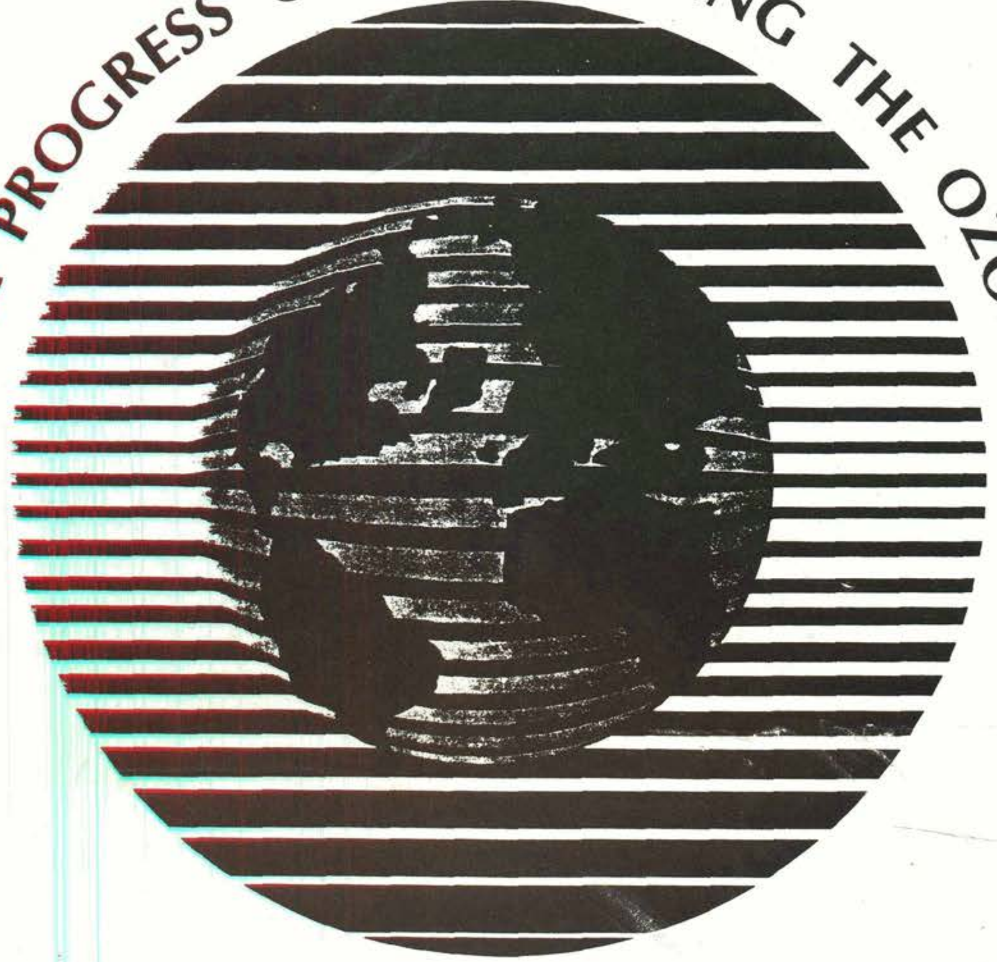
TECHNICAL PROGRESS ON PROTECTING THE OZONE LAYER



REPORT OF THE TECHNOLOGY REVIEW PANEL

PURSUANT TO ARTICLE (6) OF THE MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE THE OZONE LAYER
UNDER THE AUSPICES OF THE
UNITED NATIONS ENVIRONMENT PROGRAMME

JUNE 30, 1989

Final Report

of the

Technology Review Panel

August 1989

ACKNOWLEDGMENTS

The Technical Review Panel acknowledges with thanks the outstanding contributions from the Technical Options Committee participants, other persons, organizations, associations, and correspondents which participated in or provided input to this Review.

Refrigeration, Air Conditioning, and Heat Pumps Report

NAME	AFFILIATION	COUNTRY
Dr. L. Kuijpers, Chairman	Philips Research Labs.	Netherlands
Prof. R. Agarwal	Indian Inst. of Technology	India
A. Aguri	Daikin Ltd.	Japan
K. Anderson	Consultant	USA
Prof. G. Angelino	Politecnico Milano	Italy
R. Ares	Hussman Co.	USA
J. Baker	Harrison Rad. Div. GM	USA
T. Banse	Toshiba Cons. Prod.	Japan
R. Benstead	Electr. Council RC	U.K.
Prof. T. Berntsson	Chalmers Inst.	Sweden
Dr. S. Bhaduri	Indian Inst. of Tech	India
Yu Bingfeng	Xi'an Jiatong University	P.R. of China
F. Boldvig	Sabroe Refrig. A/S	Denmark
P. Cooper	Sainsburys Ltd.	U.K.
Dr. D. Didion	Nat. Inst. of Stds. and Tech.	USA
Dr. P.E. Frivik	SINTEF	Norway
H. Hale	Carrier Co.	USA
F. Hallett	White Consol. Inc.	USA
Dr. H. Haukas	Trondheim Technical University	Norway
F. Hayes	The Trane Co.	USA
R. Heap	SCRCA	U.K.
E. Heinzelmann	Embraco	Brazil
Dr. U. Hesse	University of Hannover	FRG
K. Hickman	York Int. Co.	USA
Dr. N. Ishikawa	Tokyo Inst. of Technology	Japan
Ren Jinlu	G. Machinery Res. Inst.	P.R. of China
Prof. H. Kruse	University of Hannover	FRG
A. Lindborg	Frigoscandia AB	Sweden
S. McDonald	Batelle Pacific NW Labs	USA
Dr. M. McLinden	Nat. Inst. of Stds. and Tech.	USA
P. Moser	Sulzer AG	Switzerland
Dr. M. Narodoslawsky	Graz University	Austria
R. Radecki	Harrison Division of GM	USA
L. Roke	Fisher & Paykel Ind.	New Zealand
P. Samuelsen	Finsam Ltd.	Norway
J. Schatten	Schatten BV	Belgium
M. Schneeberger	Oberoest. Kraftwerk AG	Austria
R. Segerstrom	Electrolux AB	Sweden
T. Statt	Dept. of Energy	USA
A. Stera (Wilson)	Lloyd's Register of Shipping	U.K.
S. Sumikawa	Diesel Kiki Co. Ltd.	Japan
Dr. J.K. Taulbee	White Consol. Inc.	USA

S. Taylor	Refrig. Recovery Sys. Co.	USA
M. Tirel	Matal SA	France
K. Tsakuhara	Mitsubishi Industries	Japan
W. Viloehr	Bosch Siemens Hausgeraete	FRG
Dr. R. Wallner	Julius Behr GmbH.	FRG
N. Yokota	Refrig. AC Ind. Ass.	Japan

Rigid and Flexible Foams Report

NAME	AFFILIATION	COUNTRY
Jean M. Lupinacci, Chairwoman	Environmental Protection Agency	USA
J. Godfrey Abbott	Dow Europe/Exiba	Switzerland
Lorraine M. Aulisio	Celotex Corporation/PIMA	USA
Craig Barkhouse	Reeves Brothers Canada/CFFMA	Canada
Michael J. Cartmell	European Isocyanate Prod. Assoc.	Belgium
Hubert Creyf	Recticel/Europur	Belgium
Ryoichi Fujimoto	Hitachi Ltd.	Japan
Dr. Leon Glicksman	Massachusetts Inst. of Tech.	USA
Reg Hurd	Brit. Rubber Manu. Assoc.	UK
Goran Johansson	PUR Utvechlings AB	Sweden
Fran W. Lichtenberg	The Society of the Plastics Ind.	USA
Dr. Max Mann	Bayer AG	FRG
David L. McElroy	Oak Ridge National Laboratory	USA
Nancy J. Sherman	Foodservice & Packaging Institute	USA
Atsuo Takei	Bridgestone Corporation	Japan

Electronics, Degreasing, and Dry Cleaning Solvents Report

NAME	AFFILIATION	COUNTRY
Dr. Stephen O. Andersen, Chairman	Environmental Protection Agency	USA
Dr. Husamuddin Ahmadzai	Statens Naturvardsverk	Sweden
Dr. Ruth Anderson (alternate)	AT&T	USA
Brian H. Baxter	British Aerospace Ltd.	U.K.
Mike Clark	Sketchley Plc.	U.K.
Per S. Dovle	Statens Forurensningstilsyn	Norway
Brian Ellis	Protonique S.A.	Switzerland
Stephen Evanoff	General Dynamics	USA
Joe R. Felty	Texas Instruments	USA
Dr. John Fisher (alternate)	AT&T	USA
Art Fitzgerald	Northern Telecom	Canada
Dr. Leslie Guth	AT&T	USA
Hitoshi Hirano	Toshiba Corporation	Japan
Sudhakar Kesavan	ICF Incorporated	USA
Leo Lambert	Digital Equipment Corporation	USA
Shigeo Matsui (alternate)	Toshiba Corp.	Japan
Prof. Haruhiko Sakurai	Keio University	Japan

