioxide and fluorocarbon agents as well as not-in-kind solutions (water based systems, dry powder systems etc). However, when a gaseous system is required and space and weight issues are important, halocarbon gases are the only choice. These agents share several common characteristics, with the details varying between chemicals. These common characteristics include the following:

1. All are electrically non-conductive;
2. All are clean agents; they vaporise readily and leave no residue;
3. All are liquefied gases or display analogous behaviour (e.g., compressible liquid);
4. All can be stored and discharged from fire protection system hardware that is similar to that used for halon 1301;
5. All (except HFC-23) use nitrogen super-pressurisation for discharge purposes;
6. All (except CF₃I) are less efficient fire extinguishants than halon 1301 in terms of storage volume and agent weight. The use of most of these agents requires increased storage capacity;
7. All are either permanent gases after discharge or are liquefied compressed gases which vaporise upon discharge (except HCFC Blend A which consists of 3.75% of a non-volatile liquid). Many require additional care relative to nozzle design and mixing.
8. All (except CF₃I) produce more decomposition products (primarily HF) than halon 1301 given similar fire type, fire size, and discharge time; and
9. All are more expensive at present than halon 1301 on a weight (mass) basis.
10. For all practical purposes none of these agents can be used as a direct (drop-in) replacement for halon 1301 in existing systems.

These agents differ widely in the areas of toxicity, environmental impact, storage weight and volume requirements, cost, and availability of approved system hardware. Each of these categories will be discussed for each agent in the following section

Toxicity

Table 1 summarises the toxicity information available for each chemical. The NOAEL is the No Observed Adverse Effect Level. This is the concentration at which no adverse effect was observed in the test specimen. The LOAEL is the Lowest Observed Adverse Effect Level. This is the lowest concentration at which an adverse effect was observed. For halocarbon agents, these levels are usually driven by the cardiotoxicity level of the agent. Several compounds including HFC-23 and FC-3-1-10 have little or no cardiotoxicity. Historically, it has been recommended that halon replacement agents should not normally be used at concentrations above the NOAEL in occupied areas. Use of agents up to the LOAEL has been permitted in occupied areas if adequate time delays and pre-discharge alarms were provided and time required

for escape was short. New recommendations have been proposed that would allow use at or above the LOAEL based on the use of a physiologically based pharmacokinetic (PB-PK) model.

It should be carefully noted that where the NOAEL value (%) is lower than the Design Concentration (%) the agent is not suitable for use in occupied areas. The term “Occupied Area” means both an area that is normally occupied by people or an area where people could be present during discharge of the fire protection system. The vast majority of fire protection applications are categorised as “Occupied Areas”.

Environmental Factors

The primary environmental factors to be considered for these agents are ozone-depletion potential (ODP), global-warming potential (GWP), and atmospheric lifetime, and these are summarised in Table 1. It is important to select the fire protection choice with the lowest environmental impact that will adequately provide the necessary fire protection performance for the specific application. The use of any synthetic compound that accumulates in the atmosphere carries some potential risk with regard to atmospheric equilibrium changes. PFCs, in particular, represent an unusually severe potential environmental impact due to the combination of extremely long atmospheric lifetime and high GWP.

International agreements and individual actions by national governments may affect future availability of these compounds and subsequent support for installed fire protection systems that utilise them. Some examples are presented below:

- HCFCs are scheduled for a production and consumption phaseout under the Montreal Protocol in 2020-2030 in developed countries and 2040 in developing countries.
- The European Union restricts HCFCs use for fire protection.
- HFCs and PFCs are included in the basket of six gases (SF₆, carbon dioxide, methane, nitrous oxide) for which flexible and binding emission reduction targets were agreed as part of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The Kyoto Protocol requires developed countries to reduce their aggregate emissions of the six gases by an average of 5% below 1990 levels. HFCs and PFCs represent less than 2% of current greenhouse gas emissions on a carbon-equivalency basis.
- The United States allows use of PFCs only when no other agent or engineering approach will meet the fire protection needs.

Table 1: Halocarbon Agents for fixed systems

Generic Name	Halon 1301	HCFC Blend A	HCFC-124	HFC-23	HFC-125	HFC-227ea	HFC-236fa	FC-2-1-8	FC-3-1-10	FIC-1311
Trade Name	BTM	NAF S-III	FE-24	FE-13	FE-25	FM-200	FE-36	CEA-308	CEA-410	Triodide
Heptane Extinguishing Concentration	3.2	9.9	6.7	12.5	8.1	6.6	6.1	7.3	5.9	3
Minimum Class B Fire Design Concentration	5	12	8	18	9.7	7.9	7.3	8.8	7.1	3.6
NOAEL (vol%)	5	10	1	50	7.5	9	10	30	40	0.2
LOAEL vol %	7.5	>10	2.5	<50	10	10.5	15	>30	>40	0.4
Suitable for Use in Occupied Areas	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	No
Mass Required Relative to Halon 1301	1	1.6	1.5	2.0	1.6	1.9	1.6	2.3	2.3	0.9
Cylinder Storage Volume Relative to Halon 1301	1	1.9	1.5	2.5	2.2	1.8	1.4	2.2	1.9	0.6
Ozone Depletion Potential	10	HCFC-22 = 0.05 HCFC-124 = 0.02 HCFC-123 = 0.02	0.02	0	0	0	0	0	0	0.0001
Global Warming Potential 100 yr*	6'900	HCFC-22 = 1,900 HCFC-124 = 620 HCFC-123 = 120	620	14'800	3'800	3'800	9'400	8'600	8'600	<1
Global Warming Potential 500 yr*	2'700	HCFC-22 = 590 HCFC-124 = 190 HCFC-123 = 36	190	11'900	1'200	1'300	7'300	12'400	12'400	<<1
Atmospheric Lifetime (years)*	65	HCFC-22 = 11.8 HCFC-124 = 6.1 HCFC-123 = 1.4	6.1	243	32.6	36.5	226	2'600	2'600	0.005

Limited use due to unsuitability for use in occupied areas or environmental concerns

* Source of GWP and ALT values "Scientific Assessment of Ozone Depletion: 1998." World Meteorological Organization, Global Ozone Research and Monitoring Project - Report No. 44

Conclusion

The only viable halocarbon alternatives to replace Halon 1301 in widespread applications are HFC-227ea, HFC-236fa and HFC-23. The other halocarbon agents are unsuitable due to toxicity or regulatory restrictions by environmental agencies. In all cases the halocarbon agents are less effective on a weight/volume basis than halon 1301. As a result all require more storage cylinders than a halon system for protection of a similarly sized hazard. In addition, as more extinguishing agent is required, the piping system and discharge nozzles will differ significantly than that normally used to discharge halon 1301.

Fire protection systems are stringently tested by certifying agencies and successful extinguishing agents are “listed” or “certified” by these agencies. A change of extinguishing agent requires re-engineering and re-testing of the equipment with the alternative agent. This usually requires the original equipment manufacturer to confirm the performance of the system with the alternative agent. In general, to meet national fire protection regulations, all fire protection systems must be listed or certified by a testing body recognised by the national fire regulations. This requirement adds to the impracticality of replacing an existing halon 1301 system by simply replacing the halon with an alternative halocarbon.

APPENDIX B – HYDROFLUOROCARBONS AND HYDROFLUOROETHERS AS ALTERNATIVES TO PERFLUOROCARBONS AND CFC-113

The introduction of hydrogen into an otherwise fully halogenated compound such as a perfluorocarbon can produce compounds called hydrofluorocarbons (HFCs). HFCs have zero ODP and atmospheric lifetimes and GWPs that are significantly lower than that of PFCs. The one commercially available HFC solvent (HFC-43-10) is non-flammable, low in toxicity and possesses the physical and chemical properties similar to CFC-113 and some PFCs (such as perfluorohexane). Table-1 summarises these properties. HFCs have successfully replaced CFCs, HCFCs, and PFCs in certain precision cleaning operations, aerosol and carrier fluid as well as in some niche industrial solvent applications.

Table 1

Properties @ 23 °C	HFC-43-10 CF ₃ CFHCFHCF ₂ CF ₃
Normal Boiling Point (°C)	55
Freezing Point (°C)	-80
Flash Point – closed cup (°C)	None
– open cup (°C)	None
Toxicity (LC50 in ppm)	11,700
Atmospheric Lifetime (yrs)	17.1
GWP (CO ₂ Equiv. For 100 Yr. ITH)	1700
ODP (CFC-11 = 1)	0
Density (g/ml)	1.58
Viscosity (cs)	0.42
Vapour Pressure (mmHg)	226
Heat of Vaporisation (cal/g)	31
Specific Heat (cal/g * °C)	0.27
Solubility Parameter (H)	6.7
Surface Tension (dynes/cm)	14.1
Solubility in Water (ppmw)	140
Solubility for Water (ppmw)	490
Flammable limits	None

Hydrofluoroethers as Alternatives to CFC-113, Perfluorocarbons and Hydrofluorocarbons

Numerous studies have shown that fluorinated compounds containing an ether linkage can result in shorter atmospheric lifetimes as compared to many of the CFC replacements currently being developed (1-7). The exceptions to this are fluorinated ethers in which the reactive hydrogen atom is located on a carbon that is otherwise completely substituted with fluorine (i.e., -CHF₂, -CHF-). For other hydrofluoroethers (HFEs), the atmospheric lifetimes are shorter with an increasing number of hydrogen atoms, particularly compounds with no fluorine substitution on the same carbon as the reactive hydrogen (i.e., -CH₂-, -CH₃). One class of HFEs is characterised by its manufacturer as “segregated” if all of the hydrogens reside on carbons with no fluorine

substitution and are separated from the fluorinated carbons by the ether oxygen (i.e., $C_xF_{2x+1}OC_yH_{2y+1}$). To date, thirteen segregated HFEs have been investigated for environmental properties. All of these compounds have demonstrated atmospheric lifetimes of 5 years or less. The shorter atmospheric lifetimes result in GWPs which are significantly lower than CFCs, PFCs, and any commercially available, non-flammable HFCs.

Two commercially available segregated HFEs (HFE-449s1 and HFE-569sf2) are non-flammable, non-ozone depleting, low in toxicity and possess the physical and chemical properties similar to CFC-113, HFCs and PFCs. Table 2 summarises these properties. HFEs have successfully replaced CFCs, HCFCs, HFCs and PFCs in certain precision cleaning operations, aerosol and carrier fluid as well as in some niche industrial solvent applications. Progress has also been made in the replacement of PFCs in some heat transfer applications such as in the semiconductor industry. The commercially available segregated HFEs cover a boiling point range of 40°C to 76°C. Research continues to develop new compounds with a boiling range from 30°C to >130°C.

While it is possible to create an HFC with a very short lifetime or an HFE with a long lifetime, the segregated HFEs are consistently short-lived and as a result have lower GWPs. Segregated HFEs can be used in many of the applications typically employing HFC or PFC liquids, leading to significant reductions in greenhouse gas emissions (80 to 99% depending upon the compounds involved in the substitution). Whenever possible, users should select the compounds with the lowest climate impacts, particularly in emissive applications.

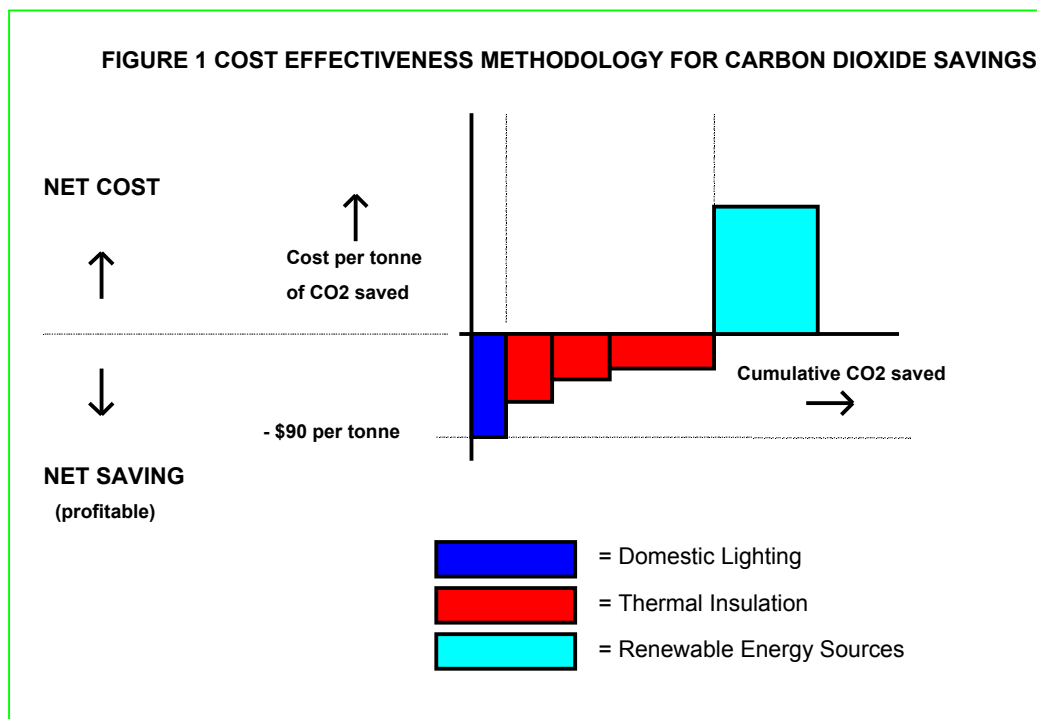
Table-2

Properties @ 23 °C	HFE-7100 C ₄ F ₉ OCH ₃	HFE-7200 C ₄ F ₉ OC ₂ H ₅
Normal Boiling Point (°C)	61	76
Freezing Point (°C)	-135	-135
Flash Point – closed cup (°C)	None	None
– open cup (°C)	None	None
Toxicity (LC50 in ppm)	>100,000	>92,000
Atmospheric Lifetime (yrs)	4.1	0.8
GWP (CO ₂ Equiv. For 100 Yr. ITH)	480	90
ODP (CFC-11 = 1)	0	0
Density (g/ml)	1.52	1.43
Viscosity (cs)	0.41	0.43
Vapour Pressure (mmHg)	202	109
Heat of Vaporisation (cal/g)	30	30
Specific Heat (cal/g * °C)	0.28	0.29
Solubility Parameter (H)	6.4	6.3
Surface Tension (dynes/cm)	13.6	13.6
Solubility in Water (ppmw)	12	<20
Solubility for Water (ppmw)	95	92
Flammable limits	None	

1. Cooper, D.L., T.P. Cunningham, N.L. Allan, and A. McCulloch, *Atmos. Env.*, 26A, 1331-1334, 1992.
2. Cooper, D.L., T.P. Cunningham, N.L. Allan, and A. McCulloch, *Atmos. Env.*, 27A, 117-119, 1993.
3. Zhang, Z., R.D. Saini, J.J. Kurylo, and R.E. Huie, *J. Phys. Chem.*, 96, 9301-9304, 1992.
4. Bartolotti, L.J. and E.O. Edney, *Int. J. Chem. Kinet.*, 26, 913-920, 1994.
5. Heathfield, A.E., C. Anastasi, P. Pagsberg and A. McCulloch, *Atmos. Env.*, 32, 711-717, 1998.
6. Wallington, T.J., et al., *J. Phys. Chem. A.*, 101, 8264-8274, 1997.
7. Christensen, L.K., et al., *J. Phys. Chem. A.*, 102, 4839-4845, 1998.

APPENDIX C – COST EFFECTIVENESS OF ENERGY EFFICIENCY MEASURES

Governments and industry endeavour to minimise the cost of actions required to meet their Kyoto targets through flexible regulatory strategies and by utilising cost effectiveness assessments such as *cost per tonne of CO₂ saved*. Many energy efficiency measures save so much energy (and hence money) during their lifetime that the investment returns a profit. Figure 1 presents the cost-effectiveness of measures along the ‘y’ axis whilst the total CO₂ reductions from the investment presented along the ‘x’ axis. The lowest cost options along the ‘x’ axis are selected until the target CO₂ savings are achieved.



Typically, the total lifetime ‘cost’ of a measure is calculated as follows:

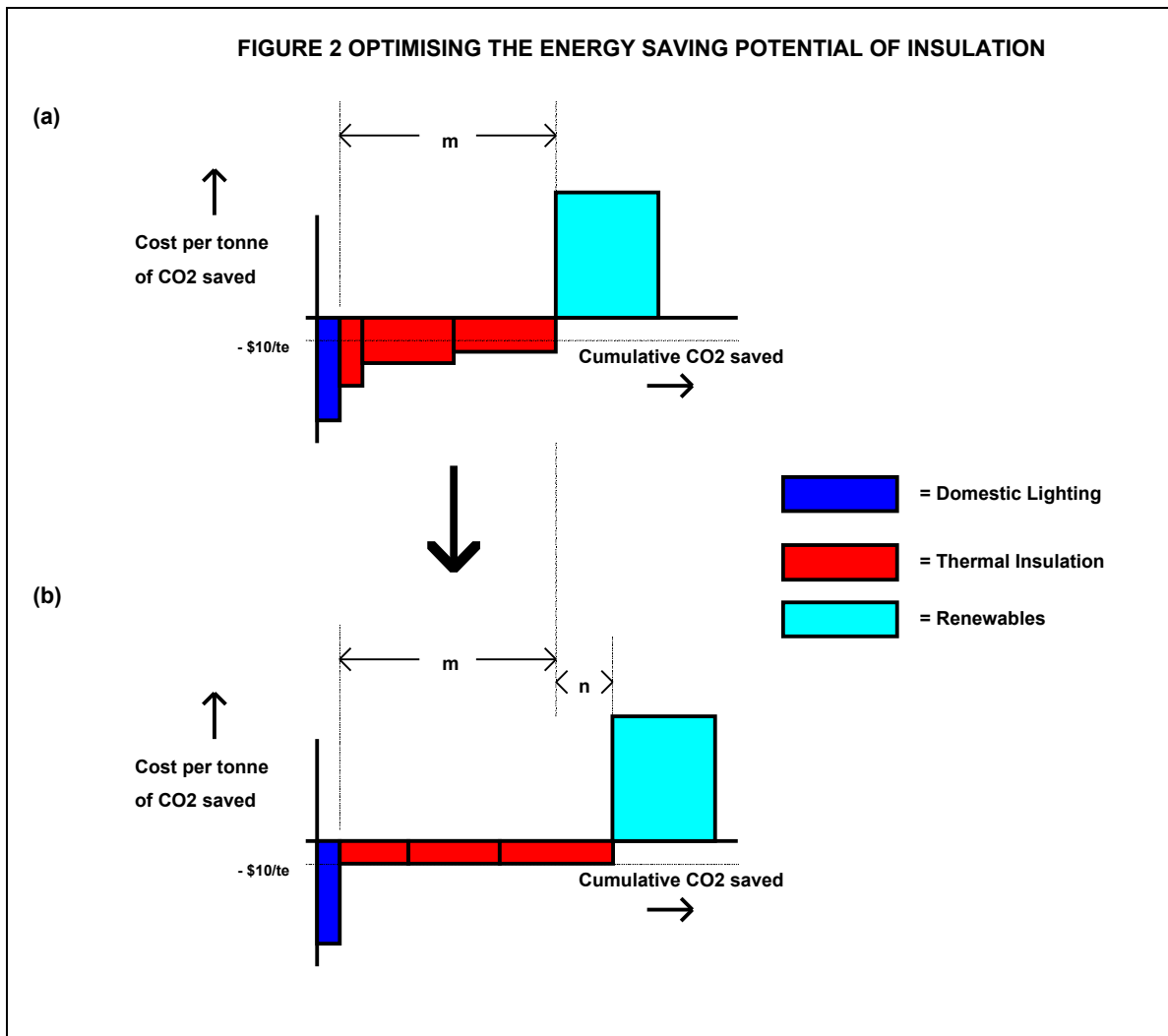
$$\text{Life-time cost} = \text{Initial investment cost}^* - [\text{Value of energy saving per year}]$$

The value of the cumulative energy saving is calculated over the full life of the measure. For thermal insulation the useful life of the investment can be anything between 15 years and 50 years. To account for the cost of money, a discount rate is applied to future savings in accordance with normal discounted cash-flow techniques. Discount rates of 5-8% provide conservative assessments of overall savings.

* Investment cost will be incremental if the measure is taken as part of the normal replacement cycle (e.g. new build or total refurbishment). However, if the measure is taken to specifically gain the energy benefit, the full cost of replacement (including labour) or a pro-rated cost based on how prematurely the equipment is retired will need to be considered. This can be a major cost element.