Halon Fire Extinguishing Agents Report

NAME	AFFILIATION	COUNTRY
Gary Taylor, Chairman	Taylor/Wagner Inc.	Canada
Hervé Bineau	Centre Nation de Prévention et de Protection	France
Walter Brunner	Enviro	Switzerland
Susan Colgan	NFPA Research Foundation	USA
Philip J. DiNenno	Hughes Associates, Inc.	USA
Chris Hartley	AFCAM	Australia
Akio Kanda	Koatsu Gas Kogyo Co. Ltd.	Japan
Takaaki Konno	Fenwal Controls of Japan	Japan
Hans Lagerhorn	Brandtekniska Ingenjorsbyran	Sweden
Tim Leah	Environment Canada	Canada
Barry Lee	Wormald International Pty., Ltd.	Australia
Jacques Levoyer	Cerberus Guinard	France
Major Thomas Morehouse Jr.	U.S. Air Force/ Department of Defense	USA
Rick Mulhaupt	NFPA Research Foundation	USA
Robert E. Tapscott	N.M.E.R.I-University of New Mexico	USA
Isabelle Wagner	Taylor/Wagner Inc.	Canada
G.O. Wiltshire	Eurofen	EEC

Aerosols, Sterilants, and Miscellaneous Uses Report

NAME	AFFILIATION	COUNTRY
Ingrid Kökeritz Chairwoman	Nat. Environmental Protection Board	Sweden
Sture Aström	Elsi-Tech HB	Sweden
William Dennis	Duke Univ. Medical Center	USA
El-Mohamadi Eid	Environmental Affairs Agency	Egypt
Gunnar Ekedahl	Nat. Environmental Protection Board	Sweden
Charles Hancock	MDT Corporation	USA
Kastuo Imazeki	Aerosol Industry Assoc. of Japan	Japan
Montfort Johnson	Montfort A. Johnson & Assoc., Ltd.	USA
Richard Knollys	Fed. of European Aerosol Assoc.	UK
Olle Mattsson	Getinge AB	Sweden
Robert Morrissey	Johnson & Johnson	USA
José I. Pons Pons	Spray Quimica C.A.	Venezuela
Vitaly Pulikov	Min. of the Chemical Industry	USSR

Technology Review Panel Report Preparation

NAME	AFFILIATION	COUNTRY
Stephen O. Andersen	U.S. EPA	USA
Andrew J. Atkinson	Environment Canada	Canada
Edward D. Brien	Environment Canada	Canada
G. Victor Buxton	Environment Canada	Canada
Jean Carbonneau	Environment Canada	Canada
Chris E. Kaczmarek	ICF Incorporated	USA
Michael S. Roth	ICF Incorporated	USA

EXECUTIVE SUMMARY

This is a summary of the assessment prepared by the Technology Review Panel based primarily on input from international expert committees called "Technical Options Committees", on reports provided directly to the Panel, and on presentations to the Panel. This assessment provides a comprehensive update on the technical progress being made throughout the world to reduce our dependency on ozone depleting substances. Progress is documented by a description of the technical options currently available in each major use sector.

The Technology Review Panel was chaired by G. Victor Buxton (Canada) on behalf of the United Nations Environment Programme (UNEP). Mr. Buxton had the responsibility for establishing the terms of reference for the technical analysis of each CFC and the halon use sector and for integrating the findings and the conclusions. Dr. Stephen O. Andersen (USA) co-chaired the Panel with responsibility for coordinating the economic analysis.

The Technical Options Committees consisted of over 100 international experts from the five principal use areas of CFCs and halons. Each of the five sector assessments was conducted by a Chairperson and a committee of experts. These five Chairpersons and their centres of responsibility were as follows:

Dr. Lambert Kuijpers (Netherlands) -- Refrigeration, Air Conditioning and Heat Pumps;

Ms. Jean Lupinacci (USA) -- Rigid and Flexible Foams;

Dr. Stephen O. Andersen (USA) -- Electronic, Degreasing and Dry Cleaning Solvents;

Mrs. Ingrid Kökeritz (Sweden) -- Aerosols, Sterilants and Miscellaneous Uses of CFCs;

Mr. Gary Taylor (Canada) -- Halon Fire Extinguishing Agents.

There are three purposes for the technical assessment. First, to provide the Parties with: a comprehensive description of the technically feasible reduction schedules; an integration of the technical information and schedules of CFC and halon reductions from the various use sectors; and, an indication of what overall phasedown period for the controlled substances is technically feasible. Second, the assessment provides a review of the relevant technical considerations of a phasedown such as: global warming characteristics; toxicity testing and product acceptability testing programmes; status of commercialisation of substitutes; current status of substitutes and alternatives to methyl chloroform and carbon tetrachloride; recovery and recycle programmes; and, recommendations on evaluation criteria for destruction technologies. Finally, this assessment, along with the five comprehensive reports on alternatives and substitutes (Technical Options Reports), collectively provide a convenient summary of state-of-the-art technological considerations for use by both developed and developing countries, including remedial measures and technical options in each sector. These reports, collectively, provide a factual foundation for building domestic regulatory programmes to meet the obligations set out in the Montreal Protocol.

This assessment with its five Technical Options Reports will be provided to a special Working Group of the Parties for their consideration along with similar reports from the Science, Effects and Economics Panels. The final recommendations on amendments to the Montreal Protocol will be contained in an integrated report prepared by the Working Group.

The key observations of this assessment are as follows:

(1) Based on the current state of technology, it is possible to phase down use of the five controlled CFCs by over 95 percent by the year 2000. The remaining use after the year 2000 would be due to refrigeration and air conditioning in systems that were designed to use CFCs and are still in service, and in other minor uses. Figure 1, page vi, shows the technically feasible phasedown projections for each of the CFC use categories. The technically feasible reductions for any intermediate date (for example a 70 percent reduction from 1986 levels by 1995) can be read from Figure 1. Given the rate of technological development, it is likely that additional technical options will be identified to facilitate the complete elimination of the controlled CFCs before the year 2000.

The key technical sector observations are as follows:

-- The refrigeration, air conditioning and heat pump sector represents approximately 25 percent of global consumption of the controlled CFCs of which 5-8 percent is used for food preservation, 1 percent being domestic refrigeration. It is necessary to distinguish between new and existing equipment. New designs using alternative refrigerants are possible now in most sub-sectors but existing equipment will have to be upgraded and replaced slowly with full substitution taking 15-20 years. Figure 2, page vii, shows the technically feasible phasedown for the various refrigeration uses. A demand for CFCs after the year 2000 is expected for service of refrigeration and air conditioning (principally automotive) in systems that were designed to use CFCs and are still in service but are not amenable to "drop-in" substitutes. Note that based on a 30 percent annual growth rate in the manufacture of domestic refrigerators, the demand from developing countries, including India and the Peoples' Republic of China, for CFC-12 at the year 2000 will represent less than 2 percent annually of the 1986 global CFC consumption levels.

-- Foam production represents approximately 25 percent of the global consumption of the controlled CFCs. It is technically feasible to reduce consumption by 60 to 70 percent by 1993 with a virtual phaseout by 1995. These reductions will be dependent on the availability of HCFCs -22, -141b, -123, etc.

-- Solvent use of CFC-113 represents approximately 16 percent of global consumption of the controlled CFCs. The predominant use is in the electronics sub-sector. There is no single universal substitute for the various CFC-113 solvent uses. All application areas have a series of options available allowing all CFC-113 solvent uses to be phased-out by the year 2000. Alternatives exist and additional substitutes are under development for dry cleaning operations. The CFC-113 phaseout is only partially dependent on HCFCs due to the large variety of non-HCFCs alternatives including product and process substitutes, water cleaning, no-clean fluxes, terpenes, white spirits (dry-cleaning) etc.

-- Aerosols in 1986 represented the largest global use of the controlled CFCs (27 percent). Sufficient technical options exist to phase out CFC use now in aerosols with the exception being some medical products and other minor uses. CFC-12 use in sterilisation can be substantially reduced using existing alternatives and can be phased out by 1995 in developed countries and somewhat later in developing countries. In food-freezing applications, CFC substitution is both technically feasible and commercially available through cryogenic techniques (liquid nitrogen).

(2) Once CFCs are phased out, the principal new sources of chlorine to the stratosphere will be methyl chloroform, carbon tetrachloride and to a much lesser extent HCFCs. Du Pont estimates that if HCFCs are allowed to satisfy new and expanding demands, including substitutes for CFCs, only 30 percent and 9 percent of the current demand for CFCs at the year 2000 will be satisfied by HCFCs and HFCs, respectively (see Figure 3, page viii). The remainder will be satisfied by non-CFC alternatives. Furthermore, industry extrapolations of World Meteorological Organization (WMO) data and U.S. EPA estimates indicate that HCFCs will make a contribution of 2-10 percent of the global warming problem out to the year 2030 (see Figure 4, page ix).

(3) There are currently no substitute chemicals with the equivalent performance of the halons in certain applications. There are however, current halon application areas where other fire protection techniques offer equivalent fire protection. Unless new alternatives are developed, this leaves the choice of continuing to use halon in essential uses with the concomitant adverse impact on the ozone layer or to accept the possibility of increased fire risk. It is recognized that conservation practices and use of other fire protection measures are important in reducing halon dependency. Some Halon Committee members are of the opinion that such measures alone are adequate to allow an orderly and complete phaseout of halon consumption by the year 2005. Other Committee members are of the opinion that these measures would allow a maximum consumption reduction of 60 percent within 5 years with the total phaseout possible if alternative chemicals are available. Other Committee members are of the opinion that it is premature to recommend any reduction until further experience with proposed alternative measures has been acquired but believe a total phaseout will be possible should substitutes become available.

(4) If the fully halogenated CFCs now controlled by the Protocol were phased out completely (with no controls on methyl chloroform, a carbon tetrachloride freeze at 1986 levels, and assuming HCFCs, with an average ODP of 0.05, captured 20 percent of what the CFC market would have been without the Protocol) chlorine concentrations would still increase by 3.7 ppb by 2100. If methyl chloroform was frozen at 1986 levels, chlorine levels would still increase by 1.7 ppb by 2020 before the concentrations would begin to decline. However, if methyl chloroform and carbon tetrachloride were phased out, chlorine concentrations could be stabilized at

1985 levels by about 2100. Substitutes currently exist for 90-95 percent of the methyl chloroform uses.