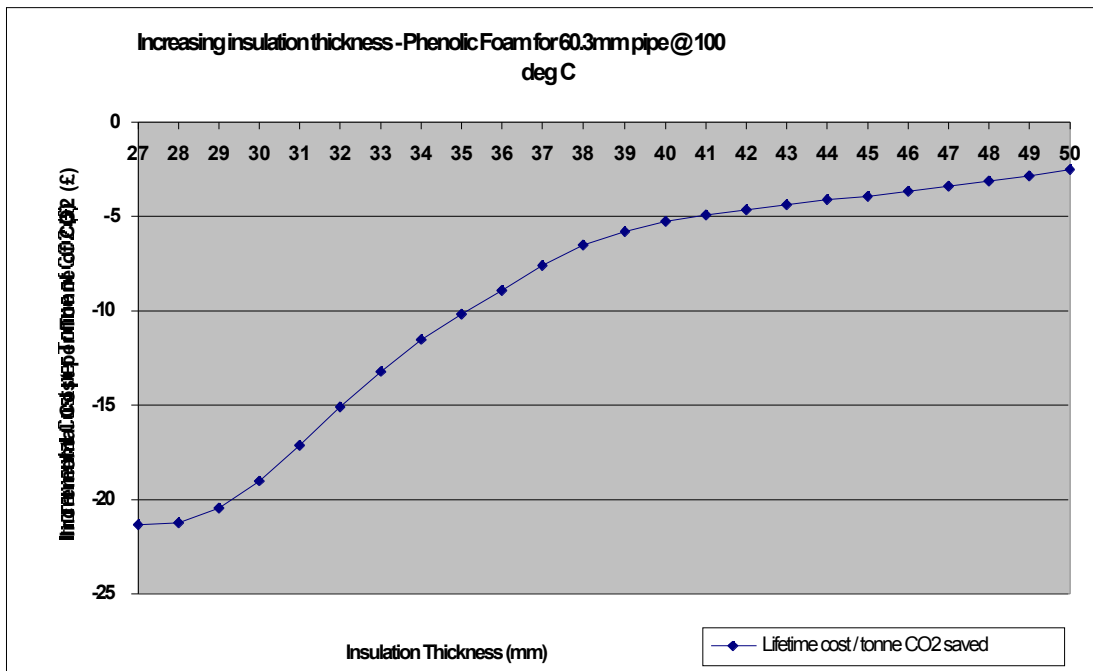
The lifetime benefits of thermal insulation measures are not only related to the product but also to the application. Accordingly, even the same insulation material will display different lifetime cost savings in different applications. Similarly, different insulation materials will have varying lifetime costs for the same application.

There is an additional value of thermal insulation that is unique in this context. It is possible to adjust the thickness of a piece of insulation to meet a target lifetime cost. Most energy efficiency measures average a net saving per CO₂ tonne of around \$10. Accordingly, where savings are significantly greater than this, it is possible to increase thickness and save more CO₂ rather than gain extra financial savings. Figure 2 illustrates this concept:



The incremental benefit that can be gained is therefore 'n' tonnes. This can make substantial impacts on the scope of CO₂ savings that are achievable and similar mechanisms are likely to be used as basis for upgrades in existing energy standards.

The figure below illustrates the increases in insulation thickness that can be achieved for pipe insulation on a 60.3mm O/D pipe at 100C.



With a budget of \$10-\$22/per ton of CO₂ reduced, a thickness from 27mm to 35mm would be justified in this case.

It should be noted that this approach would be a major change from most existing insulation standards because economic thicknesses have traditionally been selected for very short payback periods (typically 2-3 years). A lifetime costing approach is, however, consistent with the LCCP methodology and yields cost effective reductions in CO₂ emissions.

The cost effectiveness of insulation will be a substantial element in the saving of CO₂, hence more efficient insulation materials will provide greater opportunities to save additional CO₂ per unit incremental cost. In this context, the argument for retaining the option of HFC blown foams is potentially a strong one assuming that HFC costs themselves do not negate the cost-effectiveness advantage.

APPENDIX D – BREAKDOWN OF HFC, PFC & SF₆ APPLICATIONS FOR USES OTHER THAN ODS SUBSTITUTES

I. UNINTENTIONAL EMISSIONS

CHEMICAL PROCESSES

Co-production of HFC-23 when producing HCFC-22

METALLURGY

ALUMINIUM (CF₄, C₂F₆, SF₆)

Smelting process

Degassing agent in Aluminium casting

MAGNESIUM (SF₆)

Covergas for the casting of molten magnesium

NEODYMIUM (PFCs, SF₆)

Electrolytic production of neodymium

II. INTENTIONAL USE RESULTING IN EMISSIONS¹

COOLING- & HEAT-TRANSFER FLUID (C₆F₁₄, C₈F₁₆)

Direct evaporative cooling for electric and electronic apparatuses
(e.g., rectifiers, transformers, transmitters, computer elements, laser tubes)

Coolant in closed circuit of electric and electronic apparatuses
(e.g., large scale rectifiers and transformers for utility and railroad use, semiconductor manufacturing equipment)

COSMETICS (C₁₀F₁₈)

Anti-wrinkle creams & sunscreens

FEEDSTOCK

HFC-152a to produce fluoropolymers and petrochemical products

GLASS TREATMENT & ETCHING

HFC-152a in manufacturing

INFLATABLE PRODUCTS (SF₆)

Cushioning in athletic shoes

High-performance car tires

Tennis balls

¹ Some experts consider the use of HFC-152a or HFC-134a in self-chilling cans to be a new use rather than an ODS substitute.

INSULATING GAS (SF₆)

THERMAL/ACOUSTIC

Soundproof and thermal windows

Sealed stereo speaker cabinets to improve bass response

ELECTRICAL²

Switch-gear

Circuit breakers

Powerlines

Linear accelerator

Advanced surveillance radar systems (airborne warning and control system)

MEDICAL (SF₆, C₂F₆, C₃F₈, C₁₀F₁₈)

Internal tamponade (retina operations)

Collapsed lung expansion

Blood substitute (particularly for patients whose religions prohibit blood transfusions)

PROPELLANT

HFC-152a to replace HCs where VOCs are of concern

SEMICONDUCTOR MANUFACTURE (HFCs, PFCs, SF₆)

PLASMA ETCHING

CHEMICAL VAPOUR DEPOSITION PROCESSES

VAPOUR PHASE SOLDERING

Soldering (C₆F₁₄, C₁₄F₂₄, C₁₆F₂₆, C₁₇F₃₀)

Blanketing (C₆F₁₄)

TESTING & TRACERS

TESTING

Room integrity

Device integrity

Thermal shock

Liquid burn-in

Cable leak

TRACERS

Geologic mapping & atmospheric studies

² These applications have previously used CFC-12 as well as SF₆.

Description of Applications

Chemical Processes

HFC-23 is a by-product emitted during HCFC-22 production, representing between 2% and 5% of output. HCFC-22 is a “transitional substitute” under the Montreal Protocol scheduled for phaseout in non-feedstock use in 2020 in developed countries and 2040 in Article 5(1) countries. HCFC-22 is currently used as a refrigerant and foam-blowing agent and as a chemical feedstock for manufacturing synthetic polymers. Feedstock production is anticipated to grow steadily, primarily in the manufacture of fluoropolymers. Producers in the E.U., Japan, Korea and the United States are participating in voluntary programs to reduce HFC-23 emissions.

Metallurgy

Aluminium Production

Aluminium manufacturing accounts for the single largest source of PFC emissions as intermittent by-products of the smelting process. PFCs are emitted when the concentration of alumina falls too low, disrupting smelting and producing CF_4 (90%) and C_2F_6 (10%) in what is known as an “anode effect”. The U.S. has achieved a decrease in emissions from 1990 to 1996 because of voluntary emission reduction efforts by the industry.

SF_6 is used in combination with argon or nitrogen to improve the purity and strength of the metal by removing gas bubbles and solid particles from the molten aluminium. The SF_6 in the mixture is believed to be destroyed in the process.³

Magnesium Metal Production & Processing

The primary magnesium metal and part casters industry that produced magnesium from ore shifted from sulfur dioxide to SF_6 as a protective covergas for the casting of molten magnesium. The recycling industry still uses sulfur dioxide as a covergas.

Neodymium Production

PFC/ SF_6 emissions result from electrolytic production of neodymium. Neodymium is an element of the rare-earth group and is used in permanent magnet materials in NDFeB alloys.

Cooling- & Heat-Transfer Fluid

PFCs act as cooling liquids by absorbing heat from electrical components such as parts in a supercomputer or radar system. The heat is rejected by an external heat exchanger. The PFCs used are C_6F_{14} and C_8F_{16} .

Cosmetics

$\text{C}_{10}\text{F}_{18}$ (not a fully fluorinated hydrocarbon) is used as an oxygen carrier in anti-wrinkle creams and sunscreens. This liquid is not a fully fluorinated hydrocarbon, and its GWP has not been measured.

³ United States Environmental Protection Agency Office of Policy, Planning and Evaluation (2122). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996. EPA 236-R-98-006. March 1998, 3-22.

Feedstock

HFC-152a is used as a source of hydrogen fluoride in certain chemical processes (fluoropolymers, petrochemicals). The HFC is converted into other chemicals.

Glass Treatment and Etching

HFC-152a is used in small quantities to treat and etch glass.

Inflatable Products

Nike uses SF₆ in the 'Nike Air' product line as the gas to fill a cushioning pocket in the sole of their athletic shoes. Because of the large size of its molecule, SF₆ was selected as the cushioning gas after it became commercialised in 1978. This molecular property of SF₆ enabled it to slowly diffuse through the sole membrane, making it a closed system for the duration of its useful life. Approximately 65% of Nike footwear use SF₆. SF₆ is used in a small portion of tennis balls.

It is reported that at least one German automobile manufacturer uses SF₆ to inflate car tires because it escapes less quickly and provides superior shock absorption.

Insulating Gas

Thermal/Acoustic

The use of a barrier gas between the two sheets of glass rather than a partial vacuum results in more stable thermal and sound insulation properties for the window. This barrier gas may contain some SF₆, although other inert gases such as argon and krypton are also used. An awareness of SF₆ as a greenhouse gas is decreasing the already small volume used in insulated glass.

Electrical

The primary global use of SF₆ is as a dielectric in electrical transmission and distribution systems. These systems account for 80% of SF₆ use worldwide. The electric power industry has used this gas since the 1950s due to its dielectric and arc-quenching characteristics. It is used in gas-insulated substations, circuit breakers, and other switchgear. SF₆ has replaced flammable insulating oils in many applications due to its higher effectiveness and better operator safety performance. It also allows for more compact substations in dense urban areas. Emissions of SF₆ occur from leaks during servicing of substations and circuit breakers – especially from older equipment. Increased awareness and the high price of SF₆ have reduced this practice.

SF₆ is used on linear accelerators and other scientific equipment.

SF₆ is used as a dielectric gas in radar systems including airborne warning and control systems.

Medical

SF₆, C₂F₆ and C₃F₈ are used as an internal tamponade, i.e., a plugging of the eye during retina operations. The gas remains in the eye until the retina heals. There are no alternatives for these gases. In addition, C₁₀F₁₈ is used for collapsed lung expansion and as a blood substitute.

Propellant

HFC-152a is the propellant of choice for products that must meet regulations that specify maximum VOC content. Cities located in basins with little air exchange, such as Los Angeles and Mexico City, experience unhealthy photochemical smog as a result of NO_x combining with VOCs. In most locations, however, air movement removes NO_x quickly from cities to forested areas where there is typically so much naturally-occurring VOCs (terpene) that urban VOC emissions from aerosol products are environmentally unimportant.

Semiconductor Manufacture

The semiconductor industry currently emits a number of potent greenhouse gases from its manufacturing process including fluorocarbons (CF₄, C₂F₆, C₃F₈, C₄F₈, CHF₃), nitrogen trifluoride (NF₃) and sulfur hexafluoride (SF₆). These gases are used in two important processes – plasma etching thin films and cleaning chemical vapour deposition (CVD) tool chambers. Semiconductor manufacturers in Europe, Japan, Korea, Taiwan and the United States have set a global goal through the World Semiconductor Council to reduce PFC emissions by at least 10 percent below 1995 levels by 2010. This is the first time an entire industry has voluntarily agreed to reduce global climate change emissions.⁴

Testing and Tracers

PFCs C₆F₁₄, C₁₁F₂₀ and C₁₃F₂₂ are used in leak testing of hermetically sealed electrical components.

PFCs are used for tracing and tagging applications such as oil and gas field mapping, atmospheric studies and cable leak detection. Use in mapping is expected to diminish as computer modelling and other techniques are refined.

⁴ Chemical manufacturers previously had agreed to reduce N₂O emissions from adipic acid production.

APPENDIX E – BIBLIOGRAPHY SUBMITTED TO THE FCCC IN RESPONSE TO THEIR REQUEST FOR TECHNICAL INFORMATION (DECISION 13/CP.4)

Alexander, D. J. et al. “One-year Study in Dogs of the Toxicity of HFA-134a by Inhalation.” *Inhalation Toxicol*, 7(8), 1153-62 CODEN: INHTE5; ISSN: 0895-8378, 1995.

Ashford, P.K. “Thermal Insulation and its Role in Carbon Dioxide Reduction” Caleb Management Services, 1997.

Atkinson, Ward. “A Summary of the Mobile A/C Comfort Evaluation – Phoenix Alternate Refrigerant Forum.” The Earth Technologies Forum Conference Proceedings, pp. 112-120, October 1998.

Baker, James. “Mobile Air Conditioning and the Global Climate – A Summary of the Phoenix Refrigerant Forum – July 15-18, 1998.” The Earth Technologies Forum Conference Proceedings, pp. 104-111, October 1998.

Barreau, Mark. “Present European Environmentally-Friendly HCFC Substitutes in Stationary Air Conditioning.” The Earth Technologies Forum Conference Proceedings, pp. 206-214, October 1998.

Biesman G., De Vos R., Rosbotham I.D. “Comparison of Experimental and Predicted Ageing of PU Foams Blown with CFC Alternatives Proceedings of Utech '94 Paper 32, 1994.

Biesmans G., Karremans M., Randall D, Singh S.N. “Long Term Performance of Rigid Foams Blown with Non-CFC Blowing Agents” *Journal of Cellular Plastics* Vol. 34 July/August 1998.

Brandscome, Marvin. Opportunities for Reduction of HFC-23 Emissions. Research Triangle Institute.

Campbell, N.J. and A. McCulloch (1998). The Climate Change Implications of Manufacturing Refrigerants – A Calculation of “Production” Energy Contents of Some Common Refrigerants, *Trans. IchemE*, 76B, pp. 239-244.

Campbell, N.J. and A. McCulloch (1999). Coping With the Common Coolant, *Chem. & Ind.*, 5 April 1999, pp. 262-267.

Clodic, Denis. “Major Technical Options Aiming to the Limitation of Ozone Depleting Substances.” The Earth Technologies Forum Conference Proceedings, pp. 247-253, October 1998.

Clodic, Denis. “Measurement and Simulation of Energy and Fuel Consumption.” The Earth Technologies Forum Conference Proceedings, pp. 121-129, October 1998.

Cooper, Peter J. “Experience with Secondary Loop Refrigeration Systems in European Supermarkets.” Proceedings of the International Conference on Ozone Protection Technologies, pp. 506-515, November 1997.

Dalby, Richard N. "Safety Assessment of Metered Dose Inhalers Containing Flammable Propellants." *Journal of Biopharmaceutical Science*, 3(1-2), 49-57 CODEN: JBISE2, 1992.

Dekant, Wolfgang. "Toxicology of Chlorofluorocarbon Replacements." *Environmental Health Perspective Suppl.* (1996), 104 (Suppl. 1), 75-83 CODEN: EHPSEO; ISSN: 1078-0475, 1996.

DETR (Department of the Environment, Transport and the Regions). UK Emissions of HFCs, PFCs and SF6 and Potential Emission Reduction Options. Final Report Prepared by March Consulting Group, January 1999.

EC DGIII-C-4 (European Commission DG3). Opportunities to Minimise Emissions of Hydrofluorocarbons (HFCs) From the European Union. Final Report Prepared by March Consulting Group, UK, September 30, 1998.

Ensuring Patient Care. International Pharmaceutical Aerosol Consortium. 2nd Edition, June 1999.

Fischer, S.K, J.J Tomlinson, and P.J. Hughes. Energy and Global Warming Impacts of Not-in-Kind and Next Generation CFC and HCFC Alternatives. Prepared by Oak Ridge National Laboratory for Alternative Fluorocarbons Environmental Acceptability Study and U.S. Department of Energy, 1994.

Gaarenstroom P.D., Letts J.B., Harrison A.M. "Distribution of CFC-11 in Aged Urethane and Isocyanurate CLBS Foam" 32nd Annual Polyurethane Technical/Marketing Conference (October 1989).

Hara, Kiyoshi. "CFC Recovery Voluntary Plan in Japanese Industry." The Earth Technologies Forum Conference Proceedings, pp. 146-152, October 1998.

IEA, Annex 22, "Guidelines for Design and Operation of Compression Heat Pump, Air Conditioning and Refrigerating Systems with Natural Working Fluids," Final Report from Annex 22 of IEA Heat Pump Programme, editor Jorn Stene, SINTEF Energy Research (N), Report HPP-AN22-4, December 1998, ISBN 90-73741-31-9.

IPAC (International Pharmaceutical Aerosol Consortium). Ensuring Patient Care: The Role of the HFC MDI, 1997.

Jacobsen, Arne and Sintef Trondheim. "Carbon Dioxide in Marine Refrigeration Applications." The Earth Technologies Forum Conference Proceedings, pp. 153-172, October 1998.

Johnson, Robert. "Influence of Blowing Agent Selection and Foam Ageing on Energy Consumption and TEWI of Refrigerants." The Earth Technologies Forum Conference Proceedings, pp. 270-278, October 1998.

June, David and D. Ross. "Improvement in Dosing Characteristics Achieved With a New HFA Salbutamol Metered Dose Inhaler (MDI) as Compared to a Marketed CFC Salbutamol MDI." Annual Congress of the European Respiratory Society, Barcelona, Spain, September 16-20, 1995. *European Respiratory Journal*, Volume 8, No. SUPPL. 19, p. 123S ISSN: 0903-1936, 1995.

June, David et al. "Reduced Effect of Temperature on Drug Delivery Characteristics of CFC-free Metered Dose Inhalers (MDIs) Compared to Current CFC Metered Dose Inhalers." Annual Congress European Respiratory Society, Stockholm, Sweden, September 7-11, 1996. European Respiratory Journal Supplement, Volume 9, No. 23, p. 255S ISSN: 0904-1850, 1996.

June, David. "Achieving the Change: Challenges and Successes in the Formulation of CFC-free MDIs." European Respiratory Review [EUR-RESPIR-REV], Vol/Iss/Pg. 7/41 (32-34), ISSN: 0905-9180, 1997.

Kauffeld, M. (editor): Applications of Natural Refrigerants '96, IIR, 12 (1996).

Kauffeld, M., Minds, G., Madsbøll, H.: Water as Refrigerant, Scanref 25, 4 (1996), p. 5-7.

Kauffeld, M.: Breakthroughs in Mobile Hydrocarbon Refrigeration and Cooling. International CFC & Halon Alternatives Conference, Washington D.C., 23-25 Oct. 1995.

Kruse, H. "The State of the Art of Hydrocarbon Technology in Household Refrigeration." Proceedings of the International Conference on Ozone Protection Technologies, pp. 179-188, October 21-23, 1996.

Kruse, Horst. "Systems Comparison of R-22 Replacement Refrigerants." The Earth Technologies Forum Conference Proceedings, pp. 225-236, October 1998.

Leach, C. "Safety Assessment of the HFA Propellant and the New Inhaler." European Respiratory Review, 7/41 (35-36). Refs: 3 ISSN: 0905-9180 CODEN: EREWEH, 1997.

Leach, Chet L. "Approaches and Challenges to Use Freon Propellant Replacements." Aerosol Science Technology, 22(4), 328 CODEN: ASTYDQ; ISSN: 0278-6826, 1995.

Mathur, G.D. "Performance of Vapour Compression Refrigeration System with Hydrocarbons: Propane, Isobutane, and 50/50 Mixture of Propane/Isobutane." Proceedings of the International Conference on Ozone Protection Technologies, pp. 835-844, October 1996.

McCulloch, A. Halocarbon Emissions During the Next Century, Joint IPCC/TEAP Expert Meeting, ECN Petten, Netherlands, 26-28 May 1999.

McCulloch, A. (1994). Sources of Hydrochlorofluorocarbons, Hydrofluorocarbons and Fluorocarbons and Their Potential Emissions During the Next Twenty-Five Years, Environmental Monitoring and Assessment, 31, 167-194.

McCulloch, A. (1995). Future Consumption and Emissions of Hydrofluorocarbon (HFC) Alternatives to CFCs: Comparison and Estimates Using Top-Down and Bottom-Up Approaches, Environment International, 21(4), pp. 353-262.

McCulloch, A. and N.J. Campbell. The Climate Change Implications of Producing Refrigerants, presented at “Natural Refrigerants ’98,” International Institute of Refrigeration, Oslo, Norway, 2-5 June 1998.

McCulloch, A.; TEWI (Total Equivalent Warming Impact): A Tool to Design and Operate Systems for Minimum Greenhouse Impact, presented at XVIII Quadrennial Ozone Symposium, L’Aquila, I, 12-21 September, 1996.

Metered Dose Inhaler Technology 188-89. Tol S. Purewal and David J. W. Grant, eds.

Midgley, P.M. and A. McCulloch (1999). Properties and Applications of Industrial Halocarbons, Production, Sales and Emissions of Industrial Halocarbons, and International Regulations on Halocarbons, Chapters 5, 6, and 8 of The Handbook of Environmental Chemistry, Vol. 4, Part E (P. Fabian and O.N. Singh, eds.), Springer Verlag, Heidelberg.

Ministry of Environment and Energy, Denmark, Danish Environmental Protection Agency. Going Towards Natural Refrigerants, Environmental Project No. 301, 1995.