(5) With respect to carbon tetrachloride, substitutes also currently exist for the majority of its uses. However, carbon tetrachloride is needed as a chemical feedstock for the production of many of the substitute chemicals.

(6) This report describes the status of the technology for destroying CFCs and halons but does not contain criteria for "approving" destruction techniques. There are many techniques currently available and many more under development but the establishment of approval criteria requires detailed technical consideration on a "per technique" basis.

Figure 1

Technically Feasible Phasedown Projections for Major CFC Use Categories

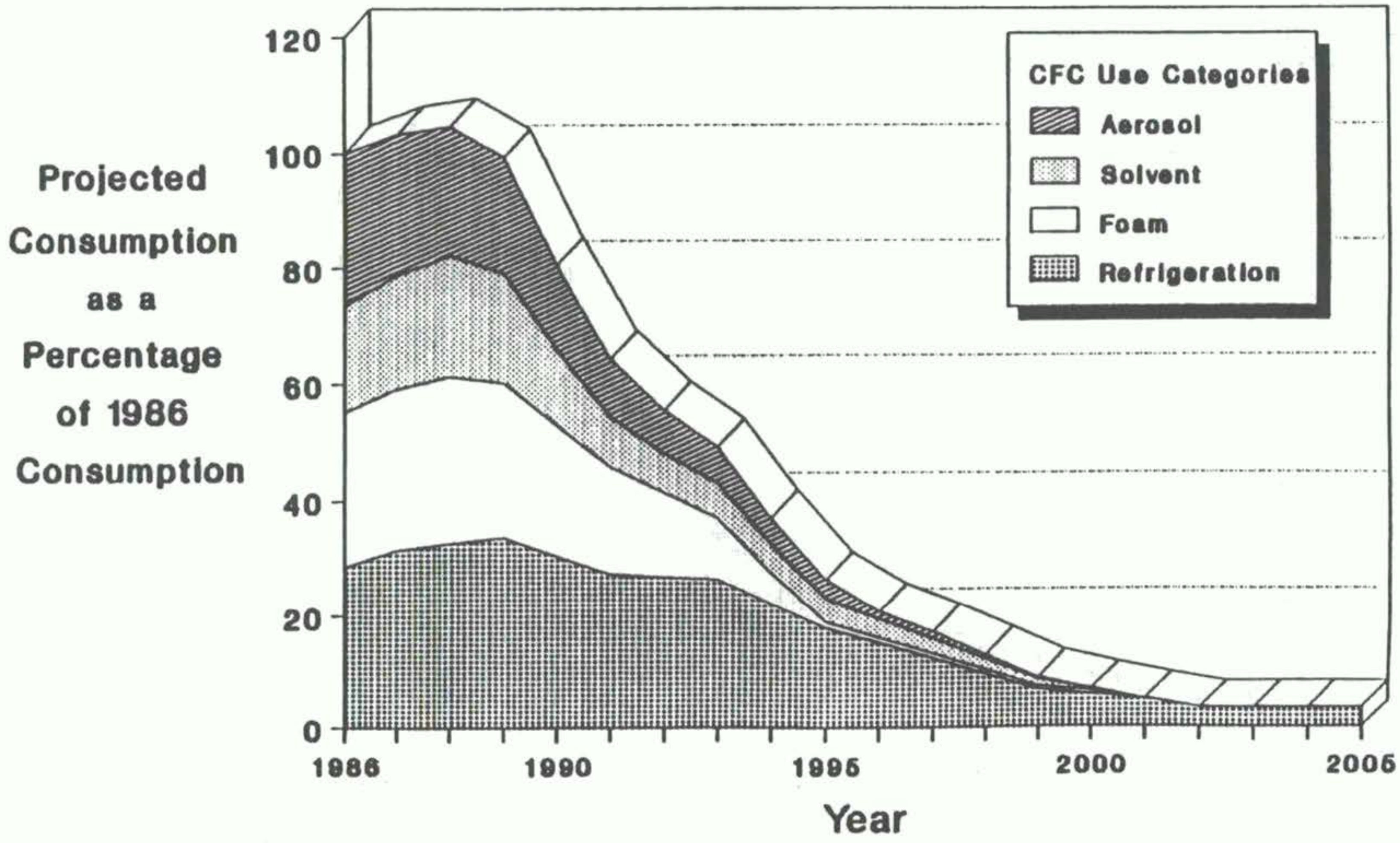
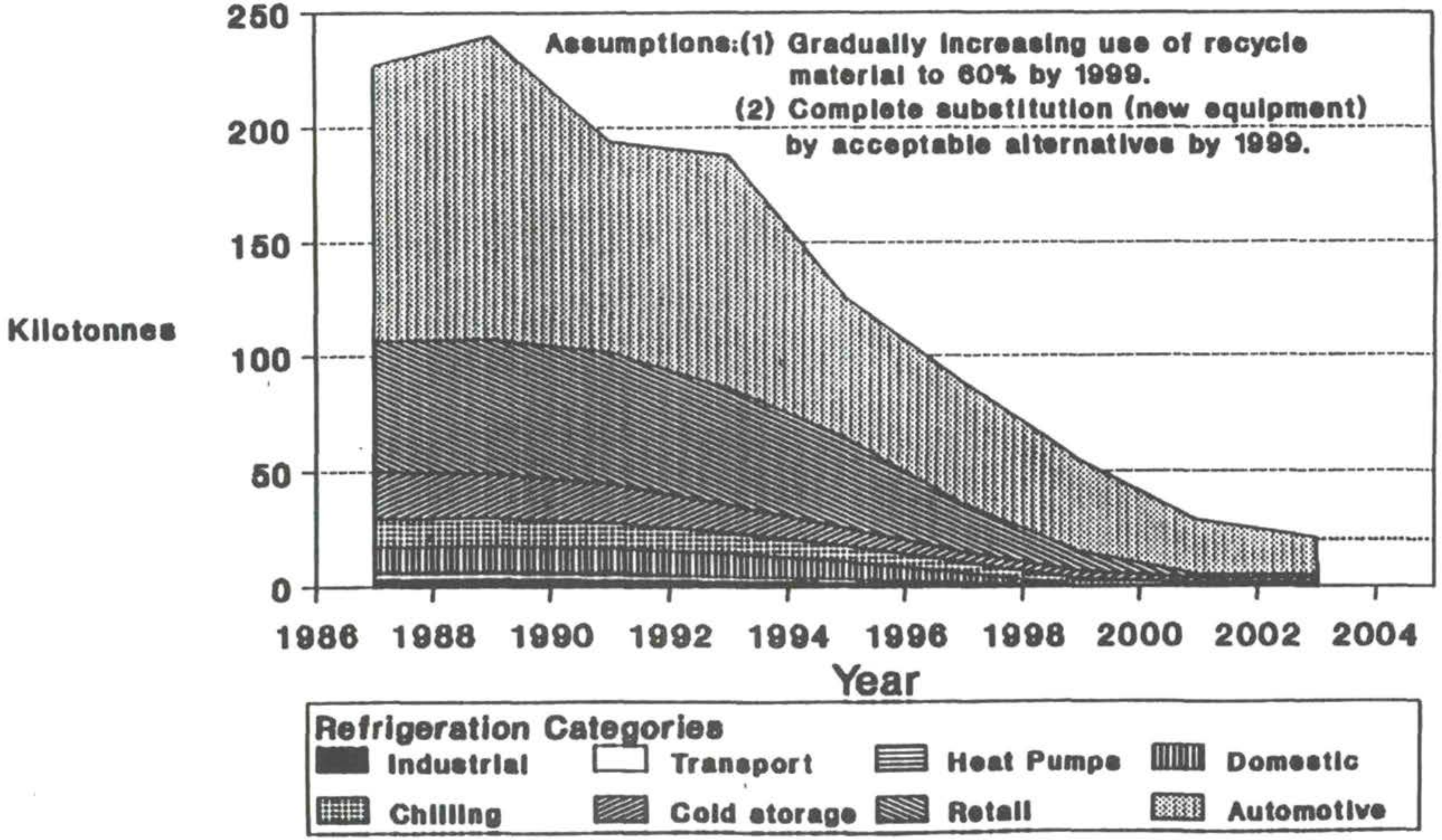