Neksa, Petter. “Carbon Dioxide as Working Fluid in Air Conditioning and Heat Pump Systems.” The Earth Technologies Forum Conference Proceedings, pp. 215-224, October 1998.

NOAA, NASA, UNEP, WMO, Scientific Assessment of Ozone Depletion: 1994, Executive Summary, World Meteorological Organisation, Global Ozone Research and Monitoring Project-Report No. 37, pp. 36, 1995. (ISBN 92-807-1569-0).

Paul, Joachim. “A Fresh Look at Hydrocarbon Refrigeration: Experience and Outlook.” Proceedings of the International Conference on Ozone Protection Technologies, pp. 252-259, October 21-23, 1996.

Price L., Michaelis L., Worrell E., Khrushch M. “Sectoral Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions” OECD Environment Directorate (1998).

Rosenqvist, Per. “Emerging Issues in Stratospheric Ozone Protection Policy – European Perspective on HCFCs and HFCs.” The Earth Technologies Forum Conference Proceedings, pp. 75-80, October 1998.

Sand, J.R., S.K. Fischer, and V.D. Baxter. Energy and Global Warming Impacts of HFC Refrigerants and Emerging Technologies. Prepared by Oak Ridge National Laboratory for Alternative Fluorocarbons Environmental Acceptability Study and U.S. Department of Energy, 1997.

Sauer, Frederique. “Containment and Leakage.” The Earth Technologies Forum Conference Proceedings, pp. 264-269, October 1998.

Smith, I. J. "The Challenges of Reformulation." *Journal of Aerosol Medicine: Deposition, Clearance, and Effects in the Lung [J-AEROSOL-MED-DEPOSITION-CLEAR-EFF-LUNG]*, Vol/Iss/Pg. 8/SUPPL. 1 (S-19-S-27), ISSN: 0894-2684, 1995.

Smith, Ian J. "The Challenge of Reformulation." *Journal of Aerosol Medicine*, Volume 8, Supplement 1, pp. S-19 – S-27, 1995.

Sonnekalb, Michael and Jürgen Köhler. "Air-Conditioning Unit Using CO₂ as Refrigerant Installed in a Bus." *Proceedings of the International Conference on Ozone Protection Technologies*, pp. 825-834, October 1996.

Sonnekalb, Michael and Jürgen Köhler. "Transport Refrigeration with a Transcritical Refrigeration Cycle using Carbon Dioxide as Refrigerant." *Proceedings of the International Conference on Ozone Protection Technologies*, pp. 124-133, November 1997.

Steven, J.H. and A. McCulloch (1989). CFCs – The Search for Alternatives, I. *Chem. E. Environmental Protection Bulletin*, 3, 3-7.

Svanström M. "Blowing Agents in Rigid Polyurethane Foam – Analytical Studies into Technical and Environmental Aspects" Chalmers University of Technology (1997).

Symonds Travers Morgan. "Construction and Demolition Waste Project in the framework of the Priority Waste Streams Programme of the European Commission – Report of the Project Group to the European Commission Part 1 – Information Document" European Commission (October 1997).

Tansey, I. "Technological Development of Airomir (Salbutamol Sulphate in CFC-free System) MDI." *British Journal of Clinical Practice [BR-J-CLIN-PRACT]*, Vol/Iss/Pg. 49/SUPPL. 79 (13-17), ISSN: 0007-0947, 1995.

UNEP (1989) CFCs for Aerosols, Sterilants and Miscellaneous Uses Technical Options Report, United Nations Environment Programme, pp. 64, June 30, 1989.

UNEP (1989) Economic Panel Report, United Nations Environment Programme, 3 Volumes, Preliminary Draft, pp. 154, 1989.

UNEP (1989) Electronics, Degreasing and Dry Cleaning Solvents Technical Options Report, United Nations Environment Programme, pp. 201, June 30, 1989.

UNEP (1989) Halon Fire Extinguishing Agents Technical Options Draft Report, United Nations Environment Programme, pp. 70, June 30, 1989.

UNEP (1989) Refrigeration, Air Conditioning and Heat Pumps Technical Options Report, United Nations Environment Programme, pp. 148, June 30, 1989.

UNEP (1989) Report of the Flexible and Rigid Foams Technical Options Committee, United Nations Environment Programme, pp. 85, June 30, 1989.

UNEP (1989) Report of the Technology Review Panel, United Nations Environment Programme, pp. 103, June 30, 1989.

UNEP (1991) Report of the Aerosols, Sterilants, Miscellaneous Uses and Carbon Tetrachloride Technical Options Committee, 1991 Assessment, United Nations Environment Programme, pp. 103, December 1991.

UNEP (1991) Report of the Economic Options Committee, 1991 Assessment, United Nations Environment Programme, pp. 142, December 1991.

UNEP (1991) Report of the Flexible and Rigid Foams Technical Options Committee, 1991 Assessment, United Nations Environment Programme, December 1991.

UNEP (1991) Report of the Halons Technical Options Committee, United Nations Environment Programme, pp. 154, December 1991.

UNEP (1991) Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 1991 Assessment, United Nations Environment Programme, pp. 294, December 1991.

UNEP (1991) Report of the Technology and Economic Assessment Panel, 1991 Assessment, United Nations Environment Programme, December 1991. (ISBN 92-807-1314-0).

UNEP (1992) Methyl Bromide: Its Atmospheric Science, Technology, and Economics, Montreal Protocol Assessment Supplement, United Nations Environment Programme, pp. 41, 1992.

UNEP (1992) Report of the Ad-Hoc Technical Advisory Committee on ODS Destruction Technologies, United Nations Environment Programme, pp. 152, 1992.

UNEP (1993) ODS Destruction Technology Update, Technology and Economic Assessment Panel, Workshop Proceedings, October 20-21, 1993, Washington, D.C., USA, United Nations Environment Programme, pp. 332, 1994.

UNEP (1993) Recommendations on Nominations for Essential Use Production/Consumption Exemptions and International Bank Management of Halons, Prepared by the Halons Technical Options Committee, United Nations Environment Programme, pp. 77, 1993.

UNEP (1993) Report of the Technology and Economic Assessment Panel, United Nations Environment Programme, July 1993.

UNEP (1994) Handbook on Essential Use Nominations, prepared by the Technology and Economic Assessment Panel, United Nations Environment Programme, pp. 43, July 1994.

UNEP (1994) Report of the Aerosols, Sterilants, Miscellaneous Uses and Carbon Tetrachloride Technical Options Committee, United Nations Environment Programme, October 1994. (ISBN 92-807-1451-1).

UNEP (1994) Report of the Economics Options Committee, 1995 Assessment, United Nations Environment Programme, 1994. (ISBN 92-807-1452-X).

UNEP (1994) Report of the Flexible and Rigid Foams Technical Options Committee, 1995 Assessment, United Nations Environment Programme, 1994. (ISBN 92-807-1453-8).

UNEP (1994) Report of the Halon Fire Extinguishing Agents Technical Options Committee, United Nations Environment Programme, pp. 174, December 1994.

UNEP (1994) Report of the Methyl Bromide Technical Options Committee, 1995 Assessment, United Nations Environment Programme, pp. 304, 1994. (ISBN 92-807-1448-1).

UNEP (1994) Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 1995 Assessment, United Nations Environment Programme, pp. 301, 1994. (ISBN 92-807-1455-4).

UNEP (1994) Report of the Solvents, Coatings and Adhesives Technical Options Committee, 1995 Assessment, United Nations Environment Programme, 1994. (ISBN 92-807-1456-2).

UNEP (1994) Report of the Technology and Economic Assessment Panel, March 1994, United Nations Environment Programme, March 1994.

UNEP (1994) Report of the Technology and Economic Assessment Panel, 1995 Assessment, United Nations Environment Programme, pp. 176, 1994. (ISBN 92-807-1450-3).

UNEP (1995) Assessment of Basic Problems Confronting Countries with Economies in Transition in Complying with the Montreal Protocol, Report of the TEAP Ad-Hoc Working Group on CEIT Aspects, United Nations Environment Programme, pp. 153, November 1995. (ISBN 92-807-1533-X).

UNEP (1995) Evaluation of the Use of Ozone Depleting Substances as Chemical Process Agents and Alternatives, Report of the Chemical Process Agents Working Group of the TEAP, United Nations Environment Programme, pp. 48, 1995. (ISBN 92-807-1486-4).

UNEP (1995) Laboratory and Analytical Uses of Ozone-Depleting Substances, Workshop Proceedings, November 29-30, 1994, Burlington, Ontario, Canada, Report of the Laboratory and Analytical Uses Working Group of the TEAP, United Nations Environment Programme, pp. 229, February 1995.

UNEP (1995) Supplement to the 1994 Assessments, March 1995, Part I: Synthesis of the Reports of the Scientific Assessment Panel and Technology and Economic Assessment Panel; Part II: Report of the Technology and Economic Assessment Panel, pp. 149; Part III: Impact of HCFC and Methyl Bromide Emissions on Ozone Depletion: A Supplement Report of the Science Assessment Panel; United Nations Environment Programme, pp.15, March 1995. (ISBN 92-807- 1476-7).

UNEP (1995) Technology and Economic Assessment Panel Report to the Parties, November 1995, Part I: Economic and Financial Implications of Methyl Bromide Control Scenarios for Article 5(1) Countries; Part II: Economic and Financial Implications of Hydrochlorofluorocarbon Control Scenarios for Article 5(1) Countries; Part III: Economic and Financial Implications of CFC, Halon, Carbon Tetrachloride, and 1,1,1, trichloroethane Control Scenarios for Article 5(1) Countries; Part IV: Economic and Financial Implications of Trade in Annex A and Annex B Substances to Article 5(1) Countries After 1995, United Nations Environment Programme, November 1995.

UNEP (1996) Final Report of the TEAP Task Force on CEIT Aspects, United Nations Environment Programme, pp. 62, November 1996. (ISBN 92-807-1629-8).

UNEP (1996) Technology and Economic Assessment Panel, June 1996 Report, Part I: Assessment of the Funding Requirement for the Replenishment of the Multilateral Fund for the Period 1997-99; Part II: Phaseout Schedules for the Controlled Substances under the Montreal Protocol; Part III: Update on the 1994 TOC Aerosols Report and the MDI Transition Strategy; Part IV: Methyl Bromide Studies; Part V: Miscellaneous Issues; Part VI: Technology and Economic Assessment Panel Activities, Update and Terms of Reference for Operation; United Nations Environment Programme, pp. 162, June 1996. (ISBN 92-807- 1593-1).

UNEP (1996) Technology and Economic Assessment Panel, March 1996 Report, Part I: Requests by Parties and TEAP Organisation and Functioning; Part II: Essential Use Nominations; United Nations Environment Programme, pp. 25, March 1996. (ISBN 92-807-1582-8).

UNEP (1997) Handbook on Essential Use Nominations prepared by the Technology and Economic Assessment Panel, United Nations Environment Programme, pp. 51, August 1997.

UNEP (1997) Technology and Economic Assessment Panel, April 1997 Report, Part I: Essential Use Nominations; Part II: The MBTOC April 1997 Progress Report to TEAP and Miscellaneous Methyl Bromide Issues; Part III: TOC Progress Reports and Specific Progress Issues, Possible Applications of HCFCs, Executive Summaries of Volume II Reports; Part IV: Progress on the Restructuring of the Technology and Economic Assessment Panel, TEAP Membership Background Information, Contact Information for TEAP Members and TOCs; United Nations Environment Programme, Volume I, pp. 221, April 1997. (ISBN 92-807-1654-8).

UNEP (1997) Technology and Economic Assessment Panel, Part I: Report of the Aerosols, Sterilants, Miscellaneous Uses and Carbon Tetrachloride TOC, Update on Developments, Issues Surrounding a Transition to Non-CFC Treatments, Evaluation of Status of Use of ODS and Alternatives; Part II: Report of the Process Agents Task Force; Part III: Assessment of the Use of Flammable Refrigerants; Part IV: Assessment of the Economic Viability of Methyl Bromide Alternatives; United Nations Environment Programme, Volume II, pp. 311, April 1997. (ISBN 92-807-1655-6).

UNEP (1998) April Report of the 1998 Technology and Economic Assessment Panel, United Nations Environment Programme, pp. 191, April 1998. (ISBN 92-807-1704-9).

UNEP (1998) Report of the Economic Options Committee, 1998 Assessment, United Nations Environment Programme, 1998. (ISBN 92-807-1727-8).

UNEP (1998) Report of the Halon Fire Extinguishing Agents Technical Options Committee, 1998 Assessment, United Nations Environment Programme, 1998. (ISBN 92-807-1729-4).

UNEP (1998) Report of the Methyl Bromide Technical Options Committee, 1998 Assessment of Alternatives to Methyl Bromide, United Nations Environment Programme, 1998. (ISBN 92-807-1730-8).

UNEP (1998) Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 1998 Assessment, United Nations Environment Programme, pp. 285, 1998. (ISBN 92-807-1731-6).

UNEP (1998) Report of the Solvents, Coatings and Adhesives Technical Options Committee, 1998 Assessment, United Nations Environment Programme, 1998. (ISBN 92-807-1732-4).

UNEP (1998) Report of the Technology and Economic Assessment Panel, 1998 Assessment, United Nations Environment Programme, pp. 286, 1998. (ISBN 92-807-1725-1).

UNEP (1999) Report of the Technology and Economic Assessment Panel, Volume 1: Assessment of the Funding Requirement for the Replenishment of the Multilateral Fund for the Period 2000-2002; Volume 2: Essential Use Exemptions, Q&PS Applications For Methyl Bromide, Progress and Development in the Control of Substances and Other Reporting Issues; United Nations Environment Programme, April 1999. (ISBN 92-807-1770-7).

UNEP (1999) Synthesis of the Reports of the Scientific, Environmental Effects and Technology and Economic Assessment Panels of the Montreal Protocol. A Decade of Assessments for Decision Makers Regarding the Protection of the Ozone Layer: 1988 – 1999, pp. 165, 1999. (ISBN 92-807-1733-2).

Vogelsberg, F.A. An Industry Perspective – Lessons Learned and the Cost of the CFC Phaseout. International Conference on Ozone Protection Technologies, October 1996.

Wertenbach, Jürgen, Jürgen Maué, and Wolfgang Volz. "CO₂ Refrigeration Systems in Automobile Air-Conditioning." Proceedings of the International Conference on Ozone Protection Technologies, pp. 855-864, October 1996.

WMO, UNEP, FAA, NASA, NOAA, Report of the International Ozone Trends Panel-1988, World Meteorological Organisation, Global Ozone Research and Monitoring Project-Report No. 18, United Nations Environment Programme (UNEP), Federal Aviation Administration (FAA), National Aeronautic and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Volume I, pp.442, 1988.

WMO, UNEP, Report of the Third Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer, World Meteorological Organisation, United Nations Environment Programme, WMO Global Ozone Research and Monitoring Project-Report No. 41, 1996.

You, Peng Zheng. "Case Studies on Energy Efficient ODS-Free Technologies." The Earth Technologies Forum Conference Proceedings, pp. 186-191, October 1998.

Zhang, Jianguo. "Prospects for HFC-152a-based Mixtures as CFC-12 Alternatives." The Earth Technologies Forum Conference Proceedings, pp. 179-185, October 1998.

**APPENDIX F – WEBSITES CONTAINING RELEVANT INFORMATION ON HFCS
AND PFCS**

SITE	DESCRIPTION	Type ⁵
cwis.nyu.edu/pages/mathmol/	MathMol (Mathematics and Molecules) Home Page	5
kulde-nett.skarland.no	KULDE-Nett – Kulde-bransjens utgangspunkt	2
www.afeas.org	Alternative Fluorocarbons Environmental Acceptability Study	5
www.airah.org.au	Australian Institute of Refrigeration, Air-Conditioning, and Heating (Inc.)	2
www.aircondition.com	Automotive Air Conditioning Information Server	4
www.akb.dk	Autoriserede Klefirmaers Branchforening	5
www.allied.com	Allied Signal	4
www.ari.org	Air-Conditioning and Refrigeration Institute	2
www.ashrae.org	American Society of Heating, Refrigerating and Air-Conditioning Engineers	2
www.ausimont.com	Ausimont	4
www.autofrost.com	Autofrost R406a R414 a Home Page	4
www.baltaircoil.com	Baltimore Aircoil	4
www.bcse.org	The Business Council for Sustainable Energy	2
www.bfs-kaelte-klima.com	Bundesfachschule	4
www.carrier.com/HomePage	Carrier – World Leader in Air Conditioning, Heating and Refrigeration Systems	4
www.cci-promotor.de	Die CCInternet im Promotor Verlag	4
www.climatenetwork.org	Climate Network Europe	3
www.coolsite.dk	The Danish Technological Institute site on Natural Refrigerants	5

⁵ Organisation Types:

1 – Government and Intergovernmental

2 – Associations

3 – ENGOs

4 – Industry

5 – Academic and Research

www.davidsuzuki.org	The David Suzuki Foundation	3
www.denix.osd.mil/denix/Public/News/OSD/Climate/talkpts.html	Department of Defense Talking Points on Climate Change and National Security	1
www.dow.com/heattrans	Dow Chemical Heat Transfer	4
www.dtic.mil/ddre/fire_suppression/cover.html	Next-Generation Fire Suppression Technology: Strategy for a National Program	1
www.dupont.com	DuPont	4
www.edf.org	Environmental Defense Fund	3
www.eeb.org	European Environment Bureau	3
www.elf-atochem.com	Elf Atochem	4
www.enme.umd.edu/ceee	Centre for Environmental Energy Engineering	5
www.epa.gov/ozone	Environmental Protection Agency Stratospheric Ozone Division	1
www.fiz-karlsruhe.de/peu/peuger.html	Projektgruppe Energie und Umwelt	5
www.foe.org	Friends of the Earth	3
www.frigorbox.it	FRIGOR-BOX Home Page	4
www.gartner-refrig.com	Gartner Refrigeration & Mfg., Inc.	4
www.genetron.com	Allied Signal Inc. Genetron	4
www.greenhousegases.org	Greenhouse Gases Inventory Consortium	5
www.greenpeace.org	Greenpeace	3
www.gtz.de/proklima/index.html	PROKLIMA: The Ozone Depleting Substances Phase Out Project in German Technical Cooperation	2
www.he.afrl.af.mil/hes/hest/default.html	Air Force Research Laboratory Human Effectiveness Directorate Operational Toxicology Branch	1
www.ici.com	ICI	4
www.iea.org	International Energy Agency	1
www.iifir.org	International Institute of Refrigeration	2
www.ilkdresden.de	Institut für Luft und Kältetechnik	5
www.ipac.com	International Pharmaceutical Aerosol Consortium	2
www.lawton.co.uk/clients/care	Calor CARE	4

www.mannlib.cornell.edu:10000/hmv1/watrsoil/surf.htm	Water Surface Tension	5
www.mmm.com/market/industrial/fluids/refheat.html	3M Specialty Fluids Heat Transfer	4
www.mst.dk/publica/01000000.htm	Report on potent greenhouse gases by Danish EPA	1
www.ngdc.noaa.gov/paleo/perspectives	NOAA Handbook on Global Warming	1
www.nist.gov	National Institute of Standards and Technology	1
www.nist.gov/srd	NIST Standard Reference Data Products Catalog	1
www.nrdc.org	Natural Resources Defense Council	3
www.osar.odessa.ua	Odessa State Academy of Refrigeration	5
www.paft.org	Programme for Alternative Fluorocarbon Toxicity Testing	5
www.panda.org	World Wide Fund for Nature	3
www.protonique.com/unepstoc	United Nations Environment Programme Solvents Technical Options Committee	1
www.rismed.com/Millennia.html	MILLENNIA, the Freon replacement	4
www.solvay.com	Solvay	4
www.teap.org	Technology and Economic Assessment Panel	1
www.teknologisk.dk	Danish Technological Institute	5
www.teriin.org	Tata Energy Research Institute	5
www.ttc.nrc.ca	Thermal Technology Centre	5
www.unepie.org	OzonAction	1
www.worldwatch.org	Worldwatch Institute	3
www.wri.org	World Resources Institute	3

APPENDIX G – DECISIONS UNDER THE MONTREAL PROTOCOL AND UNFCCC PERTAINING TO HFCS AND PFCs

Decision X/16. Implementation of the Montreal Protocol in the light of the Kyoto Protocol

Noting the need to implement multilateral environmental agreements in a coherent way for the benefit of the global environment,

Noting that the Conference of the Parties to the United Nations Framework Convention on Climate Change adopted the Kyoto Protocol to the Convention at its third meeting, held in Kyoto, from 1 to 11 December 1997,

Noting that the Kyoto Protocol requires Parties listed in Annex I of the Framework Convention on Climate Change to ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A of that Protocol do not exceed their assigned amounts as listed in Annex B during the first commitment period of 2008-2012,

Noting further that the greenhouse gases included in Annex A of the Kyoto Protocol include hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) in view of their high global warming potentials,

Noting that the Technology and Economic Assessment Panel has identified HFCs and PFCs as alternatives to ozone-depleting substances, and some Parties and enterprises have already changed over, and others are changing over, to such HFC and PFC technologies, and

Noting with appreciation that the Conference of the Parties to the Framework Convention on Climate Change at its fourth meeting adopted a decision on the relationship between efforts to protect the stratospheric ozone layer and efforts to safeguard the global climate system, in particular with reference to HFCs and PFCs,

To request, with a view in particular to assisting the Parties to the Montreal Protocol to assess the implications for the implementation of the Montreal Protocol of the inclusion of HFCs and PFCs in the Kyoto Protocol, the relevant Montreal Protocol bodies, within their areas of competence:

- (a) To provide relevant information on HFCs and PFCs to the Secretariat of the Framework Convention on Climate Change by 15 July 1999 in accordance with operative paragraph 1 of the above-mentioned decision;
- (b) To convene a workshop with the Intergovernmental Panel on Climate Change which will assist the bodies of the Framework Convention on Climate Change to establish information on available and potential ways and means of limiting

emissions of HFCs and PFCs in accordance with operative paragraph 2 of the above-mentioned decision;

- (c) To continue to develop information on the full range of existing and potential alternatives to ozone depleting substances for specific uses, including alternatives not listed in Annex A of the Kyoto Protocol;
- (d) To otherwise continue to co-operate with the relevant bodies under the United Nations Framework Convention on Climate Change and IPCC on these matters; and
- (e) To report to the Open Ended Working Group at its nineteenth meeting and to the Eleventh Meeting of the Parties to the Montreal Protocol on this work;

Decision 13/CP. 4

Relationship between efforts to protect the stratospheric ozone layer and efforts to safeguard the global climate system: issues related to hydrofluorocarbons and perfluorocarbons

The Conference of the Parties,

Noting the need to implement multilateral environmental agreements in a coherent way for the benefit of the global environment,

Recalling that the ultimate objective of the United Nations Framework Convention on Climate Change is to achieve stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system,

Noting the ongoing efforts to phase out ozone depleting substances under the Montreal Protocol on Substances that Deplete the Ozone Layer, and that hydrofluorocarbons and perfluorocarbons are among the substances which are being used as replacements for ozone depleting substances,

Noting further that hydrofluorocarbons and perfluorocarbons have high global warming potentials and are listed in Annex A to the Kyoto Protocol to the United Nations Framework Convention on Climate Change for achieving quantified emission limitations and reduction commitments of aggregated anthropogenic carbon dioxide equivalent emissions of greenhouse gases by Parties included in Annex 1 to the Convention,

Considering that the Intergovernmental Panel on Climate Change is seeking to provide further scientific and technical information on present and future sources and levels of emissions of hydrofluorocarbons and perfluorocarbons, and options to mitigate those emissions,

Noting that the Subsidiary Body for Scientific and Technological Advice with the assistance of the secretariat, is continuing its work on methodologies used by Parties for establishing estimates of emissions of hydrofluorocarbons and perfluorocarbons,

Noting further the need to consider available and potential ways and means of limiting emissions of hydrofluorocarbons and perfluorocarbons in the context of the Kyoto Protocol,

1. *Invites* Parties, the relevant bodies of the Montreal Protocol, the Intergovernmental Panel on Climate Change, intergovernmental organisations and non-governmental organisations to provide information on available and potential ways and means of limiting emissions of hydrofluorocarbons and perfluorocarbons, including their use as replacements for ozone depleting substances, to the secretariat by 15 July 1999;

2. *Encourages* the convening of a workshop by the Intergovernmental Panel on Climate Change and the Technology and Economic Assessment Panel of the Montreal Protocol in 1999 which will assist the Subsidiary Body for Scientific and Technological Advice to establish information on available and potential ways and means of limiting emissions of hydrofluorocarbons and perfluorocarbons, and *invites* the Intergovernmental Panel on Climate Change to report on the results of such a joint workshop to the Subsidiary Body for Scientific and Technological Advice at its eleventh session, if possible;

3. *Requests* the secretariat to compile the information provided, including, if available, the conclusions of the workshop, for consideration by the Subsidiary Body for Scientific and Technological Advice at its eleventh session;

4. *Requests* the Subsidiary Body for Scientific and Technological Advice to report on this information at the fifth session of the Conference of the Parties, and to seek further guidance from the Conference of the Parties on this matter at that session.

*5th plenary meeting
11 November 1998*

APPENDIX H – ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AIHA	American Industrial Hygiene Association
AIJ	Activities Implemented Jointly
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
C₂F₆	Hexafluoroethylene (CFC-116)
CANACINTRA	Camara Nacional de la Industria de la Transformacion (Mexico)
CBM	Chlorobromomethane
CDM	Clean Development Mechanism
CEIT	Countries with economies in transition
CF₄	Carbon tetrafluoride (CFC-14)
CFC	Chlorofluorocarbon
CH₄	Methane
CO	Carbon monoxide
CO₂	Carbon dioxide
COE	U.S. Army Corps of Engineers
COP	Conference of the Parties
COPD	Chronic Obstructive Pulmonary Disease
DME	Dimethyl Ether
DoD	Department of Defense (US)
DoE	Department of Energy (US)
DPIs	Dry-powder Inhalers
EGLs	Short-term Occupational Exposure Limits
ESH	Environmental, Safety & Health
EU	European Union
EXIBA	European Extruded Polystyrene Insulation Board Association
FAO	UN Food and Agriculture Organisation
FCCC	UN Framework Convention on Climate Change
FDI	Foreign Direct Investment
GEF	Global Environment Facility
GHG	Greenhouse Gas
GINA	Global Initiative for Asthma
GWP	Global Warming Potential
HAPS	Hydrocarbon Aerosol Propellants
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
IPAC	International Pharmaceutical Aerosol Consortium
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
JV	Joint Ventures
KMO	Kølebranchens Miljøordning
LCCP	Life Cycle Climate Performance

LEAP	Long-Range Energy Alternative Planning model
LOAEL	Low Observed Adverse Effect Level
MDIs	Metered Dose Inhalers
MDPIs	Multi-dose Dry Powder Inhalers
MLF	Multilateral Fund
MMTCE	Million Metric Tons of Carbon Equivalent
MOU	Memorandum of Understanding
MP	Montreal Protocol
N₂O	Nitrous oxide
NGO	Non Governmental Organisation
NGP	Next Generation Fire Suppression Technology Program
NIOSH	National Institute for Occupational Safety and Health (US)
NMVOCs	Nonmethane volatile organic compounds
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level (US)
NO_x	Nitrogen oxides
nPB	n-Propyl Bromide
O₃	Ozone
ODP	Ozone Depletion Potential
ODSs	Ozone Depleting Substances
OELS	Occupational Exposure Limits
OEWG	Open-Ended Working Group
OSHA	Occupational Safety and Health Administration (US)
PAFT	Programme for Alternative Fluorocarbon Toxicity Testing
Pb	Lead
PELs	Permissible Exposure Limits
PFC	Perfluorocarbon
PM	Particulate matter
PV	Photovoltaic
R&D	Research and Development
RMP	Refrigeration Management Plan
SBSTA	Subsidiary Body for Scientific and Technological Advice
SF₆	Sulfur hexafluoride
SME	Small and Medium Sized Enterprise
SNAP	Significant New Alternatives Program (US)
SO₂	Sulfur dioxide
SO_x	Sulfur oxides
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TOC	Technical Options Committee (of the TEAP)
UN	United Nations
UNEP	United Nations Environment Programme
UNEP TIE	United Nations Environment Programme Technology, Industry & Environment (OzonAction)
UNFCCC	UN Framework Convention on Climate Change
U.S. EPA	United States Environmental Protection Agency

VMSs	Volatile Methyl Siloxanes
VOC	Volatile Organic Compound
WGLs	Long-term Occupational Exposure Limits
WHO/NHLBI	World Health Organization/US National Heart, Lung and Blood Institute
WMO	World Meteorological Organisation
WSC	World Semiconductor Council
XPS	Extruded Polystyrene

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APPENDIX J – BIOGRAPHIES OF TASK FORCE MEMBERS

PROFESSOR RADHEY S. AGARWAL

Professor Radhey S. Agarwal is the Dean of Industrial Research and Development and a professor of Mechanical Engineering at the Indian Institute of Technology, Delhi, India. He is also a consultant to various Indian industries and visiting faculty member in international universities.

He studied Mechanical Engineering as an undergraduate and received a Master of Technology degree in Thermal Engineering in 1969 and a Ph.D. in Thermodynamics of Zeotropic CFC Mixtures and their Applications in Refrigeration in 1975 from the Indian Institute of Technology, Delhi.

Professor Agarwal conducted research on various topics related to refrigeration and air-conditioning, energy-efficient technologies, non-conventional sources of energy, thermal system simulation and optimisation, and non-ODS technologies. He has published more than 70 research papers in international journals and conferences and he has edited conference proceedings of the Indian Society of Mechanical Engineers, National Society of Refrigeration and Air-conditioning and the International Institute of Refrigeration (IIR). He is Vice President of IIR commission B-2, Chair of IIR sub-commission on Global Warming, Vice President of Indian Society of Mechanical Engineers and is a member ISHRAE.

At the beginning of international effort for CFC phaseout to protect the ozone layer, he started research and development of non-CFC refrigerants and led India in education and dissemination of the information on ozone friendly technologies.

In 1988 Professor Agarwal was appointed by Indian Ministry of Industry taskforce to assess the ODS consumption in the refrigeration and air-conditioning sub-sector and he was an active member of the team that developed the India Country Program under Montreal Protocol. Starting in 1993, he became a member of Technical and Finance Committee of MoEF responsible for policy and review of ODS phaseout projects under Montreal Protocol. Currently he is the technical advisor for updating the India Country Program and Chair of Bureau of Indian Standards on Refrigeration committee responsible for energy and Eco-labelling of refrigeration appliances and machinery.

From its founding in 1988, Professor Agarwal has been a member of TEAP Refrigeration, Air-conditioning, and Heat Pumps Technical Options Committee (RTOC). He was appointed Co-Chair for RTOC in 1996. He has also served as a member of World Bank Ozone Operations Resource Group (OORG) working groups.

Dr. Agarwal is a pioneer of the safe and efficient use of flammable Refrigerants. He developed a manual for safe use of hydrocarbon refrigerants in domestic and stand-alone commercial refrigeration appliances and produced a paper for UNEP-IE on the use of cyclopentane as foam blowing agent for polyurethane insulating foams. With Martien Janssen he conducted a study on the potential for hydrocarbon replacements in domestic and small commercial refrigeration systems. He has also carried out energy efficiency studies on domestic refrigerators using hydrocarbon refrigerants under the Ecofrig project. He has organised workshops and educated Indian industry on alternative technologies and safe conversion of domestic and commercial refrigeration appliances to use of hydrocarbon and HFC refrigerants. He organised 1998 IIR conference on Emerging Trends in Refrigeration and Air-conditioning in Delhi, India. He has also participated in workshops and conferences in Argentina, Canada, Denmark, Germany, Japan, Norway, and USA. Professor Agarwal has received the 1998 U.S. EPA Stratospheric Ozone Protection Award.

DR. STEPHEN O. ANDERSEN

Dr. Stephen O. Andersen was promoted in 1997 from his position as Deputy Director of the U.S. Environmental Protection Agency (EPA) Stratospheric Protection Division to his current position as Director of Strategic Climate Projects in the U.S. EPA Atmospheric Pollution Prevention Division.

He studied business administration and economics as an undergraduate and received his Ph.D. in Agricultural and Natural Resources Economics from the University of California, Berkeley. Before joining the EPA he worked for environmental and consumer non-governmental organisations (NGOs) and was a professor of economics and environmental studies at College of the Atlantic and the University of Hawaii.

Dr. Andersen studied stratospheric ozone depletion and climate change in the early 1970s as a member of the Climatic Impact Assessment Project that investigated the consequences of supersonic transit. In 1986 he was hired by EPA's stratospheric ozone protection office. He pioneered the EPA's voluntary approaches to ozone layer protection including the phaseout of CFC in the manufacture of food packaging, the recycling of CFC from vehicle air conditioning, the halt to testing and training with halon, and the accelerated CFC solvent phaseout in electronics manufacturing. He helped organise military support for ozone layer protection including projects to change military specifications requiring use of ODSs and three international conferences on the importance of the military to ozone layer protection. In 1992 he helped the North Atlantic Treaty Organisation (NATO) take the unprecedented step of writing directly to UNEP supporting the proposed accelerated phaseout of ozone-depleting substances.

Dr. Andersen also helped organise global technology co-operation including the early phaseout of CFCs in refrigerator manufacturing in Thailand and the corporate pledge to help Vietnam avoid increased dependence on ODSs. He served on the team that commercialised "no-clean" soldering and the team that is phasing out ODSs from solid rocket motors. Dr. Andersen helped organise the Halon Alternatives Research Corporation and the International Co-operative for Ozone Layer Protection.

Stephen Andersen Co-Chaired the 1989 Economic Assessment Panel, the 1989-1997 Solvents Coatings and Adhesives Technical Options Committee, the 1992 Methyl Bromide Assessment and since 1989 has Co-Chaired the Technology and Economic Assessment Panel (TEAP). He chaired the 1992 OEWG Contact Group on designing the Essential Use Exemption and he was a member of the 1995 Laboratory and Analytical Uses Working Group and the 1996 Process Agents Task Force.

Dr. Andersen has organised technology co-operation including the Egypt and Mexico country studies, the Thailand Leadership Initiative, and The Vietnam Pledge. He has participated in workshops and conferences in Australia, Brazil, Canada, China, Hungary, India, Indonesia, Italy, Japan, Korea, Malaysia, Mexico, Netherlands, Philippines, Russia, Saudi Arabia, Singapore, Switzerland, Taiwan, Thailand, Turkey, United Arab Emirates, United Kingdom, United States, and Vietnam. Dr. Andersen has received the 1990 EPA Gold Medal, and the 1995 EPA Fitzhugh Green Award, the 1996 Sao Paulo Brazil State Ozone Award, the 1995 UNEP Global Award, the 1998 EPA Stratospheric Ozone Protection Award, and the 1998 Nikkan Kogyo Shimbun Stratospheric Protection Award. In 1998 he was elected to the United Nations Environment Programme (UNEP) Global 500 Roll of Honour, and in 1999 he received the Vietnam Ozone Protection Award.

MR. STEVE ANDERSON

Steve Anderson is the Executive Director of AFCAM, a position he has held since the organisation was established 11 years ago.

During one of the most interesting decades in the history of air conditioning and refrigeration, AFCAM represents industry views to government both international, national and state, and keeping the industry informed of developments both in Australia and overseas.

In his capacity as Executive Director, Steve has worked with state and federal bureaucrats and politicians, interest groups and others to ensure the industry's position is well understood, while at the same time working to assist the industry meet the challenges it has confronted during that time. He represented Australian industry at the Meeting of the Parties to the Montreal Protocol in London in 1990 and was the industry representative on the Australian Government delegation to the Protocol Meetings in Copenhagen (1992), Vienna (1995) and Montreal (1997). He has also represented Australian industry at industry forums in the United States.

He has written numerous articles and spoken frequently on matters surrounding ozone depletion, energy efficiency, regulatory efficiency and related issues.

Mr. Anderson played a critical role in the establishment of the industry financed national refrigerant reclaim scheme, Refrigerant Reclaim Australia (RRA), and continues to advise that body.

The contributions of both RRA and AFCAM to ozone protection were recognised by the United States Environmental Protection Agency with the presentation of Stratospheric Ozone Protection Awards in 1995 and 1996 respectively.

In addition, as a Director of the National Public Affairs Group in Canberra, he has been involved in advising a large number of Australian companies and industry associations on government related matters over a wide range of areas and issues.

He is a graduate from the Australian National University and a member of the Australia Institute of Political Science and the Sydney Institute.

MR. PAUL ASHFORD

Mr. Paul Ashford graduated from the University of Bristol (UK) in 1979 with an honours degree in Chemistry. He immediately joined the phenolic resins business of BP Chemicals where he spent 15 years in a variety of technical and commercial roles. These included process and product development, technical service, technology licensing, business development, and finally business management. Paul Ashford was involved in the development and licensing of BP's patented technology on low thermal conductivity phenolic foams, which was subsequently exploited on a global basis.

As the manager responsible for technology licensing and business development during the emergence of the CFC issue, Mr. Ashford took personal responsibility for the management of the issue, including the technological changes required to phase out CFCs. He also became involved in the external communication of these changes; firstly with the UK Government and subsequently with the European Commission and UNEP. He was a founder member of the Foams Technical Options Committee and has taken responsibility for the phenolic foam chapter in all three TOC Reports.

In 1994, Mr. Ashford left BP Chemicals to set up his own consultancy, Caleb Management Services, with the particular aim of assisting understanding and co-operation between industry, regulators and other interest groups. In this context he has worked for private companies, trade associations, government departments and other international agencies. The latter has included substantial work for UNEP IE where he was responsible for the preparation of a series of foam case studies (1995), an update of the foam abstracts database (also 1995) and, most significantly, the Foam Technology Sourcebook in 1996. The success of the Foam Sourcebook has led to Caleb's subsequent involvement in the restructuring of the Refrigeration and Air Conditioning Sourcebook along similar lines.

Paul Ashford is also an expert in the market dynamics of the phenol, polyols, and isocyanates blowing agents and was recently engaged to carry out a study for the Multilateral Fund Secretariat on the chemical prices affecting MLF projects. In addition, the company has been involved in the quantification of global foam markets and, in particular the existing and projected use and emission of ozone depleting blowing agents.

Paul Ashford has been particularly active in the promotion of environmental awareness amongst the small- and medium-sized enterprises (SMEs) in the UK and chaired his local environmental business club for two years. He is a registered environmental auditor and is actively involved with the mechanistic elements of environmental management systems.

He has recently become active in energy efficiency in buildings, and the assessment of the potential carbon dioxide savings achievable in the European building stock. He is currently providing advice to both industry groups and the European Commission in this area.

DR. PAUL J. ATKINS

Dr. Paul J. Atkins is currently International Project Team Director for Inhalation Delivery Systems and CFC Transition at GlaxoWellcome. He has a Bachelor of Science (Honours) in Chemistry from the University of London and a Ph.D. in Physical Chemistry from the University of London.

During an industry career that has spanned over 15 years, Dr. Atkins has worked for a number of pharmaceutical companies. He began his career in the United Kingdom working for Upjohn Pharmaceuticals. He then spent 3 years working for Upjohn in their corporate headquarters in Kalamazoo Michigan, where he started the Aerosol Delivery system unit. After a brief spell at Fisons, Rochester NY, he moved to Glaxo in RTP, North Carolina where he started the Inhalation Products development Department in the pharmaceutical industry on product development. For the last 10 years he has been working on Inhaled Product development, particularly MDIs formulated with HFAs, Dry powder Inhalers and new inhaled technologies.

Dr Atkins is employed by Glaxo Wellcome R&D and has been a member of the UNEP Aerosol Technical Options Committee member for 5 years.

MR. JAMES A. BAKER

Mr. James Baker received a Bachelor of Arts and a Master of Science in Physical Chemistry in 1975. For 25 Years he has worked in Materials and Systems Development in the mobile air-conditioning industry.

Mr. Baker currently works for Delphi Harrison Thermal Systems Division of Delphi Automotive Systems where he is an engineering manager. He is a founding and continuing member of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee where he is lead author for mobile air conditioning. He serves as the mobile air-conditioning expert on the World Bank's Ozone Operations Resource Group (OORG) on projects nominated to the Multilateral Fund. In addition, Mr. Baker is a member of IPCC Expert Meeting on Good Practice in (Emissions) Inventory Preparation and serves as Chair of the Society of Automotive Engineers Climate Control Committee.

In 1989 and 1990 James Baker was co-chair of the U. S. EPA team that developed a CFC recycling standard that became the global model for service of vehicle air-conditioning. The standard was endorsed by the Society of Automotive Engineers and approved for warrantee repairs by automobile manufacturers in Australia, Canada, France, Germany, Italy, Japan, Sweden, United Kingdom, and the United States. This was the first time that vehicle manufacturers approved used or recycled parts for warrantee repair.

Mr. James Baker earned the 1990 EPA Stratospheric Protection Award and the 1997 EPA “Best-of-the-Best” award for the most significant achievements during the first decade of the Montreal Protocol.

DR. WALTER BRUNNER

Dr. Walter Brunner is an environmental consultant and is president of envico AG in Zurich, Switzerland. He studied microbiology at the Federal Institute of Technology in Zurich and received his Ph.D. for work on microbial degradation of chlorinated solvents. He spent several years doing research on microbial degradation of xenobiotics in soils before moving into the field of environmental consulting.

His involvement with ozone layer protection began in 1988, when he organised the first international conference on Halons and the Environment while working for the Swiss Fire Prevention Society (BVD). He served on the Halons Technical Options Committee (HTOC) since its inception in 1989, becoming a co-chair of the committee in 1996.

Dr. Brunner serves as national halon expert to the Swiss Government, helping develop Switzerland's halon usage reduction policy. He is in charge of the Swiss national halon register and the Swiss halon bank. He continues to advise the Swiss fire protection community on questions regarding halon management and the phaseout of halon use.

He has worked for UNEP IE, developing their halon banking information brochure for Article 5(1) Parties. He also served as a consultant to the Austrian government during halon negotiations at the European Union.

Dr. Brunner has given presentations on halon management and halon banking in Australia, China, Malaysia, Poland, and the UK.

He is a recipient of the U.S. EPA Stratospheric Ozone Award and the U.S. EPA “Best-of-the-Best” Stratospheric Ozone Award.