Figure 2

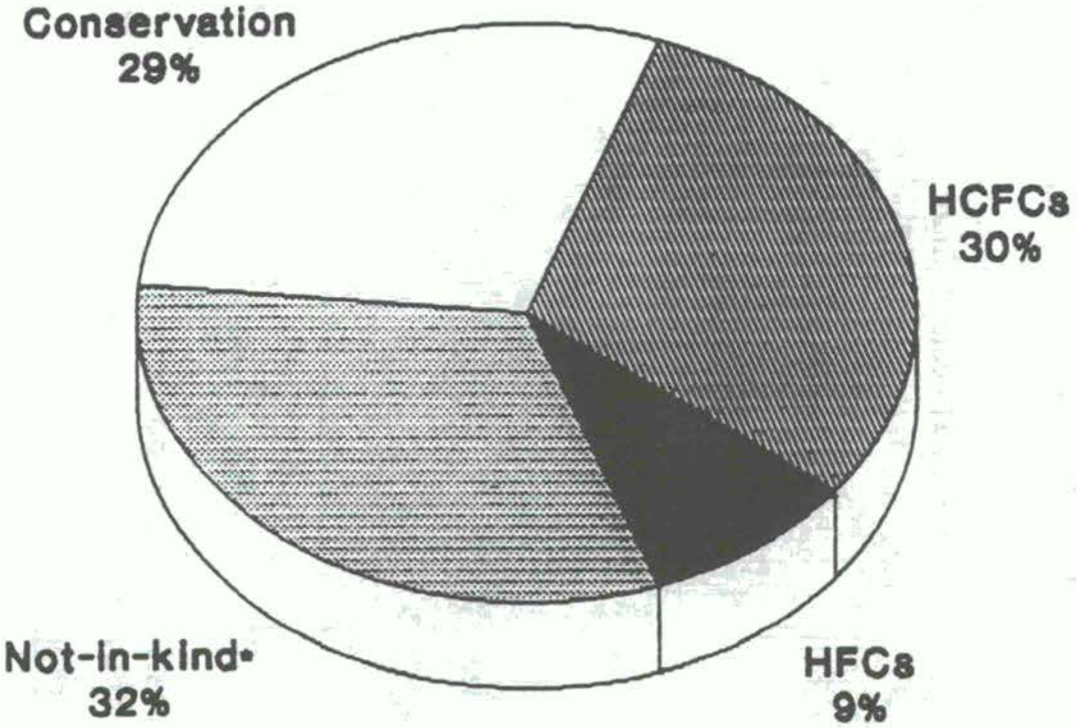
Technically Feasible Phasedown for the Various Refrigeration Uses



Source: Technical Options Report

Figure 3

Displacement of Today's CFC Demand at the Year 2000

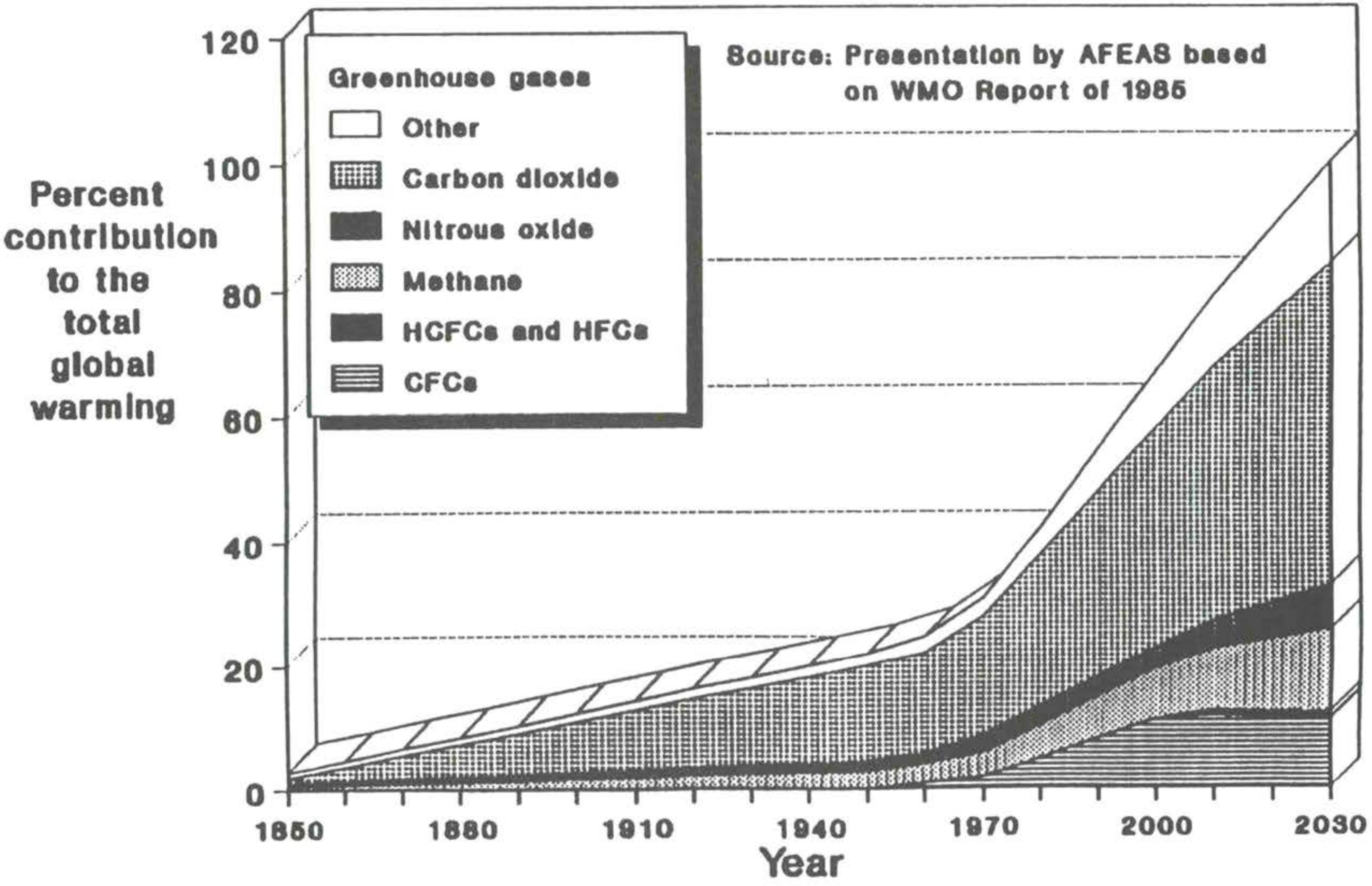


* Substitutes or alternatives other than HCFCs or HFCs

Source: DuPont

Figure 4

Relative Contributions to Greenhouse Effect



Source: Presentation by AFEAS based on WMO Report of 1985

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

1.1) Background

The Montreal Protocol on Substances that Deplete the Ozone Layer was signed in Montreal Canada on September 16, 1987 and entered into force on January 1, 1989. The Protocol sets out a schedule for addressing ozone layer depletion in both the short and the long term. The intent is to control substances that contribute significantly to the depletion of the ozone layer. In the short term it sets out a reduction schedule to phase down the global consumption and hence emissions of five of the most severe chlorofluorocarbons (CFCs), namely:

CFC-11	Trichlorofluoromethane
CFC-12	Dichlorodifluoromethane
CFC-113	Trichlorotrifluoroethane
CFC-114	Dichlorotetrafluoroethane
CFC-115	Chloropentafluoroethane

and three fire extinguishing agents called "HALONS", namely:

HALON 1211	Bromochlorodifluoromethane
HALON 1301	Bromotrifluoromethane
HALON 2402	Dibromotetrafluoroethane

The short or near term reduction schedule set out in the Protocol is as follows:

-- a freeze in consumption (defined as production plus imports minus exports of bulk chemicals) at 1986 levels

CFCs starting on July 1, 1989

Halons starting on January 1, 1992

-- a reduction in consumption of CFCs

20 percent starting on July 1, 1993

50 percent starting on July 1, 1998.

The Protocol, through a comprehensive review process, provides, over the longer term, a mechanism to review the efficacy of control measures and adjust them where, and when, appropriate. Article 6 of the Protocol specifically directs Parties to "assess the control measures provided for in Article 2 on the basis of available scientific, environmental, technical and economic information."

The assessment process has been initiated. Four international review panels have been created and directed to report on: the science (the extent of the threat); the anticipated environmental and public health effects of stratospheric ozone depletion; the technical feasibility of meeting, possibly tightening, and perhaps extending the requirements of the Montreal Protocol; and, the related anticipated economic consequences.

1.2) Composition and Function of the Technical Review Panel

The Technical Review Panel was comprised of: the Chairperson (**Mr. G. Victor Buxton -- Canada**), with responsibility for assembling and editing the Panel Report; Co-chairperson, (**Dr. Stephen O. Andersen -- USA**), with responsibility for coordinating the economic analysis; and, five chapter Chairpersons, with responsibility for evaluating technical options to reduce or eliminate dependency on the use of the controlled substances in each of the five major use categories. These five chapter Chairpersons and their centres of responsibility were as follows:

Dr. Lambert Kuijpers (Netherlands) -- Refrigeration, Air Conditioning and Heat Pumps;

Ms. Jean Lupinacci (USA) -- Rigid and Flexible Foams;

Dr. Stephen O. Andersen (USA) -- Electronic, Degreasing and Dry Cleaning Solvents;

Mrs. Ingrid Kökeritz (Sweden) -- Aerosols, Sterilants and Miscellaneous Uses of CFCs;

Mr. Gary Taylor (Canada) -- Halon Fire Extinguishing Agents.

In order to provide the wide international perspective in the review, sub-committees of global experts were formed to prepare comprehensive "Technical Options Reports." Both the Review Panel Chairperson and UNEP, Nairobi, staff contacted many countries to encourage their active participation in this review process. Furthermore, the sub-committee chairpersons contacted producers, manufacturers, and trade associations to arrange for additional technical input.

More than 100 committee members, from 22 countries, participated in the preparation of the five Technical Options Reports and another 150 persons either provided input or reviewed sections of the various reports. In addition, representatives from both PAFT (Programmes for Alternative Fluorocarbon Toxicity Testing) and AFEAS (Alternative Fluorocarbon Environmental

Acceptability Studies) via EFTC (European Fluorocarbon Technical Committee) made formal technical presentations to the full Panel.