DR. NICK CAMPBELL

Dr. Nick Campbell received a Bachelor of Science (Honours) in Chemistry from the University of Southampton and a PhD in Inorganic Chemistry and Spectroscopy from the University of London.

After working for three years in the Characterisation and Measurement Group at ICI Mond Division in Runcom, UK specialising in spectroscopy, Dr. Campbell became the Technical Marketing Manager for “Arklone,” ICI’s trade name for CFC-113 cleaning products and subsequently for “Genklene,” ICI’s trade name for 1,1,1-trichloroethane. This led, in March 1987, to involvement in the Montreal Protocol and in 1991, to involvement in climate change. In 1992, Dr. Campbell became Regulatory and External Relations Manager for ICI Klea. He is now Environment Manager of Fluorochemicals for Elf-Atochem, based in Paris, France.

Dr. Campbell is a member of the Aerosols, Sterilants, Carbon Tetrachloride and Miscellaneous Uses Technical Options Committee and the Process Agents Task Force. He has co-chaired the UNEP Report on Inadvertent Emissions and Process Losses and was a member of the UNEP Destruction Committee. He is Chairman of the European Fluorocarbon Technical Committee (EFCTC) and attends a number of European Union and UK ozone and climate-related committees. He is a recipient of the U.S. EPA Stratospheric Ozone Protection Award.

DR. SUELY CARVALHO

Dr. Suely Carvalho is deputy chief of the Montreal Protocol Unit at the United Nations Development Programme in New York. She also co-ordinates Article 5(1) countries activities approved under the Multilateral Fund for Latin America countries.

She graduated in Physics in Sao Paulo, Brazil, and received her Ph.D. degree from Purdue University in 1979. She was a research associate for one year at the National Superconducting Cyclotron Laboratory at Michigan State University, in East Lansing, Michigan.

In Brazil she worked for the National Nuclear Energy Commission co-ordinating several projects related to environmental impact of Nuclear Fuel Cycle activities, mainly uranium mining and milling. As a full time professor at the Institute of Physics of the University of Sao Paulo, she worked in co-operation with several national and international institutions including NOAA and NASA doing measurements of air pollutants in remote areas in the Amazon and Antarctica, to contribute to global climate change studies.

Dr. Carvalho was an invited adviser to the Brazilian delegations of several Meetings of the Parties to the Montreal Protocol. She was instrumental in launching the first industry advisory body to the Government of Brazil on ozone related issues; served as an important advisor to industry associations; provided important information on the impacts of the Montreal Protocol, and advised government and industry on new technologies and transition strategies.

Dr. Carvalho was director of technology transfer at the environmental protection agency of Sao Paulo, called CETESB, under the Secretary of Environment. She pioneered the first program to implement the Montreal Protocol and the first state-level program in Brazil to reduce emissions of greenhouse gases in co-operation with the federal government. She organised several workshops and awareness campaigns at various levels in the public and private sectors. During her time at CETESB she organised the celebration of the International Ozone Day with the presence of Dr. Mario Molina, Dr. Stephen Andersen, and

Brazilian authorities. During the ceremony, the decree ending procurement of new ODS equipment by all state government institutions was launched.

Dr. Carvalho has co-chaired the UNEP Technology and Economic Assessment Panel since 1993 and is a member of the Economics Options Committee. She was a member of the Task Force for the Replenishment of the Multilateral Fund in 1996 and participated in conferences and workshops in Argentina, Brazil, Panama, Mexico, USA and the EU to discuss technology transfer to developing countries.

Dr. Carvalho was awarded the 1996 EPA Stratospheric Ozone Protection Award, the 1997 EPA "Best-of-the-Best" in the Protection of the Ozone Layer Award and the 1997 UNEP Global Award in recognition of her contribution to the protection of the ozone layer.

DR. DENIS CLODIC

Dr. Denis Clodic is Deputy Director of the Centre for Energy Studies, Ecole des Mines de Paris. He received a Bachelor of Engineering (Conservatoire National des Arts et Mtiers) and a Ph.D. in Mechanical Engineering from Ecole des Mines de Paris for the "Study and simulation of an absorption-diffusion system."

Dr. Clodic manages a research team of 35 persons conducting studies in thermodynamics and heat transfer. Current activities include:

- Improvement of energy efficiency of domestic refrigerators
- Measurement and simulation of energy consumption of Mobil Air Conditioners
- Measurement of leak rates of hoses and fittings
- Measurement of concentration of flammable refrigerants in rooms, due to leaks in domestic refrigerators, freezers and air conditioning systems
- Development of integrated cascades for low temperature applications
- Paper drying, and improvement of comfort of human body.

Dr. Clodic has 15 patents and has published over 40 international conference papers, and two books on refrigerant containment and recovery/recycling. He is a member of the Refrigeration Technical Options Committee, Chair of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Technical Committee on Refrigerant Containment, Member of the Designation and Safety Classification of Refrigerants for the French Association of Air Conditioning and Refrigerating Engineers (AICVF), and Chair of the Technical Committee for the Alliance Françaises Froid Climatisation (AFCE).

He has earned the ARI Awards for Alternative Refrigerants Evaluation Program, the U.S. EPA Stratospheric Ozone Protection, and the French Association of Air Conditioning and Refrigerating Engineers Stratospheric Ozone Protection Award (Missenard)

MR. JORGE CORONA

Mr. Corona heads the Foreign Affairs section of the Environmental Commission of the National Chamber of Industries of Mexico (CANACINTRA) in Mexico. He is a graduate of the Universidad Nacional Autónoma de México School of Chemistry.

Mr. Corona has worked for the Royal Dutch/Shell Group at their headquarters in The Hague, Industrias Polifil (a synthetic fibre manufacturer in Mexico), and as the operations director of San Rafael (Mexico's largest pulp and paper mill). In 1982, Mr. Corona started his own company, Astral Internacional, (later known as Quimica Blakor) and served as General Director until 1997.

Mr. Corona has served in a variety of professional associations and positions. He has been Vice-chair of the synthetic fibre section of the National Association of Chemical Industry (ANIQ); President of the Industry Association of the State of Tlaxcala, Mexico; President of the Mexican Aerosols Institute (IMAAC); Chair of aerosols section of the National Chamber of Industries (CANACINTRA); and Director of Ecology of CANACINTRA.

Since 1989, Mr. Corona has been instrumental in organising a wide range of activities to help developing country's efforts to phase out ODSs. He has participated in the International Conferences on Ozone Protection Technologies and Earth Technology Forums in Washington, D.C.; co-ordinated workshops in Mexico City in co-operation with the U.S. EPA, CANACINTRA and SEDUE (Mexican Environment Secretariat); and organised a workshop for disseminating ODS free technologies, in the "maquiladora" (in-bond) electronics industry in Tijuana, Baja California, Mexico. He organised the Programme for Technology Transfer in Electronics Industry with the U.S. EPA, UNEP and Nortel, CANACINTRA and the Mexican Electronics Manufacturers Association. He secured voluntary agreements between industry sectors and the Mexican Government to phaseout ODS in aerosols, solvents, refrigeration, plastic foams, halons, and CFC manufacturers. He also participated in technology transfer workshops organised by U.S. EPA and the World Bank; helped develop the Mexico Country Programme; and worked with the Swedish Environmental Agency to develop Kenya's Country Programme. He was the driving force and architect behind the Mexican government initiative to accelerate the phaseout of ODS ahead of Montreal Protocol schedule, which served to inspire several other Article 5(1) Parties to accelerate their phaseout as well. Mexico's program calls for a 2000 phaseout, rather than the 2010 allowed under the Protocol.

Mr. Corona has participated in technology transfer workshops on ODS alternatives, management policies, and recycling technologies in preparation of implementation projects in Mexico, Thailand, Japan, Indonesia, Ecuador, Kenya, Switzerland, Liechtenstein, Germany, Sweden, UK, Venezuela, the Netherlands, and Italy. He prepared Country Programmes for Colombia, Costa Rica, Bolivia, Paraguay, Nicaragua, and El Salvador.

Mr. Corona has supported projects involving technology transfer, policies, management, and project implementation in solvents, foams, aerosols, refrigeration, and methyl bromide. He serves as Co-Chair of the Solvents, Coatings and Adhesives Technical Options Committee; member of the Methyl Bromide Technical Options Committee; and a member of the Technical and Economics Assessment Panel.

Mr. Corona's awards include the Mario Molina Award granted by the Mexican Chemistry Society (SQM), the 1991 EPA Stratospheric Protection Award, and the EPA "Best-of-the-Best" Stratospheric Ozone Protection Award.

MR. YUICHI FUJIMOTO

Mr. Yuichi Fujimoto graduated from the University of Tokyo in Electrical Engineering in 1956. He has worked as an electrical engineer for heavy manufacturing including rolling mills and other equipment. In 1988 he became Director of the Japan Electrical Manufacturers' Association (JEMA) where he organised Japanese industry to protect the ozone layer and became a key co-operator with the Ministry of International Trade and Industry (MITI), the Environment Agency, and the Ministry of Foreign Affairs. As the director of JEMA, Mr. Fujimoto led Japanese efforts to phase out CFCs in electronics manufacturing. In 1996 he moved to the Japan Industrial Conference for Ozone Layer Protection (JICOP) as an advisor.

Mr. Fujimoto helped motivate Japanese companies to advocate early phaseout of ozone-depleting substances including the pledges of accelerated phaseout by Asahi Glass, Hitachi, Honda, Matsushita Electric, Mazda, Minebea, Mitsubishi Electric, Nissan, Sanyo, Seiko Epson, Toshiba, and Toyota. He was a chief organiser of the international "Pathfinder" leadership conferences in Woodshole Massachusetts (1990), Yauntville California (1992), Osaka Japan (1994), Nara Japan (1996), and Tokyo Japan (1997). In 1997, he persuaded MITI and the Electronics Industry Association of Japan to form a voluntary partnership to reduce PFC emissions.

Mr. Fujimoto also helped organise Japan's extensive technology-sharing program focused in Southeast Asia, including conferences in China, Indonesia, Korea, Malaysia, Philippines, Singapore, Thailand, and Vietnam. He was critical in organising global technology co-operation including the early phaseout of CFCs in refrigerator manufacturing in Thailand and the corporate pledge to help Vietnam avoid increased dependence on ODSs.

Mr. Fujimoto is a senior advisor to the UNEP Technology and Economics Assessment Panel and is a member of the UNEP Solvents, Coatings, and Adhesives Technical Options Committee.

Mr. Fujimoto earned the 1993 EPA Stratospheric Protection Award and the 1997 "Best-of-the-Best" Stratospheric Protection Award. His leadership helped JEMA earn the 1991 EPA Stratospheric Protection Award, the 1997 Best-of-the-Best Award and the 1997 UNEP Global Award.

DR. MIKE JEFFS

Dr. Mike Jeffs joined ICI in 1967 after receiving Bachelor of Science and Ph.D. degrees in physics from the University of Wales. He has held several research and commercial posts in the UK and joined the Polyurethanes Business in 1975. He has been based in Everberg (near Brussels) since 1982 at the Business' global headquarters and has held global roles since 1986 in both marketing and in environmental affairs. He is currently the International Environmental Affairs Manager. The polyurethane business of ICI was acquired by Huntsman in 1999.

Dr. Jeffs has been involved with the ozone (CFC) issue since 1985 and with business development, especially in Asia Pacific and including China and India, where there are strong environmental drivers. His responsibilities include developing sustainable strategies and also managing Business' issue management team. He is the issue manager for the Ozone and Climate Change issues. He received the U.S. EPA Stratospheric Ozone Award in 1993 and "The Best of the Best" award in 1997 and an MBE for services to the environment in 1995. He has been a member of the UNEP Foams Technical Options Committee since 1990 and was a lead author for rigid foams for the 1994 and 1998 reports. He also acts as a consultant to UNEP and is the foam representative on the OORG at the World Bank.

DR. MICHAEL KAUFFELD

Dr. Michael Kauffeld holds a Masters and Doctorate degree in mechanical engineering from the University of Hannover, Germany. Since 1986, he has worked with a variety of development projects within the field of refrigeration. Most of his work has focused on alternative working fluids, such as air, ammonia, carbon dioxide, hydrocarbons and secondary refrigerants. Michael Kauffeld has written more than 40 scientific publications. He acts as leader of a newly established Ice Slurry Centre, which joins the forces of eight companies, a university institute and the Danish Technological Institute, where he is employed. Currently he is working on the formulation of refrigerant management plans for Uruguay, Jamaica and Syria. He has served on the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee since 1997.

DR. BARBARA KUCNEROWICZ-POLAK

Dr. Barbara Kucnerowicz-Polak is Adviser to the Head of Polish Fire Service, with responsibility for international co-operation on chemical safety, including implementation of the recent European Union directives and OECD recommendations regarding chemical safety programs.

She graduated with a Master of Science in Engineering specialising in chemistry from the Technical University of Warsaw, took many postgraduate courses related to chemical safety in industry, and completed a Ph.D. in combustion chemistry.

Dr. Polak has extensive experience in combustion science and fire protection research, has published approximately 70 papers national and international professional journals, and holds six patents. She has held positions as university professor in Poland, Canada, and India.

Dr. Polak has organised awareness, education, and training programs on halon issues for government and business leaders, and technical staff within the fire protection community. She has also organised international workshops on issues related to phasing out halon production for CEITs. Dr. Polak became a member of the HTOC in 1993, and has served as its co-chair and as a TEAP member since 1996. To maximise accessibility of important HTOC and TEAP information she translated HTOC and TEAP documents into Russian.

Dr. Polak developed Poland's national strategy for phasing out halon, including a set of guidelines that provide step by step technical approaches to implementing Montreal Protocol decisions for the fire protection community. She took responsibility for widespread national distribution of the guidelines, advised regulatory authorities on approvals for alternative technologies and equipment, and was instrumental to the successful introduction of environmentally preferable alternatives to halons into the Polish market.

Barbara Polak is a recipient of the UNEP Stratospheric Ozone Award, and the U.S. EPA Stratospheric Ozone Protection Award.

DR. LAMBERT KUIJPERS

Dr. Lambert Kuijpers is currently an independent consultant with a part time assignment on the faculty of Technology Management, Department of Technology for Sustainable Development, Technical University Eindhoven. At the Technical University Eindhoven, Dr. Kuijpers is involved in the development of environmental projects for several developing countries.

After college graduation, Dr. Kuijpers was involved in nuclear fusion research at the KFA Research Centre in Jülich, Germany. He received a Ph.D. degree from the Technical University in Eindhoven. Before joining Philips Research Laboratories in the Netherlands, Dr. Kuijpers carried out post-doctoral studies at several European research institutes until 1978.

At Philips, he was involved in thermodynamic research for refrigeration, air conditioning, and heat pumps. The group he managed concentrated on the introduction of new refrigerants, new compressor concepts, and control strategies for small refrigeration equipment to increase energy efficiency. Before the Montreal Protocol was signed, Dr. Kuijpers began the effort under the umbrella of the International Institute of Refrigeration to make an inventory of measures that refrigeration companies could take to cope with the CFC reduction schedule proposed in the original 1987 Montreal Protocol. The results of this study were reported at several conferences in 1988. He left the Philips Company in 1992.

Dr. Kuijpers has been intensely involved in activities under the Montreal Protocol Assessments. Since 1988 he has been Co-Chair of the Refrigeration, Air Conditioning, and Heat Pumps TOC and since 1992 has been Co-Chair of the TEAP. He also co-chaired the 1993 Inadvertent Losses Working Group, the 1995 and 1996 Task Force on Aspects of Countries with Economies in Transition (CEITs), the 1997 Task Force on Flammable Refrigerants, the 1997 Task Force on Replenishment of the Multilateral Fund, and the 1999 Task Force on Replenishment of the Multilateral Fund. Since 1992, Dr. Kuijpers has been a member of the Ozone Operations Resource Group of the World Bank, and is a reviewer of many refrigeration investment project proposals. Since the early 1990s, Dr. Kuijpers has also been an advisor to UNEP IE in Paris, particularly to their OzonAction Program.

In undertaking CEIT investigation, Dr. Kuijpers designed all aspects of the work including data collection and reporting. He also participated in many meetings of the Implementation Committee under the Montreal Protocol. He participated in the Conferences of the Parties to the United Nations Framework Convention on Climate Change (FCCC) in 1995-1997 and in many UNFCCC subsidiary body meetings held in Bonn, Germany.

Dr. Kuijpers published many articles on refrigeration topics in the 1980s. He attended many conferences and meetings on refrigeration in the 1980s and 1990s. He has also published many articles on environmental issues including Montreal Protocol developments, particularly in relation to refrigeration, on energy efficiency and the "Total Equivalent Warming Impact" and on the parallels between the implementation of the Montreal and the Kyoto Protocols.

Within the framework of the Montreal Protocol, Dr. Kuijpers participated in many workshops and seminars in several developing and CEIT countries including Egypt, Kenya, Latvia, Lebanon, Malaysia, Mauritius, Thailand, Uganda, and Venezuela. He earned the 1993 EPA Stratospheric Ozone Protection Award, the 1997 UNEP Ozone Award, and the 1997 U.S. EPA "Best-of-the-Best" Award. Dr. Kuijpers is a member of ASHRAE, the British Institute of Refrigeration, the German Refrigeration Society DKV, and the Dutch Association for Refrigeration.

DR. MOHINDER MALIK

Dr. Mohinder Malik is manager of Materials and Process Technology Department at Lufthansa German Airlines in Hamburg, Germany.

Dr. Malik studied Metallurgical Engineering at the University of London and graduated with an Honours Degree in 1962. During his studies in London, he worked with British Oxygen Company in the field of joining technology. Since 1962, he has been with Lufthansa German Airlines and worked in broad field of materials and processes involved in aircraft maintenance and overhaul.

As Chair of the European Airlines Committee for Materials Technology (EACMT), Dr. Malik ensured that environmental protection aspects were introduced in the work plan of the Committee in 1980. A working group was formed in 1985 to look into the possibility of eliminating all halogenated hydrocarbons including CFCs and methyl chloroform in aircraft maintenance and overhaul. He co-ordinated a concerted action initiated at Lufthansa in 1986 to eliminate the use of halogenated hydrocarbons and stepwise substitute materials and processing techniques were introduced. This led to elimination of all controlled materials under Montreal Protocol in aircraft maintenance work by 1994.

Through channels of EACMT information on Lufthansa's experience with alternative technologies was passed on to other airlines, and aircraft and engine manufacturers. This accelerated the phaseout of ozone-depleting solvents in this sector. In 1994 Dr. Malik hosted a large group of representatives from the U.S. EPA and STOC members to witness ODS-free maintenance and overhaul of aircraft, engines and electronic components and assemblies.

In 1995 a team of engineers from U.S. Air Force and Lufthansa jointly compiled four case studies on processing of aircraft oxygen systems after scrutinising all details of the operation at Lufthansa.

Since 1992 Dr. Malik has been Co-ordinator of the EU Commission research and development program - (COST-501) B "High Efficiency Low Emission Technology for Gas Turbines" and has continuously passed on the experience gained in utilisation of ODS-free technologies in this sector.

Since mid-1996 Dr. Malik has served as Co-Chair of Solvents, Coatings and Adhesives Technical Options Committee. During this period he has helped to organise workshop/seminars in Asian and Arab regions.

Recently as Chair of the International Institute of Welding's "Select Committee on Thermal Spraying and Coatings Technology" he persuaded the Governing Council to incorporate ozone layer protection and climate change issues in all activities of the IIW.

Dr. Malik earned the 1995 US EPA Stratospheric Protection Award and the 1997 "Best-of-the-Best" Stratospheric Protection Award.

DR. MACK MCFARLAND

Dr. Mack McFarland received a B.S. in chemistry from the University of Texas at Austin in 1970 and a Ph.D. in Chemical Physics from the University of Colorado in 1973. From 1974 through 1983 – first as a Post-Doctoral Fellow at York University and then a research scientist at the NOAA Aeronomy Laboratory – Mack planned, conducted, and interpreted field experiments designed to probe the cycles that control atmospheric ozone concentrations. These studies included measurements of gases and processes important to the global climate change issue. In 1983, Mack joined the DuPont Company with responsibility for co-ordination of research programs; assessment and interpretation of scientific information on stratospheric ozone depletion and global climate change; representing DuPont in scientific meetings and before regulatory bodies, the media and customers; facilitating the preparation of scientific assessments; and for development and implementation of business strategies.

During 1995 and 1996 Mack was on loan to the Atmosphere Unit of the United Nations Environment Programme where he represented UNEP at international meetings, assisted in strategy development for the Atmosphere and other UNEP programs, and prepared policy relevant materials for publication. In 1997 he was on loan to the IPCC Working Group II Technical Support Unit.

Dr. McFarland is co-author of more than 40 scientific publications primarily about reaction kinetics and atmospheric measurements of trace gas concentrations. He has been involved as an author, contributor or reviewer of every major international assessment on stratospheric ozone depletion and global climate change. Mack has given hundreds of presentations on the science of ozone depletion and climate change to DuPont management, DuPont's customers, media representatives, government representatives and scientists. The value of his contributions to DuPont has been recognised through a C&P Flagship Award, Environmental Respect Awards, and Environmental Excellence Awards.