The sections in this Technology Review Panel Report, describing generally methyl chloroform, carbon tetrachloride, and the status of recovery and recycle and destruction techniques, reflects the currently available technical literature. The sector-specific technical conclusions are based on the findings of the five Technical Options Committees. Linkages with the science (including ODP and GWP data) was referred to the Science Panel Chairman for review. The report incorporates technical information supplied to the Panel formally during presentations by industry representatives, and informally through telecommunications. The report integrates these findings in order to provide focused technical observations for use by a Working Group which will be formed to integrate the four Panel reports (Technology, Science, Effects, and Economics) into one report. This Panel report also provides expert judgments on what reductions (based on our knowledge base as of today) are technically feasible by what date. The five Technical Option Reports have undergone extensive peer review. The Panel Report and the five Technical Option Reports will be distributed internationally. These reports will provide the best available technical information on reductions that can be achieved (and by what means) in each of the major use categories.

TECHNICAL CONSIDERATIONS

2.1) Ozone Depletion Potential (ODP) and Global Warming Potential (GWP)

The concentration of ozone in the earth's atmosphere varies with altitude. The maximum concentrations are found at altitudes of 25-40 kilometres. Ozone is created by the action of ultraviolet (UV) radiation from the sun on oxygen molecules (O_2) creating ozone (O_3). Ozone has the ability to adsorb harmful UV_b radiation from the sun before reverting back through natural processes to molecular oxygen (O_2). However, chlorine and bromine containing compounds that are sufficiently stable migrate to the stratosphere (located 15 to 45 kilometres above the earth's surface) where over time (5-100 years or more) the high energy radiation from the sun causes them to decompose releasing the chlorine or bromine. The chlorine and/or bromine then reacts with the other gases in the stratosphere, the net result of which is an enhanced reduction in the concentration of ozone while the chlorine or the bromine remains. The chlorine and bromine act as catalysts for this destruction process, each atom participating in as many as 100,000 destruction reactions before being washed out of the atmosphere.

Chemicals which contain only chlorine, fluorine and carbon are called fully halogenated chlorofluorocarbons or simply CFCs. Similar compounds which are not fully halogenated and contain hydrogen atoms in addition to the chlorine, fluorine and carbon are called HCFCs. Their stability in the atmosphere and hence their adverse impact on the ozone layer is greatly diminished due to the presence of the hydrogen atom. Chemicals containing fluorine, carbon and perhaps hydrogen but no chlorine or bromine are referred to as hydrofluorocarbons (HFCs) or fluorocarbons (FCs). HFCs and FCs that are currently under development as substitutes do not exert an ozone depletion potential but may contribute to global warming.

The halons (fire extinguishing agents) are fully halogenated hydrocarbons generally containing bromine. The chlorine in Halon-1211 adversely affects the ozone layer in the same manner as the CFCs and the bromine in Halon-1211, -2402, and -1301 is also an ozone depletion chemical. ODP factors for halons range from 3-10.

Several other man-made chemicals also deplete the ozone layer, namely: 1,1,1-trichloroethane (also known as methyl chloroform, TCA, CH_3CCl_3) and carbon tetrachloride (CCl_4). These will be discussed later.

Factors governing the relative efficiency of these compounds to destroy ozone are recognised to be:

(1) Rate of release of the compound into the atmosphere;

(2) Rate of removal of the compound in the troposphere and its persistence in the stratosphere; and

(3) Efficiency of the compound in destroying ozone in the stratosphere.

Ozone depletion potential (ODP) is defined[9] as the model calculated ozone depletions under steady state conditions. More specifically, it is defined as the ratio of calculated ozone column change for each mass unit of a gas emitted into the atmosphere relative to the calculated depletion for the reference gas CFC-11. ODP provides a useful yardstick for estimating the relative destruction potential of various chemicals.

The ability of a compound to absorb infrared radiation characterises global warming potential. Fisher et al[9] have defined global warming potential (GWP) as the ratio of calculated warming for each unit mass of a gas emitted into the atmosphere relative to the calculated warming for a mass unit of reference gas CFC-11 or CFC-12. (We have used the CFC-12 referenced GWP data[9] because there is more data available for this reference gas.)

Both ODP and GWP estimate the relative, yet different, adverse environmental impacts of alternative substitute chemicals. Both need to be taken into account when judging the environmental acceptability of chemicals. Tables A through G summarize the reported values of ODP and GWP [3,4,9] for the chemicals discussed in this Panel Report and in the various supporting Technical Options Reports. The GWP values are relative to CFC-12. The ODPs values are relative to CFC-11. The ODP values for the controlled substances are taken from Annex A of the Montreal Protocol.

2.2) Global CFC and Halon Use

In 1928, working for the Frigidaire Division of General Motors, Thomas Midgley discovered the useful properties of CFCs as the result of a deliberate attempt to find a new and safer coolant for use in refrigerators. Between 1931, when E. I. du Pont de Nemours & Co. had begun commercial production of CFC-12, and the early 1950's, CFCs had supplanted other chemicals such as ammonia and sulphur dioxide as the coolant of choice for most applications. Continuing this trend, the international production of CFC-12 increased some 35 times from 545 tonnes in 1931 to almost 20,000 tonnes by 1945.

TABLE A

Fully Halogenated Chlorofluorocarbons (CFCs)

SUBSTANCE		ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
CFC-11	Trichlorofluoromethane	1.0	0.34
CFC-12	Dichlorodifluoromethane	1.0	1.0
CFC-13	Chlorotrifluoromethane	0.45	-
CFC-111	Pentachlorofluoroethane	-	-
CFC-112	1,1,2,2-Tetrachlorodifluoroethane	0.96	-
CFC-113	1,1,2-Trichloro-1,2,2-trifluoroethane	0.80	0.49
CFC-114	1,2-Dichlorotetrafluoroethane	1.0	1.50
CFC-115	Chloropentafluoroethane	0.60	2.80

TABLE B

Partially Halogenated Chlorofluorocarbons (HCFCs)

SUBSTANCE		ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
HCFC-21	Dichlorofluoromethane	0.04	0.10
HCFC-22	Chlorodifluoromethane	0.05	0.098
HCFC-31	Chlorofluoromethane	0.05	0.10
HCFC-121	Tetrachlorofluoroethane	-	-
HCFC-122	1,1,2-Trichlorodifluoroethane	-	-
HCFC-123	1,1-Dichloro-2,2,2-trifluoroethane	0.02	0.0064
HCFC-124	1-Chloro-1,2,2,2-tetrafluoroethane	0.02	0.10
HCFC-131	1,1,2-Trichlorofluoroethane	-	-
HCFC-132b	1,2-Dichloro-1,1-difluoroethane	0.05	0.02
HCFC-133a	1-Chloro-2,2,2-trifluoroethane	0.05	0.02
HCFC-141b	1,1-Dichloro-1-fluoroethane	0.10	0.029
HCFC-142b	1-Chloro-1,1-difluoroethane	0.06	0.11
HCFC-151	Chlorofluoroethane	-	-
HCFC-225ca	1,1-Dichloro2,2,3,3,3-pentafluoropropane	-	-
HCFC-225cb	1,3-Dichloro1,1,2,2,3-pentafluoropropane	-	-

TABLE C

Halocarbons with No Chlorine or Bromine (HFCs)

SUBSTANCE		ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
HFC-23	Trifluoromethane, fluoroform	0	-
HFC-32	Difluoromethane, methylene fluoride	0	-
HFC-41	Fluoromethane, methyl fluoride	0	-
HFC-125	Pentafluoroethane	0	0.10
HFC-134a	1,1,1,2-Tetrafluoroethane	0	0.039
HFC-143a	1,1,1-Trifluoroethane	0	0.34
HFC-152a	1,1-Difluoroethane, ethylidene fluoride	0	0.0091
HFC-161	Fluoroethane	0	-

TABLE D

Common Azeotropic Mixtures (CFCs and HCFCs)

SUBSTANCE	ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
CFC-500-(CFC12/HFC152a-(73.8/26.2 wt%))	0.74	0.76
CFC-501-(CFC12/HCFC22-(25/75 wt%))	0.30	0.30
CFC-502-(HCFC22/CFC115-(48.8/51.2 wt%))	0.34	0.5-1.6
CFC-503-(CFC13/HCFC23-(59.9/40.1 wt%))	0.27	-
CFC-504-(HFC32/CFC115-(48.2/51.8 wt%))	0.31	-

TABLE E

Bromofluorocarbons (HALONS)

SUBSTANCE	ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
HALON-1211 Bromochlorodifluoromethane	3	-
HALON-1301 Bromotrifluoromethane	10	0.8
HALON-2402 Dibromotetrafluoroethane	6	-

TABLE F

Fluorocarbons (FCs)

SUBSTANCE	ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
FC-14 Tetrafluoromethane(carbon tetrafluoride)	0	-
FC-116 Hexafluoroethane	0	-

TABLE G

Other Chemicals of Concern

SUBSTANCE		ODP RELATIVE TO CFC-11	GWP RELATIVE TO CFC-12
HC-10	Tetrachloromethane, carbon tet.	1.11	0.12
HC-20	Trichloromethane, chloroform	-	-
HC-30	Dichloromethane, methylene chloride	-	-
HC-40	Chloromethane, methyl chloride	-	-
HC-50	Methane	0	-
HC-110	Hexachloroethane, perchloroethane	-	-
HC-120	Pentachloroethane	-	-
HC-130	Tetrachloroethane, acetylene tetrachloride	-	-
HC-140a	1,1,1-Trichloroethane, methyl chloroform	0.11	0.0074
HC-150	1,2-Dichloroethane, ethylene chloride	-	-
HC-160	Chloroethane, ethyl chloride	-	-