MR. ABID N. MERCHANT

Mr. Abid N. Merchant received a Bachelor of Chemical Engineering from Bombay University, a Masters of Chemical Engineering from Auburn University and a Master of Business Administration from Delaware University.

Mr. Merchant has 30 years experience DuPont in various supervisory and technical assignments. For the last 15 years he has been a lead person to find replacements for CFC-113. He also has over 50 patents and a large number of publications and presentations on solvent alternatives to CFC-113.

Mr. Merchant has been a member of the Solvents TOC since 1996 and is also a member of the U.S. Department of Defense Bearing Group, the ASTM D-26 Committee, and the Advisory Board of "Parts Cleaning" Magazine.

MR. E. THOMAS MOREHOUSE JR.

Mr. E. Thomas Morehouse Jr. is an Adjunct Research Staff, member of the Institute for Defense Analyses. From 1978-1994 he was employed by the United States Air Force.

He received his Bachelor of Science degree in Electrical Engineering from Union College New York in 1978 and his Master of Science degree in Mechanical Engineering from Boston University, Massachusetts in 1985.

As an active duty military officer, he held a variety of positions in facilities, energy, and environmental engineering and management at all levels of command including major command, Service headquarters staff, and the office of the Secretary of Defense. From 1986 through 1989, managed the Air Force research and development program on alternatives to the use of halons for military applications. From 1989 through 1991 was responsible for the development and implementation of Air Force ODS budget and policy, and from 1991 through 1993 on pollution prevention budget and policy, which included ODS. From 1993 through 1994, he was the military assistant to the Deputy Under Secretary of Defense (Environmental Security) and assisted in the establishment of programs covering the breadth of military environmental programs. From 1994 to present, he has been on the research staff of the Institute for Defense Analyses, an independent non profit organisation dedicated to providing independent and objective studies and analyses to the Secretary of Defense on matters of national security. He had published studies on a wide range of environmental issues affecting the military.

From 1989 through 1996, he co-chaired the Halon Technical Options Committee. He is an original member of the Technology and Economics Assessment Panel and remains a senior expert member for military issues. From 1996 he served as a Senior Advisor to TEAP.

Mr. Morehouse has been participating in international policy and technology co-operation projects involving plans, policies, strategies and technologies for management of ODS in China, Germany, Indonesia, South Korea, Malaysia, Mauritius, Mexico, India, Poland, Singapore and Vietnam. He was a key organiser of the First, Second, and the Third International Workshops on the Role of the Military in the Montreal Protocol (1991, 1993, 1997 respectively), and the First International Workshop on the Role of the Military in Climate Protection (1997). Additional work in this area includes the Asia Pacific-Indian Ocean Defense Environmental Workshop, the Western Hemisphere Defense Environmental Conference, and many other multilateral conferences, workshops and military to military information exchange. He is a recipient of the 1992 EPA Stratospheric Protection Award, and the 1997 "Best of the Best" Stratospheric Protection Award.

MR. HARUO OHNISHI

Mr. Haruo Ohnishi graduated from Kobe University in Japan in 1970 with a major in mechanical engineering and worked in the Air conditioning Equipment Design Department of the Air-conditioning and Refrigeration Manufacturing Division of Daikin Industries for 24 years.

From 1993 to 1996 Mr. Haruo Ohnishi was a vice-chair of JRAIA Alternative Refrigerant Evaluation Program Technical Committee (JAREP/TC) and from 1994 to 1998 he was chair of Alternative Refrigerant Flammability Evaluation Committee (ARFEC) of JRAIA Refrigerant Committee from 1994 to 1998. These two committees evaluate non-ODS alternative refrigerants in JRAIA. Currently, Mr. Ohnishi is a committee member of Japan Society of Refrigerating and Air Conditioning Engineers (JSRAE) Technical Committee for Evaluation of Natural Refrigerants and since 1998 is also a member of the ISO/TC68/SC8/WG5 committee in Japan. Since 1996, Mr. Ohnishi is a member of UNEP Refrigeration, Air Conditioning, and Heat Pumps Technical Options Committee.

Mr. Ohnishi is a member of the Japan Air-conditioning and Refrigeration Industry Association (JARIA) and since 1997 is a member of Refrigeration TOC.

ROBERTO A. PEIXOTO

Roberto A. Peixoto is presently Professor of Mechanical Engineering at Maua Technological Institute (Sao Paulo, Brazil), where he is co-ordinates studies and research in energy and environment, and consults the Brazilian government and industries, and international institutions. He is also a technical advisor to the Brazilian Industry Association of Refrigeration and Air Conditioning for issues related to Montreal Protocol implementation and new refrigerants.

He received a Bachelor of Science and a Master of Science in Naval Engineering from the University of Sao Paulo and a Ph.D. in Mechanical Engineering and Thermal Sciences from the University of Sao Paulo, Brazil.

From 1981 to 1996 he was researcher engineer of the Thermal Systems Group at the IPT - Technical Research Institute of Sao Paulo, performing studies and researches for the industry in thermal engineering area, mainly in refrigeration, air conditioning and heat pumps. From 1988 to 1990 he also served as Head of the Thermal Systems Group. During 1991 he was visiting professor and researcher at University of S. Paulo developing research for CFC-12 substitution in household refrigerators for the largest Brazilian refrigerator manufacturer.

In 1992 and 1993 he was Visiting Scholar and Researcher Engineer at the Air Conditioning and Refrigeration Center, University of Illinois at Urbana-Champaign, USA conducting research on the use of alternative refrigerants in small hermetic refrigeration systems involving experimental activities and numerical simulation. Dr. Peixoto has published more than 40 papers in Brazilian and International Conferences and journals.

In 1990 Dr. Peixoto was one of the organisers of the first International Seminar on Ozone Layer Protection held at University of S. Paulo, and since then he has been involved in the CFC phase out in the refrigeration and air conditioning sector developing projects for industry conversion through Montreal Protocol Multilateral Fund support. He was the technical advisor for updating the Brazilian Country Program in this sector and presently he is involved in the development of a strategy for SMEs in the manufacturing and servicing areas. Dr. Peixoto has been also involved in the training and dissemination of information on technologies to protect the ozone layer in Brazil and other countries in Latin America

During 1996 and 1997 Dr. Peixoto helped, as a technical advisor to the State of S. Paulo Environmental Agency, to establish the Ozone Layer Protection Program in the State of S. Paulo. Since 1996 Dr. Peixoto has been a member of the UNEP Refrigeration Air Conditioning and Heat Pumps Technical Options Committee involved mainly in the Commercial refrigeration chapter.

MS. JILL PHILLIPS

Ms. Jill Phillips is a Program Analyst in the Climate Protection Division of the U.S. Environmental Protection Agency (EPA). She graduated with honours from Wellesley College in Wellesley, Massachusetts, with a Bachelor of Arts in Economics. Before joining the EPA, Ms. Phillips worked as an Associate at PricewaterhouseCoopers in Phoenix, Arizona, where she specialised in commercial valuation and environmental litigation pertaining to property value diminution. Ms. Phillips managed the preparation of the HFC/PFC Task Force Report and participated in HFC workshops in the Netherlands and the United States. She also manages the EPA Climate Protection Awards.

MR. WIRAPHON RAJADANURAKS

Mr. Wiraphon Rajadanuraks received his Bachelor Degree in Civil Engineering from Khon Kaen University in 1970, and Master of Science in Civil Engineering from the University of Texas at Austin in 1974. He had been working at the Department of Industrial Works as a factory inspector since 1970. In 1988, he worked in the planing Division where he started to be involved in the ODS phaseout in 1992. In 1994, he has been transferred to the Hazardous Substances Control Division as the Manager of Ozone Protection Unit and became the Director of the Hazardous Substances Control Division in 1995. He received the stratospheric Ozone Protection Award from the U.S. EPA in 1997.

MS. SALLY RAND

Ms. Sally Rand is currently Director of PFC/HFC Voluntary Programmes in the U.S. Environmental Protection Agency (EPA) Climate Protection Division. Previously, Ms. Rand worked for six years in EPA's Stratospheric Protection Division and served as Team Leader and Foam Sector Manager in the Significant New Alternatives Policy (SNAP) Programme.

Ms. Rand has a Bachelor of Science and Diploma in Economics from the London School of Economics, and earned a Master of Science in Environmental Health at the Harvard School of Public Health. Before joining EPA, she worked at the Environmental Law Institute, a non-profit environmental policy research centre.

Since beginning work on ozone layer protection in 1992, Sally Rand participated in the development and implementation of the only regulatory program that evaluated the potential environmental, health and safety risks of CFC replacements. She worked closely with the U.S. foam industry to evaluate technical progress in completing the transition, including participation as an ex-officio member of the American Home Appliance Association Insulation Technical Assessment Committee. In addition to U.S. domestic programmes, Ms. Rand participated in technology co-operation forums sponsored by UNEP IE on small and medium enterprises, and safety, and helped organise a 1998 workshop on CFC replacement technologies for the India foam industry.

Ms. Rand joined the Flexible and Rigid Foam Technical Options Committee in 1993 and became Co-chair in 1995. She served as a member of the Technology and Economic Assessment Panel since 1995, and was a member of the 1996 TEAP Process Agent Task Force.

MR. LEE KHENG SENG

Mr. Lee Kheng Seng earned a Bachelor of Engineering (Mechanical) (Hon) from the National University of Singapore and a Postgraduate Diploma in Environmental Management from Dresden University of Technology.

For the last 14 years he has worked in the Singapore Ministry of the Environment where he has been posted to various departments including the Engineering Services Department, the Pollution Control Department, and the Strategic Planning and Research Department. He is currently the Senior Engineer (International Environment) in the International Environment and Policy Department.

Mr. Lee Kheng Seng has been involved with the Montreal Protocol issue since 1989 when Singapore first became a Party. His responsibility included the setting of policies to comply with the Protocol and measures to discourage the non-essential use of products using or containing ozone-depleting substances.

MR. RAJENDRA M. SHENDE

Mr Rajendra M. Shende is Chief of the Energy and OzonAction Unit of UNEP's Division of Technology, Industry and Economics in Paris.

He studied Chemical Engineering at the Indian Institute of Technology and has experience in the private sector in project management, research and development, technology transfer, environmental impact assessment, cleaner production and renewable energy. He has an extensive background of working in the chlorine, bromine and fluorine industry and was responsible for setting up a PTFE (polytetrafluoroethylene) plant which used HCFC-22 as a raw material (1985). In 1986-88 he worked on research and development and commercialization of clean technology using enzymes to produce semi-synthetic antibiotics.

During 1989-1992 he was engaged in setting up collaboration in research and development with other countries to develop alternative technologies to ozone depleting substances. He was a member of the government-appointed Task Force on National Strategy for Phasing-out Ozone Depleting Substances (ODS) in India and had taken part, as industry advisor, in the negotiations of the Montreal Protocol meetings from 1988 to 1992.

In 1992 he joined UNEP's office in Paris as Coordinator of the OzonAction Programme to assist developing countries in complying with the Montreal Protocol to Protect the Ozone Layer. Under his leadership the OzonAction Programme has assisted nearly 100 developing countries all over the world and Countries with Economies in Transition (CEITs) to develop their action plans and strategies to respond to the challenge of the phaseout of ODS and to set up their National Ozone Units. More than 100 developing countries have been engaged in networking activities of this programme for the implementation of ODS phaseout. Mr. Shende was instrumental in developing technology source books, technology options booklets, case studies, numerous information papers on sectoral topics, training and resource modules, handbooks, guidelines and policy papers to assist government and industry in developing countries.

As Programme leader he pioneered new approaches for assisting small countries with their Refrigerant Management Plans, total phaseout plans and policy mentor's networks.

In 1998 he was appointed as Chief of the Energy and OzonAction Unit of UNEP DTIE in Paris. In this capacity he is leading the activities that assist governments and industries in sustainable use of energy and efficient ways of managing energy resources. He is developing strategic approaches to provide policy and technical assistance of cross-cutting issues between the Montreal Protocol and the Kyoto Protocol through the clearinghouse mechanism.

He has organised workshops on technology, co-operation, safety-awareness on climate issues, SMEs and sector specific issues including the Clean Development Mechanism in more than 20 countries. He is Review Editor for IPCC's Special Report on Technology Transfer and corresponding member of UNEP's Technical Options Committee for Refrigeration, Air Conditioning and Heat Pumps and member of the Editorial Board of OzonAction in China.

MS. LALITHA SINGH

Ms. Lalitha Singh has until recently been Advisor in the Ministry of Chemicals and Fertilisers, Government of India, and is currently independent expert working on sustainable development and environmental issues of chemical manufacturing and use.

She has Masters Degree in Chemistry and wide experience in industrial chemistry, technology transfer, and technology forecasting and planning.

Before she joined the Ministry, she worked in the Indian Institute of Petroleum where she pioneered many demand forecasting and end-use analysis studies that were instrumental in launching the Five-Year Plans on Hydrocarbon and Petrochemical Industry in India. Simultaneously, she initiated and participated in Technology Absorption and Development Plans in these sectors.

Ms. Singh's responsibilities in the Ministry included policy development and promotion of chemical and petrochemical industry growth, taking into consideration the international technology developments. Activities included project promotion, screening, approval and monitoring. Her continuous interaction with the Indian Chemicals industry, international technical community, and research institutions contributed to major inputs into the policy planning and establishment of industry in line with global developments. During this development process, she focused on sustainable development and safety and environmental issues. She has been an important participant in the dialogue within the chemicals industry on establishing air and water pollution standards in India.

Ms. Singh has been chairperson and member of many committees on research programs, technology development, and Scientific Advisory Committees for the hydrocarbon and petrochemical sectors. She has been a member of delegations of Government of India on bilateral co-operation in petrochemical sector to countries in Southeast Asia and the Middle East.

Ms. Singh has carried out studies for UNIDO, UNCTAD, and UNEP on technology transfer, safety issues in petrochemical industry, and ozone-related areas. She has been a member of the Intergovernmental Consultation Groups organised by UNIDO. She has been involved in Montreal Protocol-related activities at the national level, even before the preparation of the country program, as a member of working groups initiated by the government and industry. She has been a member of the committee that screens projects to be submitted to Multilateral Fund, and is an expert member of the committee to review and update the India Country Programme.

Ms. Singh has been co-chair of the Technical Options Committee of Rigid and Flexible Foams and member of the Technology and Economic Assessment Panel from 1996.

She has been chairperson of the "Panel on Chemical Industry 2020" for the Technology Assessment Forecasting Council of India (TIFAC) in 1997.

Ms. Singh has attended many seminars and workshops and often chaired sessions on the petrochemical industry, Montreal Protocol awareness, and sectoral ODS phaseout. Ms. Singh published many reports and papers on environment, safety, and ODS phaseout issues in the Hydrocarbon, Chemical, and Petrochemical sectors.

MR. GARY TAYLOR

Mr. Gary Taylor is by profession a fire protection consultant. He is a principal of Taylor/Wagner Inc. of Toronto, Canada.

Mr. Taylor has wide experience in the use of halons in fire protection, based on numerous fire protection design projects that utilised halons and his tenure as Chair of the National Fire Protection Association Technical Committee on Halogenated Extinguishing Agent Systems.

He has served as co-chair of the Halons Technical Options Committee (HTOC) since its inception in 1989. The Halons Technical Options Committee has been instrumental in the safe global transition to alternatives to the use of halons. Protection of life and property is an important aspect of the work of the fire protection professionals that serve as members of the HTOC and a safe transition is a very important issue to the fire protection community.

Mr. Taylor has met with the fire protection communities in China, the United Arab Emirates, India, Venezuela, the United States, Canada, Australia, United Kingdom, Switzerland, Mexico, and Finland to explain the halon issue and report on the technical options available to fire protection professionals. He has also met with environmental groups and policy makers in many of these same countries and others to discuss the options available to encourage and support a safe transition.

During this same period of time Mr. Taylor continued his work and involvement in his chosen profession. He has been involved in the design of fire protection measures for aircraft hangar projects around the world, has served as a member of the Canadian Commission on Building and Fire Codes and serves as Chair of the Standards Council of the National Fire Protection Association.

Mr. Taylor acted as a consultant to FONDOIN of Venezuela in the design and implementation of a national halon strategy that made it possible for Venezuela to phaseout all halon imports on the same schedule as the non-Article 5(1) countries.

Utilising his experience in helping technical people to reach a consensus view and provide understandable explanations of complex technical issues, Mr. Taylor served as co-chair and facilitator of the Process Agents Task Force during 1996 and 1997.

Mr. Taylor is a recipient of the UNEP Stratospheric Ozone Award, the U.S. EPA Stratospheric Ozone Award, and the U.S. EPA Best of the Best Stratospheric Ozone Award.

DR. HELEN TOPE

Dr. Helen Tope graduated with a Bachelor of Science (Honours) in Chemistry from Monash University, Australia in 1984. She completed a Ph.D. in synthetic organic chemistry in 1992 studying synthetic approaches to novel organic semiconductors.

Dr. Tope has worked for the Environment Protection Authority Victoria, Australia, since 1991. During this time, she has been involved in the development of policy for ozone layer protection, management of chemicals and hazardous industrial wastes, the development of air emissions inventories for the cities of Brisbane and Auckland, and as part of EPA's emergency response to environmentally hazardous incidents.

She is Co-Chair of the UNEP Aerosols, Sterilants, Miscellaneous Uses, and Carbon Tetrachloride Technical Options Committee and a member of the UNEP Technology and Economics Assessment Panel. She has participated in seminars, colloquia, and conferences for ozone layer protection and on behalf of the Aerosols Technical Options Committee in Australia, Canada, Kenya, and the United States.

DR. ASHLEY WOODCOCK

Professor Woodcock is Professor of Respiratory Medicine at the University of Manchester UK. He is a practising Physician at the North West Lung Centre, with a particular interest in the management of Asthma and Chronic Obstructive Lung Diseases.

He qualified with a BSc (1st class honours) in human physiology in 1972 and obtained his medical (MB ChB honours) in 1975. Subsequently he received his research degree (MD) and became a Fellow of the Royal College of Physicians (FRCP UK). He has clinical experience in developed and developing countries.

His main research interests are in the environmental causation and treatment of asthma and his avowed aim is to cure asthma! – a disease which affects up to 200 million people worldwide. He heads a research team of 20 scientists and physicians working on aspects of environmental control of lung diseases.

Professor Woodcock is Co- chair of the UNEP Aerosols, Sterilants, Miscellaneous Uses, and Carbon Tetrachloride Technical Options Committee and a member of the UNEP Technology and Economics Assessment Panel. He has taken part in numerous seminars/conferences on ozone layer protection, particularly in the area of CFC transition for metered dose inhalers for the treatment of asthma and COPD.

**APPENDIX K – CONFERENCES AND WORKSHOPS WHERE TASK FORCE MEMBERS PUBLICLY SOLICITED
TECHNICAL INFORMATION¹**

DATE (1999)	LOCATION	WORKSHOP OR CONFERENCE AND/OR ORGANISATION	TASK FORCE MEMBERS	AUDIENCE²	SECTORS³
February 17	Arlington, Virginia	The Alliance for Responsible CFC Policy/ The International Climate Change Partnership	S. Andersen S. Rand R. Russell	INGO, GO, CO	R, F, S
Countries: USA					
March 1 – 3	Thailand	“Lessons Learned in Technology Transfer under the Multilateral Fund” NAM S & T Centre = Centre for Science and Technology of the Non-Aligned and other Developing Countries	S. Andersen R. Shende Y. Fujimoto	NOUs, INTO CO, TEAP, IPCC, INGO	R,S,H,F,A
Countries: Australia, Bangladesh, China, India, Indonesia, Italy, Japan, Republic of Korea, Laos, Malaysia, Philippines, Thailand					

¹ Task Force members informally collected technical information at the “CO₂ Technology in Refrigeration, Heat Pump and Air Conditioning Systems IEA/IIR/IZW Workshop,” Mainz Germany, 18 March 1999; and the “First IIR Workshop on Ice Slurry Technology,” Yverdon Switzerland, 27-28 May 1999.