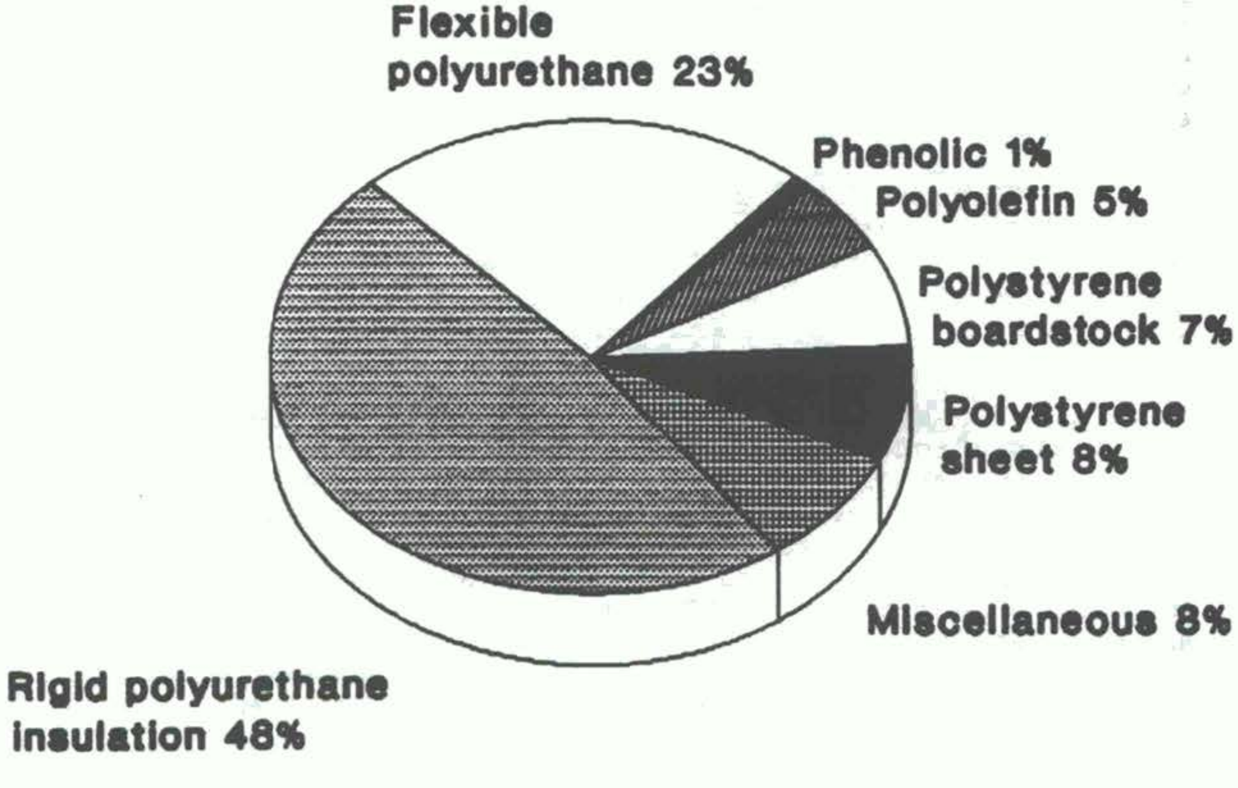
Other uses of CFCs were developed during the 1940's. Dow Chemical introduced an insulation product under the trade name "Styrofoam" which used CFC-12 as the blowing agent and the resulting combined demand from refrigerators and foam almost doubled the demand for CFC-12 from 20,000 to 35,500 tonnes between 1945-1950. Also introduced during the war years were aerosol products (using CFCs as propellants) containing pesticides for use in the control of malaria. The growth in the use of aerosol toiletry products which followed helped push the total market for CFCs-11 and 12 to a high point of 445,000 tonnes by 1974.

Other market developments have also had a significant impact on the growth of demand for CFCs. In the early 1950's, flexible polyurethane foams were introduced to the furniture market. By the end of the decade the use of high performance polyurethane insulating foams were contributing to the rapidly growing demand for CFC-11. Figure 5, page 10, shows the global use in 1986 for the various foams.

The increased use of CFCs in commercial refrigeration and air conditioning equipment also contributed to the growth of the CFC market. The rise in demand for factory installed air conditioning in cars in North America, Japan and elsewhere has been dramatic. Whereas only 25 percent of the new American cars were equipped with factory installed air conditioning in 1965,

Figure 5

Global Use of CFCs in the Production of Rigid and Flexible Foams, 1986



Source: Technical Options Report (Foams) nearly 9 out of every 10 new American cars included air conditioning in 1987. Currently, the demand for CFCs for mobile air conditioning accounts for more than half of the USA demand in CFC-12 and 40 percent of the world demand for CFCs in refrigerant applications.

In a number of regions of the world, the electronics and precision cleaning industry has created an increased demand for CFC-113. Although less significant on a world basis, other applications such as gas sterilisation are responsible for a CFC market in North America.

Illustrations are presented to indicate the demand for CFCs both with respect to geographic region and usage in the 1986 base year. Figure 6a, page 12, shows the relative demand for CFCs on a geographic basis (UNEP data) indicating that Western Europe and North America together account for 67 percent of the global demand. Figure 6b, page 12, (data provided by Committees or best estimates) illustrates the global use pattern.

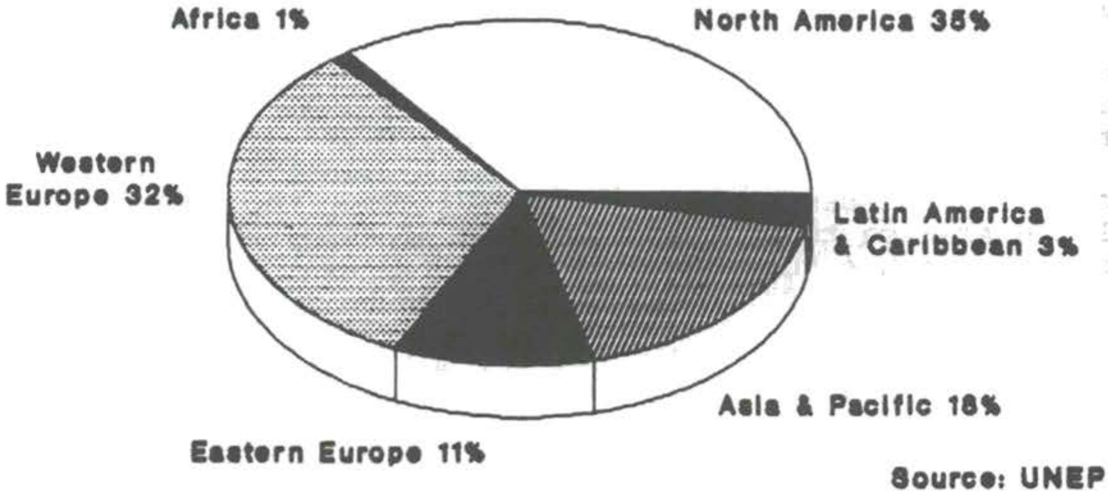
Figure 3, page viii, describes how Du Pont sees the future market being satisfied in the year 2000. Not-in-kind (NIK) refers to products, chemicals, gases or mixtures other than CFCs, HCFCs, and HFCs. Du Pont's analysis indicates that NIK products will displace 32 percent of the market now using CFCs. Conservation practices, better operating techniques, and recycling throughout the useful life of the equipment (including new equipment designed to use HFC/HCFC alternates) will reduce CFC demand by 29 percent. HFCs will, in their estimate, only capture 9 percent of the CFC market because removal of all chlorine from the molecule makes the compounds poor solvents and their vapour pressures are too high for many refrigeration applications. The HCFCs are expected to meet the critical applications that no other technologies can serve. Du Pont's market analysis takes into account the following assumptions: most open cell foams will use NIK technology; about 2/3 of cleaning agent demand will be met by NIK technology or improved conservation, recycle and recovery techniques; energy efficient insulating foams will use primarily HCFCs; and, most refrigeration applications will use HFCs and/or HCFCs but demand will be reduced due to improved conservation practices.

Figure 4, page ix, illustrates the relative contribution to global warming from the various atmospheric gases. This curve, obtained from the AFEAS (see page 20 for description of AFEAS), was derived from a WMO report of 1985. CFCs, in 1985, accounted for approximately 13 percent of the global warming. Currently it is estimated that CFCs account for 15-20 percent of global warming. The projections shown are industry estimates. Based on these projections of anticipated market penetration, HCFCs and HFCs are not likely to make a large contribution to the global warming problem.

Figure 6

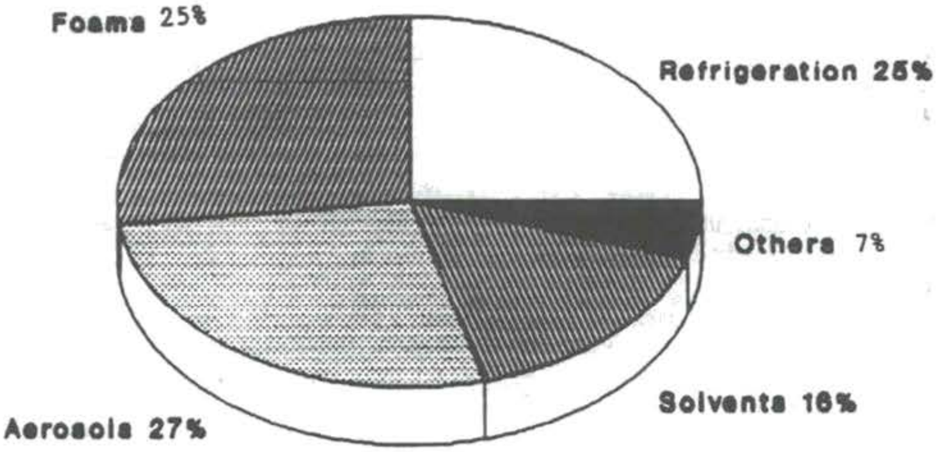
1986 World Usage of Controlled CFCs

(a) by Region



Source: UNEP

(b) by Use



Source: Sector data or best estimates.