² ENGO = environmental NGO

INGO = industry association

INTO = international organisation

GO = government organisation

CO = company

MO = military organisation

AO = academic organisation and institutes

³ R = refrigeration, air-conditioning, heat pumps

S = solvents, coatings, and adhesives

H = halon fire protection

F = foams

M = medical

A = aerosol

DATE (1999)	LOCATION	WORKSHOP OR CONFERENCE AND/OR ORGANISATION	TASK FORCE MEMBERS	AUDIENCE	SECTORS
March 15	Japan	Japan Electrical Manufacturers Association (JEMA), Japan Industrial Conference on Ozone Layer Protection (JICOP)	S. Andersen Y. Fujimoto H. Ohnishi	CO, GO, INGO	
Countries: Japan, USA					
May 5 – 7	Budapest, Hungary	“NATO Workshop on Approaches to Implementing Pollution Prevention Technologies at Military Bases”	T. Morehouse	GO, MO	R, H, S
Countries: Azerbaijan, Belgium, Canada, Czech Republic, Estonia, Georgia, Germany, Hungary, Kazakhstan, Latvia, Lithuania, Moldova, the Netherlands, Norway, Poland, Sweden, UK, USA					
May 4-5	Mexico City, Mexico	“Workshop for Latin America on Technology Assessment in Refrigerants and Air Conditioning”	S. Carvalho J. Corona M. Kauffeld R. Peixoto	GO, INTO, CO	R
Countries:					
May 5 – 7	Bali, Indonesia	“Seminar on ODS Phaseout: Solutions for Refrigeration”	R. S. Agarwal Y. Fujimoto	INGO, INTO, GO, CO, AO	R, F
Countries: Bangladesh, China, Laos, Malaysia, Myanmar, Nepal, India, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Thailand, Vietnam					
May 10 – 12	Jordan	5 th Meeting of the Regional Network of ODS Officers for West Asia	T. Morehouse	GO, MO	R, S, H
Countries: Bahrain, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, United Arab Emirates, USA, Yemen					

DATE (1999)	LOCATION	WORKSHOP OR CONFERENCE AND/OR ORGANISATION	TASK FORCE MEMBERS	AUDIENCE	SECTORS
May 26 – 28	Petten, Netherlands	“The Joint IPCC/TEAP Expert Meeting on Options for the Limitation of Emissions of HFCs and PFCs”	R. Agarwal S. Andersen S. Anderson P. Ashford J. Baker N. Campbell S. Carvalho D. Clodic J. Corona Y. Fujimoto M. Jeffs B. Kucnerowicz-Polak L. Kuijpers M. McFarland A. Merchant M. Malik T. Morehouse H. Ohnishi W. Rajadanuraks S. Rand R. Russell R. Shende (Represented by Dana Mun)	GO, ENGO, INGO, CO, AO	R, H, S, M

Countries: Australia, Austria, Belgium, Canada, People’s Republic of China, Denmark, Finland, France, Germany, India, Japan, Kenya, Mexico, The Netherlands, Poland, Sri Lanka, Sweden, Switzerland, Thailand, UK, USA, Vietnam

DATE (1999)	LOCATION	WORKSHOP OR CONFERENCE AND/OR ORGANISATION	TASK FORCE MEMBERS	AUDIENCE	SECTORS
May 31 – June 2	Berlin, Germany	Heat Pumps – A Benefit for the Environment	R. Agarwal S. Andersen H. Ohnishi	GO	R
Countries: Austria, Belgium, Belorussia, Canada, Denmark, Finland, Germany, Ireland, Italy, Hong Kong, Japan, Korea, Luxembourg, the Netherlands, Norway, Poland, Spain, Sweden, Switzerland, UK, USA					
June 13	Geneva, Switzerland	“Workshop on HCFC Alternatives”	R. Agarwal S. Andersen W. Brunner S. Carvalho D. Clodic J. Corona Y. Fujimoto M. Kauffeld L. Kuijpers	ENGO GO INGO CO AO INTO	F, R, S
Countries: Algeria, Austria, Belgium, Benin, Botswana, Brazil, Canada, China, Colombia, Comores, Congo, Denmark, Dominican Republic, El Salvador, Fiji, Finland, France, Gambia, Germany, Ghana, Hungary, Iceland, India, Indonesia, Italy, Japan, Kenya, Latvia, Lebanon, Malaysia, Mauritius, Mexico, Netherlands, Nigeria, Panama, Papua New Guinea, Philippines, Portugal, Republic of Korea, Seychelles, Singapore, South Africa, Sweden, Switzerland, Tajikistan, Tanzania, Turkmenistan, United Kingdom, United States, Western Samoa, Republic of Yemen, Zimbabwe					
August 3 – 6	Sao Paulo, Brazil	“VI Conbrava Brazilian Refrigeration, Ventilation and Air Conditioning Conference”	M. Kauffeld R. Peixoto		R
Countries: Brazil, Germany					
August 13	Australia		S. Anderson H. Tope	INGO, GO, CO, MO	R, S, H, F, M, A
Countries: Australia					

DATE (1999)	LOCATION	WORKSHOP OR CONFERENCE AND/OR ORGANISATION	TASK FORCE MEMBERS	AUDIENCE	SECTORS
September 8 – 10	Netherlands	“Second International Symposium on Non-CO ₂ Greenhouse Gases”	P. Ashford M. McFarland L. Kuijpers	ENGO, GO, INGO, CO, AO, INTO	F, R
Countries: Japan, Netherlands, New Zealand, Taiwan, USA, Vietnam					
September 12 – 14	Taiwan	“1999 Taipei International Conference on Atmosphere Protection”	S. Andersen S. Rand	GO, MO	R, S, H
Countries: Japan, Netherlands, New Zealand, Taiwan, USA, Vietnam					
September 15	USA	“10 th Annual Solvent Substitution Workshop”	T. Morehouse	MO, AO, CO	S
Countries: USA					
September 16 – 17	Korea	“1999 Industry Workshop on Ozone and Climate Protection”	S. Andersen S. Rand	GO, CO, INGO	
Countries: Korea					
September 19 – 24	Sydney, Australia	“XX th International Congress of Refrigeration”	M. Kauffeld	AO, CO	R
Countries: 59 countries represented					
September 19 – 21	Vietnam	“International Exhibition and Conference on Environment in Vietnam”	S. Andersen T. Morehouse S. Rand	GO, INGO, INTO, CO	
Countries: Australia, Malaysia, Singapore, USA, Vietnam					

APPENDIX L – ATMOSPHERIC VALUES FOR VARIOUS OZONE-DEPLETING SUBSTANCES AND THEIR SUBSTITUTES

Compound	Chemical Formula	Lifetime ⁴ (years)	ODP ⁵	GWPs from IPCC SAR ¹ 100 year GWPs ³		GWPs from 1998 Ozone Assessment ²			VOC ⁷
				100 year GWPs		100 year GWPs		500 year GWPs	
				Direct	Net ⁶	Direct	Net ⁶	Direct	
Carbon dioxide	CO ₂	See footnote ⁸	-	1	-	1	-	1	Exempted
CFC-11	CCl ₃ F	45	1	3800	540 to 2100	4600	-1680 to 3610	1600	Exempted
CFC-12	CCl ₂ F ₂	100	1	8100	6200 to 7100	10600	6900 to 10200	5200	Exempted
CFC-13	CClF ₃	640	1			14000		16300	Exempted
CFC-113	CCl ₂ FCClF ₂	85	0.8	4800	2600 to 3600	600	1740 to 5330	2700	Exempted
CFC-114	CClF ₂ CClF ₂	300	1			9800		8700	Exempted
CFC-115	CClF ₂ CF ₃	1700	0.6			10300		14300	Exempted
HCFC-21	CHCl ₂ F	2	0.04			210		65	
HCFC-22	CHClF ₂	11.8	0.055	1500	1300 to 1400	1900	1500 to 1840	590	Exempted
HCFC-123	CHCl ₂ CF ₃	1.4	0.02	90	20 to 50	120	0 to 100	36	Exempted
HCFC-124	CHClFCF ₃	6.1	0.022	470	390 to 430	620	450 to 590	190	Exempted
HCFC-141b	CH ₃ CCl ₂ F	9.2	0.11	600	170 to 370	700	-130 to 570	220	Exempted
HCFC-142b	CH ₃ CClF ₂	18.5	0.065	1800	1600 to 1700	2300	1740 to 2210	720	Exempted
HCFC-225ca	CF ₃ CF ₂ CHCl ₂	2.1	0.025			180		55	Exempted
HCFC-225cb	CClF ₂ CF ₂ CHClF	6.2	0.033			620		190	Exempted
Halon-1301	CBrF ₃	65	10	5400	-85400 to -14100	6900	-97030 to -9510	2700	
Halon-1211	CBrClF ₂	11	3			1300		390	
Halon-2402	C2F4Br2	20 ⁹	6						
HFC-23	CHF ₃	243	-	11,700	-	14800	-	11900	Exempted
HFC-32	CH ₂ F ₂	5.6	-	650	-	880	-	270	Exempted
HFC-41	CH ₃ F	3.7	-	150	-	140	-	43	
HFC-125	CHF ₂ CF ₃	32.6	-	2800	-	3800	-	1200	Exempted
HFC-134	CHF ₂ CHF ₂	10.6	-	1000	-	1200	-	370	Exempted
HFC-134a	CH ₂ FCF ₃	13.6	-	1300	-	1600	-	500	Exempted
HFC-152	CH ₂ FCH ₂ F	0.5	-			43	-	13	
HFC-152a	CH ₃ CHF ₂	1.5	-	140	-	190	-	58	Exempted
HFC-143	CH ₂ FCHF ₂	3.8	-	300	-	370	-	120	
HFC-143a	CH ₃ CF ₃	53.5	-	3800	-	5400	-	2000	Exempted

Compound	Chemical Formula	Lifetime ⁴ (years)	ODP ⁵	GWPs from IPCC SAR ¹ 100 year GWPs ³		GWPs from 1998 Ozone Assessment ² 100 year GWPs		VOC ⁷	
				Direct	Net ⁶	Direct	Net ⁶	500 year GWPs	
								Direct	
HFC-161	CH ₃ CH ₂ F	0.25	-			10	-	3	Exempted
HFC-227ea	CF ₃ CHFCF ₃	36.5	-	2900	-	3800	-	1300	Exemption pending
HFC-236cb	CH ₂ FCF ₂ CF ₃	14.6	-			1400	-	430	
HFC-236ea	CHF ₂ CHFCF ₃	8.1	-			1000	-	310	Exempted
HFC-236fa	CF ₃ CH ₂ CF ₃	226	-	6300	-	9400	-	7300	Exempted
HFC-245ca	CH ₂ FCF ₂ CHF ₂	6.6	-	560	-	720	-	22/0	
HFC-245fa	CF ₃ CH ₂ CHF ₂	7.7 ¹⁰	-			1040 ¹⁰	-	320 ¹⁰	Exempted
HFC-365mfc	CF ₃ CH ₂ CF ₂ CH ₃	10.2	-			910	-	280	Exempted
HFC-43-10mee	CF ₃ CHFCF ₂ CF ₃	17.1	-	1300	-	1700	-	530	Exempted
HFE-E125	CF ₃ OCHF ₂	165	-			15300	-	10000	
HFE-E134	CHF ₂ OCHF ₂	29.7	-			6900	-	2200	
HFE-E143a	CH ₃ OCF ₃	5.7	-			970	-	300	
HFE-E227ea1	CF ₃ OCHFCF ₃	11	-			1500	-	460	
HFE-E236ea2	CF ₃ CHFOCHF ₂	5.8	-			960	-	300	
HFE-E236fa1	CF ₃ OCH ₂ CF ₃	3.7	-			470	-	150	
HFE-E245cb2	CF ₃ CF ₂ OCH ₃	1.2	-			160	-	50	
HFE-E245fa1	CHF ₂ CH ₂ OCF ₃	2.2	-			280	-	86	
HFE-E245fa2	CF ₃ CH ₂ OCHF ₂	4.4	-			340	-	110	
HFE-E254cb2	CHF ₂ CF ₂ OCH ₃	0.22	-			25	-	8	
HFE-E263fb2	CF ₃ CH ₂ OCH ₃	0.1	-			11	-	3	
HFE-E329mcc2	CF ₃ CF ₂ OCF ₂ CHF ₂	6.8	-			890	-	280	
HFE-E338mf 2	CF ₃ CF ₂ OCH ₂ CF ₃	4.3	-			540	-	170	
HFE-E347mcc3	CF ₃ CF ₂ CF ₂ OCH ₃	1.3	-			140	-	43	
HFE-E347mcf2	CF ₃ CF ₂ OCH ₂ CHF ₂	2.8	-			360	-	110	
HFE-E356mcc3	CF ₃ CHFCF ₂ OCH ₃	0.94	-			98	-	30	
HFE-E356pcc3	CHF ₂ CF ₂ CF ₂ OCH ₃	0.93	-			110	-	33	
HFE-E356pcf 2	CHF ₂ CF ₂ OCH ₂ CHF ₂	2.0	-			260	-	80	
HFE-E356pcf 3	CHF ₂ CF ₂ CH ₂ OCHF ₂	1.3	-			180	-	55	
HFE-E365mc3	CF ₃ CF ₂ CH ₂ OCH ₃	0.11	-			11	-	4	
HFE-E374pc2	CHF ₂ CF ₂ OCH ₂ CH ₃	0.43	-			47	-	14	

Compound	Chemical Formula	Lifetime ⁴ (years)	ODP ⁵	GWPs from IPCC SAR ¹ 100 year GWPs ³		GWPs from 1998 Ozone Assessment ² 100 year GWPs		VOC ⁷	
				Direct	Net ⁶	Direct	Net ⁶	500 year GWPs	
								Direct	
HFE-E347mmy2	(CF ₃) ₂ CFOCH ₃	3.5	-			340	-	110	
HFE-E338mmz2	(CF ₃) ₂ CHOCHF ₂	3.1	-			370	-	110	
HFE-E356mmz2	(CF ₃) ₂ CHOCH ₃	0.25	-			26	-	8	
HFE-E347mcc3	n-C ₃ F ₇ OCH ₃	4.9 ¹¹	-						
HFE-E449s4/ HFE- E449mmyc3	n-C ₄ F ₉ OCH ₃ / i- C ₄ F ₉ OCH ₃	5.0	-			390	-	120	Exempted
HFE-E569sf4/ HFE- E569mmyc3	n-C ₄ F ₉ OC ₂ H ₅ /i- C ₄ F ₉ OC ₂ H ₅	0.77	-			55	-	17	Exempted
2,2,2-Trifluoro- ethanol	CF ₃ CH ₂ OH	0.46	-			52	-	16	
2,2,3,3,3-Penta- fluoropropanol	CF ₃ CF ₂ CH ₂ OH	0.43	-			43	-	14	
Hexafluoroiso- propanol	(CF ₃) ₂ CHOH	1.4	-			150	-	46	
PFC-14	CF ₄	50000	-	6500	-	5700	-	8900	Exempted
PFC-116	C ₂ F ₆	10000	-	9200	-	11400	-	17300	Exempted
PFC-218	C ₃ F ₈	2600	-	7000	-	8600	-	12400	Exempted
PFC-31-10	C ₄ F ₁₀	2600	-	7000	-	8600	-	12400	Exempted
PFC-41-12	C ₅ F ₁₂	4100	-	7500	-	8900	-	13200	Exempted
PFC-51-14	C ₆ F ₁₄	3200	-	7400	-	9000	-	13200	Exempted
PFC-c-318	c-C ₄ F ₈	3200	-	8700	-	11200	-	16400	
Sulfur hexafluoride	SF ₆	3200	-	23900	-	22200	-	32400	
Nitrogen trifluoride	NF ₃	740	-			10800	-	13100	
n-Propylbromide	C ₃ H ₇ Br	0.03 ¹⁰							
Ammonia	NH ₃		-						

Compound	Chemical Formula	Lifetime ⁴ (years)	ODP ⁵	GWPs from IPCC SAR ¹ 100 year GWPs ³		GWPs from 1998 Ozone Assessment ² 100 year GWPs		VOC ⁷	
				Direct	Net ⁶	Direct	Net ⁶	500 year GWPs	
								Direct	
Sulfur dioxide	SO ₂		-						
Methylene chloride	CH ₂ Cl ₂	0.46				10		3	
Propane	CH ₃ CH ₂ CH ₃	0.04 ¹²	-			3 ¹³		3 ¹³	Yes
n-Butane	CH ₃ CH ₂ CH ₂ CH ₃	0.02 ¹²	-			3 ¹³		3 ¹³	Yes

¹Global Warming Potentials (GWPs) in these columns were taken from the Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (SAR) (*Climate Change 1995: The Science of Climate Change*, J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.), Cambridge University Press, Cambridge, UK, 1996.). A blank indicates that no value was listed in the assessment report. These GWPs for HFCs, PFCs and SF₆ are the values adopted for the Kyoto Protocol according to Paragraph 3 of Article 5 of Decision 1/CP.3 (FCCC/CP/1997/7/Add.1): “3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technical Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.” and Paragraph 3 of Decision 2/CP.3 (FCCC/CP/1997/7/Add.1): “3. Reaffirms that global warming potentials used by Parties should be those provided by the Intergovernmental Panel on Climate Change in its Second Assessment Report (“1995 IPCC GWP values”) based on the effects of the greenhouse gases over a 100-year time horizon, taking into account the inherent and complicated uncertainties involved in global warming potential estimates. In addition, for information purposes only Parties may also use another time horizon, as provided in the Second Assessment Report.”

²Except as noted, GWP values in these columns were taken from *Scientific Assessment of Ozone Depletion: 1998*, World Meteorological Organization Global Ozone Research and Monitoring Project Report No. 44, Geneva, 1999.

³As stated in footnote “¹,” 100 year GWPs listed in the IPCC SAR are to be used for the purposes of the Kyoto Protocol. Note that GWPs were not listed in the SAR for a number of compounds shown in the table. The 100 year GWP of a compound provides an estimate of its influence on global climate to that of carbon dioxide, the reference compound, over the first 100 years after emission to the atmosphere. Since carbon dioxide persists in the atmosphere for well over 100 years (see footnote “⁸”) GWPs for longer time horizons such as the 500 year time horizon listed in the last column also provide valuable information relative to a goal of stabilization of greenhouse gas concentrations as stated in Article 2 of the UN Framework Convention on Climate Change.

⁴Except as noted, lifetime values were taken from *Scientific Assessment of Ozone Depletion: 1998*, World Meteorological Organization Global Ozone Research and Monitoring Project *Report No. 44*, Geneva, 1999.

⁵ODP (Ozone Depleting Potential) values are those adopted under the Montreal Protocol on Substances that Deplete the Ozone Layer. Dashes, “-“ indicate that the compounds have negligible potential to deplete the ozone layer.

⁶Net GWPs include both the direct effect on global climate due to a compounds ability to absorb infrared radiation and the indirect effect due to the compounds ability to deplete stratospheric ozone. The ranges shown for compounds is due to the significant uncertainty in the indirect effect term. A blank indicates that no value was listed in the assessment report. A dash, “-“ indicates that the net GWP will be identical to the direct GWP.

⁷Federal Register. 51.100 Definitions. Vol. 63, No. 68. Thursday, April 9, 1998. Rules and Regulations. P. 17333. “Exempted” means that the compound has been determined to be negligibly photochemically reactive and is not designated as a VOC under U.S. law.

⁸The effective atmospheric lifetime of carbon dioxide cannot be described in terms of a simple exponential decay as for the other compounds listed in the table (see the IPCC SAR for more information). However, a significant fraction of an amount of carbon dioxide persists well over 100 years after it has been released to the atmosphere.

⁹*Scientific Assessment of Ozone Depletion: 1991*, World Meteorological Organization Global Ozone Research and Monitoring Project *Report No. 25*, Geneva, Switzerland, 1992.

¹⁰Personal communication from Donald Wuebbles.

¹¹Personal communication from John Owens.

¹²Lifetime calculated based on reaction rate constant with OH taken from R. Atkinson, *J. Phys. Chem. Ref. Data Monograph 2*, 1994 and methyl chloroform lifetime of 5.7 years taken from *Scientific Assessment of Ozone Depletion: 1998*, World Meteorological Organization Global Ozone Research and Monitoring Project *Report No. 44*, Geneva, 1999.

¹³GWP based on conversion to carbon dioxide in atmosphere as taken from *Climate Change: The IPCC Scientific Assessment*, J.T. Houghton, G.J. Jenkins and J.J. Ephraums (eds.), Cambridge University Press, Cambridge, UK, 1990.

APPENDIX M – Toxicity Values for Various Ozone-Depleting Substances and Their Substitutes

COMMON NAME	CHEMICAL	CAS No./ECETOC	ACCEPTABLE OCCUPATIONAL LONG-TERM EXPOSURE (ppm)	ACCEPTABLE OCCUPATIONAL SHORT-TERM EXPOSURE (ppm)	CARDIOTOXIC LOAEL (ppm)	CARDIOTOXIC NOAEL (ppm)	ACCEPTABLE LONG-TERM PUBLIC EXPOSURE (RfD or RfC) (ppm) [#]
CFC-11	Trichlorofluoromethane	75-69-4	NA	NA	5,000 ^d	1,100 ^d	0.05 ^e
CFC-12	Dichlorodifluoromethane	75-71-8	1,000 ^a	NA	50,000 ^d	25,000 ^d	0.04 ^e
HCFC-21	Dichlorofluoromethane	75-43-4	10 ^a	NA	10,000 ^v	NA	NA
HCFC-22	Chlorodifluoromethane	75-45-6	1,000 ^a	1,250 ^m	50,000 ^d	25,000 ^d	14 ^e
HCFC-123	2,2-Dichloro-1,1,1-trifluoroethane	306-83-2	10 ^t	NA	20,000 ^d	10,300 ^d	2 ^g
HCFC-124	1-Chloro-1,2,2,2-tetrafluoroethane	2837-89-0 ECETOC 1989	1,000 ^h	3,000 ⁱ	25,000 ^d	10,000 ^d	50 ^g
HCFC-141b	1,1-Dichloro-1-fluoroethane	1717-00-6 ECETOC 1994a	500 ^h	1,000 ^j	5,000 ^d	2,500 ^d	20 ^k
HCFC-142b	1-Chloro-1,1-difluoroethane	75-68-3 ECETOC 1991	1,000 ^h	5,000 ^v	50,000 ^d	25,000 ^d	12 ^e
HCFC-225cb	1,3-Dichloro-1,1,2,2,3-pentafluoropropane	507-55-1	NA	NA	20,000 ^f	NA	NA
HFC-23	Trifluoromethane	75-46-4	1,000 ⁿ	3,000 ⁿ	500,000 ^o	300,000 ^o	2 ⁿ
HFC-32	Difluoromethane	75-10-5 ECETOC 1995a	1,000 ^h	3,000 ^{sg}	350,000 ^f	200,000 ^d	2 ^s
HFC-125	Pentafluoroethane	354-33-6	1,000 ⁿ	3,000 ⁿ	100,000 ^o	75,000 ^d	2 ⁿ

COMMON NAME	CHEMICAL	CAS No./ECETOC	ACCEPTABLE OCCUPATIONAL LONG-TERM EXPOSURE (ppm)	ACCEPTABLE OCCUPATIONAL SHORT-TERM EXPOSURE (ppm)	CARDIOTOXIC LOAEL (ppm)	CARDIOTOXIC NOAEL (ppm)	ACCEPTABLE LONG-TERM PUBLIC EXPOSURE (RfD or RfC) (ppm) [#]
HFC-134a	1,1,1,2-Tetrafluoroethane	811-97-2 ECETOC 1995b	1,000 ^h	3,000 ⁱ	80,000 ^o	50,000 ^d	20 ^e
HFC-143a	1,1,2-Trifluoroethane	420-46-2	1,000 ⁿ	3,000 ⁿ	300,000 ^o	25,000 ^o	20 ^{ff}
HFC-152a	1,1-Difluoroethane	75-37-6	1,000 ^p	5,000 ^b	150,000 ^o	50,000 ^d	15 ^e
HFC-227ea	1,1,1,2,3,3,3-heptafluoropropane	43-89-0	1,000 ⁿ	3,000 ⁿ	>105,000 ^o	90,000 ^o	2 ⁿ
HFC-236ea	1,1,1,2,3,3-hexafluoropropane	431-63-0	NA	NA	35,000 ^q	25,000 ^q	NA
HFC-236fa	1,1,1,3,3,3-hexafluoropropane	690-39-1	1,000 ^c	NA	150,000 ^r	100,000 ^r	NA
HFC-43-10mee	1,1,1,2,3,4,4,5,5,5-decafluoropentane	138495-42-8	200	N/A	N/A	N/A	N/A
HFE 7100	Methoxy-nonafluorobutane	*	600 ^t	>104,000 ^t	NA	100,000 ^u	20 ^t
HFE 7200	Ethoxy-nonafluorobutane	*	250 ^w	NA	50,000 ^x	20,000 ^x	NA
PFC-218 (C ₃ F ₈)	Perfluoropropane	76-19-7	1000 ^y	NA	NA	NA	0.5 ^{ee}
PFC-410 (C ₄ F ₁₀) (FC-3-1-10)	Perfluorobutane	335-25-9	1,000 ^z	10,000 ^z	>400,000 ^g	400,000 ^g	NA
PFC-614 (C ₆ F ₁₄) (FC-5-1-14)	Perfluorohexane	355-42-0	1,000 ^z	10,000 ^z	>400,000 ^g	400,000 ^g	NA
SF ₆	Sulfur hexafluoride	2551-62-4	1,000 ^a	NA	NA	NA	NA

COMMON NAME	CHEMICAL	CAS No./ECETOC	ACCEPTABLE OCCUPATIONAL LONG-TERM EXPOSURE (ppm)	ACCEPTABLE OCCUPATIONAL SHORT-TERM EXPOSURE (ppm)	CARDIOTOXIC LOAEL (ppm)	CARDIOTOXIC NOAEL (ppm)	ACCEPTABLE LONG-TERM PUBLIC EXPOSURE (RfD or RfC) (ppm) [#]
CO ₂	Carbon dioxide	124-38-9	5,000 ^{jl}	30,000 ^{kk}	15,000 ^v	30,000 ^v	NA
CH ₃ CH ₂ CH ₃	Propane	74-98-6	1,000 ^{jl}	NA	1,000 ^v	NA	NA
CH ₃ CH ₂ CH ₂ CH ₃	n-Butane	106-97-8	800 ^{ll}	NA	NA	5,000 ^v	NA
C ₆ H ₁₀	d-Limonene	5989-27-5	30 ^h	NA	24,000 ^{aa}	24,000 ^{aa}	1.2 ^{bb}
HCC-30	Methylene chloride	75-09-2	50 ^{cc}	NA	NA	NA	0.02 ^e
R-764	Sulfur dioxide	7445-09-5	2 ^a	5 ^{dd}	NA	NA	NA
CF ₃ I ~	Trifluoroiodomethane	2314-97-8	150 ^{hh}	2000 ⁱⁱ	4,000 ^{hh}	2000 ^{hh}	3.6 ^{hh}
R-717	Ammonia	7664-41-7	25 ^{cc}	35 ^{dd}	NA	NA	0.10 ^e

Developmental toxicity has not been addressed in this table because it is felt that the exposure limits set by EPA for the general population (the RfD or RfC) are sufficiently protective of maternal and fetal health. These values are by definition those to which the general population, including sensitive subpopulations, can be continually exposed without the occurrence of adverse effects.

Values have been converted from mg/m³ to ppm for convenience.

* Not applicable—chemical is a blend.

~ Compound used in various blends.

^a OSHA PEL. ACGIH Worldwide. 1991. Documentation of the Threshold Limit Values and Biological Exposure Indices. Sixth Edition. Vols I-III.

^b Estimated: 1 or 0.1 x the NOAEL or LOAEL for cardiotoxicity. ICF Consulting. 1993. Risk Screen on the Use of Substitutes for Class I Ozone-Depleting Substances: Foam-Blowing Sector. End-Use: Polyurethane Skin Forms. Draft. March 31, 1993.

^c Based on AIHA's "good housekeeping" limit (see footnote ^f)

^d Calm, James M. 1996. The Toxicity of Refrigerants. Presented at the International Refrigeration Conference, Purdue University, July 1996.

^e EPA's IRIS Website. <http://www.epa.gov/ngispgm3/iris/index.html>. Accessed August 4, 1999.

^f PAFT Website. <http://www.paft.org>. Accessed August 3, 1999.

^g EPA. 1994. ASNAP Technical Background Document: Risk Screen on the Use of Substitutes for Class I Ozone-Depleting Substances: Fire Suppression and Explosion Protection (Halon Substitutes).@ Stratospheric Protection Division. March, 1994.

^h AIHA WEEL. 1997 WEELs Complete Set. AIHA.

ⁱ Based on ACGIH's excursion limit recommendation. EPA. 1994. ASNAP Technical Background Document: Risk Screen on the Use of Substitutes for Class I Ozone-Depleting Substances: Sterilization.@ Stratospheric Protection Division. March, 1994.

^j Based on ACGIH's "good housekeeping" limit (see footnote ^k)

^k EPA. 1994. ASNAP Technical Background Document: Risk Screen on the Use of Substitutes for Class I Ozone-Depleting Substances: Foam-Blowing Agents.@ Stratospheric Protection Division. March, 1994.

^l Based on ACGIH's excursion limit recommendation (see footnote ^o)

^m NIOSH STEL. ACGIH Worldwide. 1991. Documentation of the Threshold Limit Values and Biological Exposure Indices. Sixth Edition. Vols I-III.

ⁿ Estimated by analogy to HFC-134a (see footnote ^o)

^o EPA. 1994. ASNAP Technical Background Document: Risk Screen on the Use of Substitutes for Class I Ozone-Depleting Substances: Refrigeration and Air Conditioning.@ Stratospheric Protection Division. March, 1994.

^p Based on ACGIH's "good housekeeping" limit (see footnote ^o)

^q Acurex Environmental Corporation. 1996. Final Report: Acute Cardiac Sensitization Study of HFC-236ea in Dogs by Inhalation. Prepared for EPA under Contract No. 68-D2-0063. June 7, 1996.

^f ICF Consulting. 1997. Halon Sector SNAP Risk Screens. Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 1-16, Task 02. July 31, 1997.

^s Estimated by analogy to HFC-134a (see footnote ^g)

^t Estimated by analogy to HFC-134a. ICF Consulting. 1996. SNAP Assessments for HFE-7100. Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 0-18, Task 10. June 28, 1996.

^u 3M Website. <http://www.3mco.fi/market/industrial/fluids/7100.htm>. Accessed August 4, 1999.

^v ACGIH Worldwide. 1991. Documentation of the Threshold Limit Values and Biological Exposure Indices. Sixth Edition. Vols I-III.

^w ICF Consulting. 1999. Acceptable Exposure Limit (AEL) for T-6333 (HFE-7200). Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 3-08, Task 03. March 18, 1999.

^x ICF Consulting. 1999. Review of Toxicity Studies on T-6333 (HFE-7200). Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 3-08, Task 03. March 24, 1999.

^y Estimated by analogy to propane (see footnote ^o)

^z Based on animal data and similarity to other HFCs (see footnote ^g)

^{aa} Level shown to induce cardiotoxicity in 50% of the treated dogs (Clark and Tinston 1973) (see footnote ^k)

^{bb} Extrapolated from 8-hour TLV-TWA. EPA. 1994. ASNAP Technical Background Document: Risk Screen on the Use of Substitutes for Class I Ozone-Depleting Substances: Aerosols. @ Stratospheric Protection Division. March, 1994.

^{cc} ACGIH TLV-TWA. ACGIH Worldwide. 1991. Documentation of the Threshold Limit Values and Biological Exposure Indices. Sixth Edition. Vols I-III.

^{dd} OSHA STEL. ACGIH Worldwide. 1991. Documentation of the Threshold Limit Values and Biological Exposure Indices. Sixth Edition. Vols I-III.

^{ee} Extrapolated from 8-hour TLV-TWA (see footnote ^o)

^{ff} Estimated based on limited data (see footnote ^o)

gg Estimated by analogy to HFC-134a. ICF Consulting. 1999. Updated Occupational Exposure Modeling Results. Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 3-06, Task 03. July 19, 1999.

hh ICF Consulting. 1999. Final Version of Ikon® B Risk Screen. Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 3-06, Task 03. June 23, 1999.

ii Short-term exposure limit of 2,000 ppm based on NOAEL for cardiotoxicity. ICF Consulting. 1999. Final Version of Ikon® B Risk Screen. Memorandum for EPA under Contract No. 68-D5-0147, Work Assignment 3-06, Task 03. June 23, 1999.

LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH = American Conference of Government Industrial Hygienists

AIHA = American Industrial Hygiene Association

CAS = Chemical Abstract Service

ECETOC = European Chemical Industry Ecology and Toxicology Centre

IRIS = Integrated Risk Information System

LOAEL = Lowest Observed Adverse Effect Level

NA = Not available

NIOSH = National Institute for Occupational Safety and Health

NOAEL = No Observed Adverse Effect Level

OSHA = Occupational Safety and Health Administration

PEL = Permissible Exposure Limit

PAFT = Programme for Alternative Fluorocarbon Toxicity Testing

RfC = Reference Concentration (for inhalation exposure)

RfD = Reference Dose (for oral exposure)

STEL = Short-Term Exposure Limit

TLV = Threshold Limit Value

WEEL = Workplace Environmental Exposure Level

TWA = Time-Weighted Average

APPENDIX N – Available Information on Government and Industry Initiatives on HFCs

A number of governments have taken, or are planning to take, initiatives to control the use or emissions of HFCs and PFCs. Descriptions of initiatives taken by EU member states Austria, Belgium, Denmark, France, Germany, Italy, the Netherlands, and the United Kingdom are presented at the UNFCCC website, www.unfccc.de.

Australia

Industry is developing a four-stage strategy to limit emissions of HFCs. This includes:

- Extension of codes of practice to cover HFCs
- Extension of activities of Re-Claim Australia to cover the recovery and recycling of HFCs
- Ban on disposable HFC containers
- National certification for technicians

Canada

The Canadian Federal Government has initiatives for the control of ODSs and their halocarbon alternatives. The first task has been prohibition of the release of, mandate the recovery of, and limitation of the dispersive uses of all CFCs, HCFCs and HFCs. Actions have included:

- Certification of technicians
- No venting
- Mandatory recovery and recycling
- Limitation on HFCs replacing ODS in existing areas

A more detailed analysis of HFC applications is underway.

Denmark

Measures already in place:

- Use of HFCs as fire extinguishing agents is not allowed.
- Only registered enterprises and/or individuals, possessing the necessary knowledge and recovery equipment, are allowed to purchase refrigerant.
- All refrigerants must be recovered and recycled, including HFCs.
- The 1998 National List of Undesirable Substances includes HFCs, PFCs and SF₆ as undesirable due to their greenhouse effect.
- Copenhagen has adopted regulation entering into force by July 1999 requiring leakage tests of all large refrigeration systems containing CFC, HCFC, HFC and PFC refrigerants. HFC and PFC refrigeration systems containing less than 100 kg must be checked per annum and systems containing more than 100 kg must be checked 4 times per annum. There are more frequent checks for CFC and HCFC equipment.

Japan

The Japanese Government adopted a law in October 1998 to promote measures to cope with global warming. These measures encourage central and local governments, businesses and citizens to adopt emission reduction measures for the basket of greenhouse gases included in the Kyoto Protocol.

United States

The U.S. Government has the following regulations under the Clean Air Act:

- No venting regulations for all ODS replacements
- Mandatory recovery and recycling
- Definition of acceptable replacements for ODS applications under the Significant New Alternatives Program (SNAP)

The U.S. EPA is targeting and working with key HFC, PFC and SF₆ industrial emitting sectors, developing specialised knowledge and designing customised programs to focus on emission reductions that can be achieved now.

Industry groups have also taken, or are planning to take, voluntary actions to limit emissions or use of HFCs, PFCs and SF₆. These initiatives can best be viewed as actions to define and implement “responsible use” of HFCs, PFCs, and SF₆.

“Responsible Use” is an element of sustainable development that can be guided by the following principles:

Use HFCs and PFCs only in applications where they provide safety, energy efficiency, environmental, or economic advantage.

Limit emissions of HFCs and PFCs to the lowest practical level during manufacture, use, servicing and disposal of equipment and products.

If HFCs and PFCs are to be used, select the compound with the smaller GWP that meets the application requirements.⁹

⁹HFCs and PFCs have a wide range of atmospheric lifetimes and potential to contribute to global climate change. The global warming potential (GWP) is a measure of these potentials. Some HFE and newly developed HFC compounds that are potential substitutes for ODSs, PFCs, and HFCs, may have atmospheric lifetimes and GWPs within the range of the HFCs currently included in the Kyoto Protocol.

Examples of Responsible HFC, PFC and SF₆ Use

EPA Partnerships with Electric Power Systems (SF₆)

In April 1999, the United States Environmental Protection Agency joined with 48 electric utilities and local governments in a new partnership to reduce emissions of sulfur hexafluoride (SF₆) from circuit breakers, gas-insulated substations, and switchgear. Electric power systems that join the partnership agree to estimate their emissions of SF₆; establish a strategy for replacing older, leakier equipment; implement SF₆ recycling; ensure that only knowledgeable personnel handle SF₆; and to submit annual progress reports. Within eighteen months of joining, partners agree to set technically and economically feasible emission reduction goals. EPA will be a clearinghouse for technical information on successful strategies to reduce emissions, will track emission reductions and will work to recruit additional electric power system operators to join the partnership. Participants value the benefits voluntary programs offer: cost-effective pollution prevention, technological innovation and information sharing, flexibility and quick implementation, and positive company recognition.

World Semiconductor Council (PFCs)

The Semiconductor Council (WSC) consists of the Semiconductor Industry Association, Electronic Industries Association of Japan, Korea Semiconductor Industry Association, and European Electronic Component Manufacturers Association. Established on the basis of co-operative efforts within the global industry, the WSC identified environmental, safety and health-related issues (ESH) as one of the key areas for co-operative effort. In particular, an ESH Task Force was chartered and PFC emissions reductions selected as the first challenge.

Accomplishments to date include the adoption of Voluntary Agreements to reduce PFC emissions, sharing of technical information related to PFC emissions reduction technologies, consensus to utilise common metrics and measurement protocols, and formation of a PFC subgroup of technical experts to implement consensus programs.

The Joseph Company (HFCs)

The original beverage Chill Can[®] was to have been launched in the summer of 1997 and would have emitted approximately 35-75 grams of HFC-134a or HFC-152a per can directly into the atmosphere. In response to EPA concerns, The Joseph Company voluntarily withdrew the HFC design and developed an alternative technology that uses organic carbon adsorption of CO₂. The Joseph Company pledged not to manufacture or license the original HFC product and will discourage the use of the HFC technology as environmentally unacceptable.

Japan Action Plan for Reducing Emission from Medical Aerosols (HFCs)

The Japan Action Plan calls for the transition from HFCs to non-HFCs where feasible and limits the development, manufacture and marketing of HFC MDIs to medically indispensable needs. By reducing emissions, destroying waste and shifting to alternative therapies, the plan's goal is to achieve a 25% reduction in overall use and emissions compared to the use projected for 2010.

Japan Action Plan for Reducing Emissions in Manufacturing and Marketing (PFCs)

The Japan Action Plan for reducing PFC emissions has a goal of 30% emission reduction per unit of production output by 2010. The plan's strategy is containment and chemical yield optimisation, recovery, recycling or destruction, and improved filling transport and "heal" recovery. Partnerships include PFC manufacturers, the National Institute of Materials and Chemical Research.

Great Lakes Chemical Responsible Care[®] Initiative (HFCs)

HFC-227ea¹⁰ is a replacement for halon 1301 in total flooding fire suppression applications. Great Lakes Chemical Corporation is working with government, industry and end users to reduce emissions of HFC-227ea to de minimus levels at the manufacturing, distribution, handling, and end use stages of the product lifecycle.

Reduction of emissions at the manufacturing stage is achieved with a simplified process with fewer pipe-joints and gasketed components and with less overfluorination and process venting. Reduction of emissions during handling, distribution, and system installation is accomplished with best practices. HFCs are recovered from equipment during service or decommissioning and either recycled or transformed into other useful chemical products.

This voluntary initiative has the goal to reduce emissions throughout all stages of the product lifecycle by involving customers and their service organisations in a comprehensive strategy managed by the chemical supplier.

Japan Action Plan for Reducing Emissions from Power Equipment (SF₆)

The Japan Action Plan for Reducing SF₆ Emissions from Power Equipment involves utility leadership by the Federation of Electrical Power Companies and manufacturer leadership by the Japan Electrical Manufacturers Association. The plan's strategy includes containment, recycling, less frequent overhaul on new devices, and the creation of a national partnership between utilities, equipment suppliers, and chemical manufacturers. The plan will reduce the volume of emissions during manufacturing from the current 30% of purchased volume to 3% of purchased volume by 2005. The volume of emissions during machine inspections will be reduced from the current 40% of purchased volume to 3% of purchased volume by 2005. Currently 100% of the SF₆ in equipment at the time of disposal is emitted, but with the plan will be reduced to 1% by 2005. The Federation of Electric Power Companies estimates that without action, SF₆ emissions would total about 190 tonnes in 2010, but with the plan in place will total about 40 tonnes.

¹⁰ Marketed under the Great Lakes Chemical Company tradename FM-200

APPENDIX O – INDUSTRY NGO, AND ENVIRONMENTAL NGO PERSPECTIVES ON HFC CONTROLS

Members of the TEAP HFC/PFC Taskforce conducted workshops, seminars, and interviews with government and NGO stakeholders to determine the various perspectives on the possible implications of controls on HFCs to implementation of the Montreal Protocol. These discussions occurred in Australia, Egypt, Germany, Hungary, Japan, Jordan, Mexico, Netherlands, Poland, Singapore, Switzerland, Taiwan, Thailand, United States, and Vietnam. TEAP Technical Options Committees held similar discussions at their annual meetings in Cyprus, Germany, Netherlands, Singapore, and Switzerland. The following sections outline those perspectives:

Competition between HFC and HC refrigerants motivates technical breakthroughs and incremental gains in energy efficiency. Market forces will support the selection of the best technology if energy efficiency standards are stringent.

HFC Suppliers and Proponents

HFC suppliers and their proponents made considerable investments in order to rapidly phase out the use of ODSs. Additional investments will be necessary to complete the global phaseout of ODSs.

The Kyoto Protocol is designed to achieve climate protection through a flexible “basket approach” respecting the autonomy of national implementation plans. Specific HFC controls advocated under Montreal, Kyoto, or national implementation plans could violate the spirit of national autonomy and increase the total cost of compliance by limiting market choice.

The Montreal Protocol is well known for the history of increasing stringency by expanding the list of controlled substances and accelerating the phaseout. There is a concern that climate protection agreements could adopt an approach similar to phaseout rather than an approach of emission reduction and “responsible use” that is more consistent with scientific information and technical and economic feasibility.

It would be unfair and uneconomic to target HFCs for controls merely because they are among the first uses to be studied. HFC suppliers and users are frustrated that HC refrigerants are given the label “natural” when they are mass-produced industrial products with their own environmental and safety concerns and which may or may not provide high energy efficiency. The “natural designation” gives the perception that HCs are good for the environment while HFCs are bad for the environment.

HC Suppliers and Proponents

Proponents of HC technology are frustrated by what they view as exaggerated claims of flammability risk by HFC competitors.

HC proponents are further frustrated that HFC competitors admit that small appliances can be safe with HC refrigerants but that liability concerns prevent their marketing in “litigious” countries like the United States or “safety conscious” countries like Japan. Proponents note that companies making these arguments market other consumer products with comparable or higher risk.