Figure 7, page 14, is a series of scenarios prepared by the USA/EPA, which shows the anticipated impact of controlling or restricting future emissions of methyl chloroform (1,1,1-trichloroethane) and carbon tetrachloride (CCl_4). It shows that if the fully halogenated CFCs now controlled by the Protocol were phased-out completely (with no controls on methyl chloroform, a CCl_4 freeze at 1986 levels, and assuming HCFCs capture 20 percent of what the CFC market would have been without the Protocol and the substitutes average ODP is 0.05), chlorine concentrations would still increase by 3.7 ppb by 2100. If methyl chloroform were frozen at 1986 levels, chlorine levels would still increase by 1.7 ppb by 2020 before the concentrations would begin to decline. However, if methyl chloroform and CCl_4 were phased-out, chlorine concentrations could be stabilised at 1985 levels by about 2100.

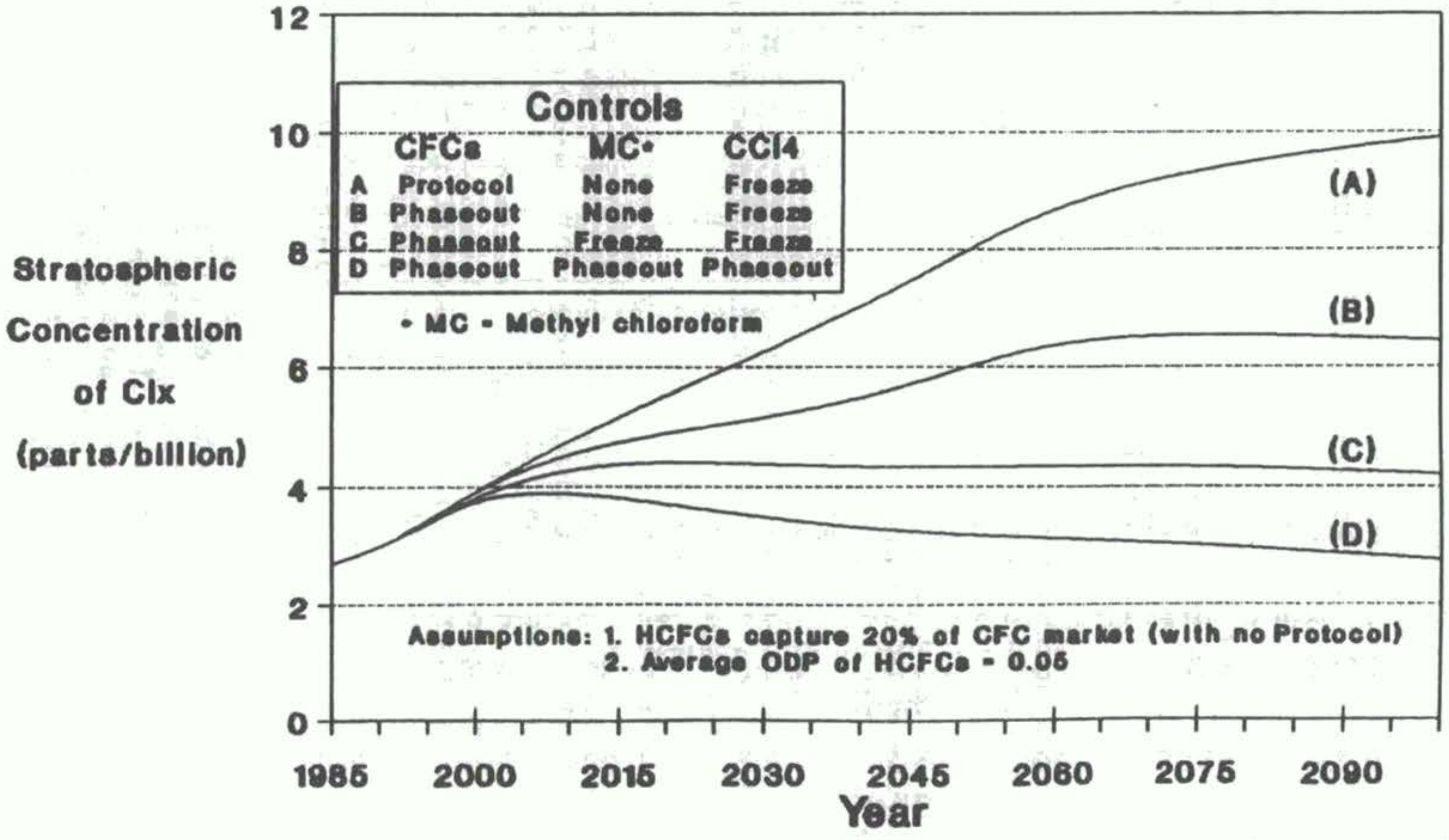
The changing use patterns of halons are also very important because of their very large ODP and their historical rate of growth. Developed at the end of World War II, global consumption of Halons 1211, 1301 and 2402 had reached approximately 25 kilotonnes by the year 1986. World demand for halons increased rapidly between 1973 and the signing of the Montreal Protocol in 1987 due to extensive use in providing fire protection for valuable electronic equipment. Figure 8, page 15, illustrates the historic growth pattern for halons and the anticipated impact of the cap as a result of the Montreal Protocol, and the schedules that could be achieved under a 50 percent reduction or a total phaseout scenario.

2.3) <u>Carbon Tetrachloride</u>

At the time of the signing of the Montreal Protocol (September 1987) carbon tetrachloride (CCl_4) was known to have a high ozone depletion potential (ODP = 1.11) but it was erroneously believed that its only significant use was as a feedstock in the production of CFC-11 and -12. Since chemical feedstocks are destroyed in the manufacture of other chemicals, control of carbon tetrachloride was considered unnecessary. However, the scientific advisory group to UNEP has reported that concentrations of CCl_4 in the atmosphere continue to increase indicating that there are very large non-feedstock uses.

The major end uses of CCl_4 worldwide are still thought to be for the production of CFC-11 and -12. However, it can also be used in the production of pesticides (chlorothalonil, dimethyl tetrachloroterephthalate, picloram, permethrin and cypermethrin); as a solvent in the manufacture of synthetic rubber and dyes; metal degreasing; as a dry cleaning agent and fabric spot removing fluid; as a fire extinguishing agent; and as a grain fumigant. Due to the toxicity of CCl_4, use in many countries has

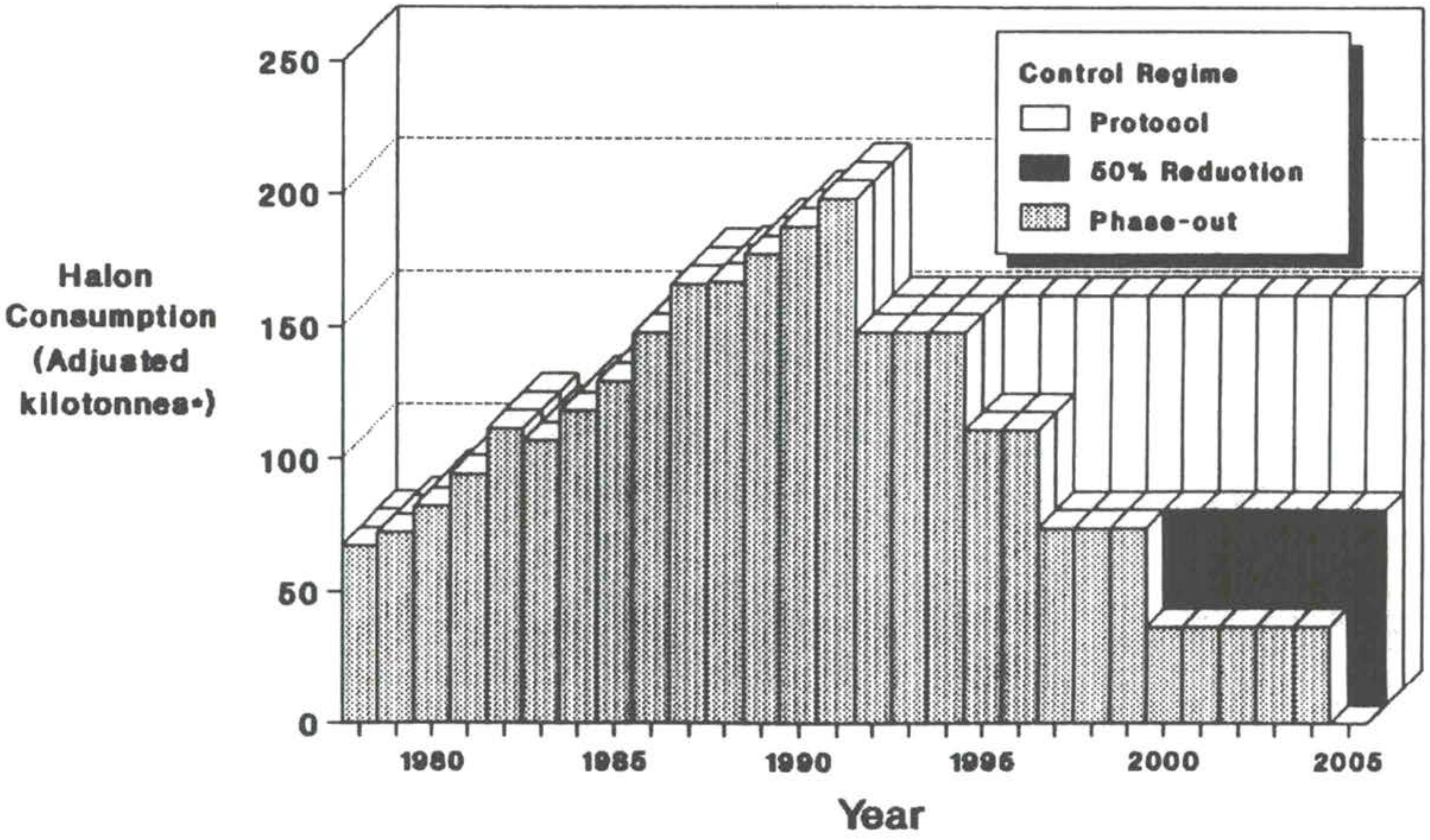
Figure 7
Clx Concentration: 1985 - 2100



Source: USA/EPA

Figure 8

Projected Halon Consumption



• Sum of kilotonnes of each Halon multiplied by its respective ozone depletion potential (ODP).

Source: UNEP/CEFIC

been reduced or prohibited but increasing atmospheric concentrations indicate that CCl_4 must still be used in many countries of the world for non-feedstock applications.

Other minor uses of carbon tetrachloride include: as a solvent for waxes, oils, fats and resins; in the manufacture of drugs and lubricants; in the processing of uranium salts and metal alloys; as a solvent in the production of chlorinated paraffins and tetrachloropyridine; as a scrubbing liquid to recover chlorine from a tail gas or inert gas vent stream following liquefaction (in chlorine production); and, as a diluent for nitrogen trichloride which is often formed in chlorine production.

Global production capacity and output for CCl_4 is thought to be in the order of 1080 and 954 kilotonnes respectively, in 1987-88[16], with the approximate regional distribution as follows:

	PRODUCTION CAPACITY (KILOTONNES)	CONSUMPTION (KILOTONNES)	NON-FEEDSTOCK CONSUMPTION	
			(KILOTONNES)	(PERCENT)
Western Europe	50.6%	42.9%		6.1%
USA	26.2%	35.7%		2.8%
Japan	6.5%	9.3%		9.0%
Eastern Europe, PRC, India	Unknown	Unknown	Unknown	Unknown
Others	16.7%	12.1%		Unknown

No information was available on the use of this chemical in Eastern Europe, the Peoples Republic of China, India and the other developing countries but it is thought to be significant.

When the USA and other countries prohibited the use of CCl_4 acceptable substitutes were developed for most uses. However, more information will have to be collected to further define the technical control options.

2.4) <u>Methyl Chloroform</u>[10]

Methyl chloroform (1,1,1 trichloroethane) is a versatile all purpose solvent (significantly used by industry because of its powerful cleaning properties, non-flammability under normal conditions of use, and low toxicity). It was introduced in the mid-1950's as a cold cleaning solvent substitute for carbon tetrachloride. Today methyl chloroform is used primarily for vapour degreasing and cold cleaning of fabricated metal parts and other materials. Other applications include:

- fluoropolymer synthesis;
- for dry cleaning cloths;
- as a carrier for a wide range of oils, waxes, and metal soaps (scotch guard or dirt repellent finishes on textiles, protective coatings on metal components, silicone coatings for paper and textiles);
- as a solvent in adhesive formulations (natural and synthetic rubbers and resin adhesives; bonding polystyrene components such as mastics, sealants, and tire repair cements);
- in aerosols to solubilise many of the active ingredients or to reduce flammability of other propellants;
- in the electronics industry where it is used to develop dry film photoresistors and in semiconductors where it is used for secondary cleaning;
- in the manufacture of fluorocarbon and fluoropolymers where it serves as a raw material for polyvinylidene fluoride fluoropolymer;
- in steel manufacture as a constituent of extreme pressure lubricants and in the application of foundry mould dressings; and
- for the production of coatings and inks, textiles and other miscellaneous uses.

Methyl chloroform has a solvent power comparable to that of trichlorethylene but stronger than perchlorethylene. It is less powerful than methylene chloride, a commonly used paint stripper. It is generally considered to have a low toxicity. Methyl chloroform under normal conditions is usually considered to be non-flammable but concentrations of 6.5-16.5 percent in air can be ignited.

Concerns for the carcinogenicity risk of methylene chloride, perchlorethylene, and trichlorethylene have encouraged industry to make greater use of methyl chloroform. Even though the ODP of methyl chloroform is low (0.11) the large quantities in use result in ozone depletion in the order of the current contribution of CFC-113.

Limited global consumption data (production, imports, exports) exists for methyl chloroform. There are reportedly 12 firms that produce this chemical[10] and these firms are currently collecting, through an independent auditor, historic production and emission data. These data are to be published in a scientific journal in late 1989. Additionally, the methyl chloroform industry[10] is funding an independent market research study to establish the most likely global production and emission patterns for the future (assuming no global controls). The results of this study are also expected to be available in late 1989. A paper prepared by a CEFIC workshop[12] estimates the annual consumption figures in Western Europe between 1974 and 1985 (in 1985 it was 33 million pounds). A report (currently a draft) prepared for USA/EPA[13], estimates that in 1984, the United States, Western Europe, and Japan consumed an estimated 1,200 million pounds of methyl chloroform.

It is estimated[10] that solvent cleaning applications account for approximately 80 percent of the use of this chemical; cold cleaning 35 percent, vapour cleaning 35 percent, and Hi-Tech and aerosol applications which also include uses where the solvent is acting as a cleaning agent ten percent.

In the usual vapour recovery process, methyl chloroform is recovered and recycled to accrue chemical cost savings. It is also possible to recover methyl chloroform via redistillation in a still when used in cold cleaning applications.

Many alternatives are available but water cleaning is the most versatile substitute process and is currently used in about 40-50 percent of the cleaning market. Aqueous cleaning offers the following advantages[13] over methyl chloroform solvent-based cleaning:

- eliminates methyl chloroform emissions;
- can be adapted to replace most methyl chloroform cleaning processes;
- removes the same contaminants that are currently removed with methyl chloroform;
- operating costs are comparable to methyl chloroform cleaning (depending upon the specific process conditions); and
- proven performance in many cleaning operations.

There is a significant energy penalty associated with switching from methyl chloroform to water cleaning unless hot rinse waters are recycled.[10]

Table H[13], page 19, outlines available substitutes for methyl chloroform in the four major use areas.

TABLE H

Substitutes for Principle Uses of Methyl Chloroform

Major Use Area	Use Sector	Available Substitutes
Cleaning Solvents	Vapour degreasing	Aqueous cleaning Solvent emulsions Hydrocarbon emulsions
	Cold cleaning	Aqueous cleaning Solvent emulsions Hydrocarbon emulsions
	Solder flux removal	Aqueous cleaning
	Silicon oxidation	Anhydrous chlorine
Adhesive Solvents	Active solvent in solvent-borne adhesives	Water-based adhesives Hot melt adhesives Radiation cured adhesives High solids Powders Non-volatile solids and liquids Reactive liquids
	Diluent or coalescent in water borne adhesives	Undetermined
Aerosols	Automobile and industrial aerosols	Petroleum distillates Toluene, Xylene Alcohols, Ketones Water-based aerosols Aromatic hydrocarbons Acetone Alkyl Acetates
	Household aerosols[c]	Petroleum distillates Aromatic hydrocarbons Water-based aerosols Dimethyl ether
	Pesticides	Petroleum distillates Alcohols Water-based aerosols Dimethyl ether

[a],[b],[c] substitutes are not yet available or identified for some specific products.

2.5) Toxicity Testing and Product Acceptability Programmes

A number of companies have initiated collaborative studies to evaluate the toxic effects of HCFC/HFC substitutes. Three industry consortiums, Programs for Alternative Fluorocarbon Toxicity Testing (PAFT), have been established. PAFT 1 commenced its work on December 1, 1987 and is engaged in testing the toxicological effects of HCFC-123 and HFC-134a. The companies are: Akzo (Netherlands), Allied Signal (United States), Asahi Glass (Japan), Atochem (France), Daikin Industries (Japan), Du Pont (United States), Hoechst AG (Germany), ICI Chemicals & Polymers (UK), ISC Chemicals (UK), Kali Chemie AG (Germany), Montefluos Spa. (Italy), Racon (USA), Showa Denko (Japan), and Ulsan Chemicals (USA).

A second team (PAFT 2) which includes: Akzo (Netherlands), Allied Signal (United States), Atochem (France), Daikin (Japan), Du Pont (United States), ISC Chemicals (UK), Pennwalt (United States) and Solway and Company (Belgium), was established to accelerate the toxicity testing of HCFC-141b. The studies include: the preparation of acute toxicity profiles; estimates of the potential for genotoxicity, mutagenicity or birth defects; chronic toxicity profiles; and, carcinogenicity forecasts.

A third team (PAFT 3) includes Allied-Signal (USA), Atochem (France), Daikin (Japan), Du Pont (USA), ICI (UK), I.S.C. Chemicals (UK) and Montefluos (Italy). This team was convened to develop toxicity profiles on substitutes which appear to have the physical and chemical properties needed for the commercially viable replacement of existing CFCs. HCFC-124 and HFC-125 have been identified as promising potential candidates and having created sufficient interest from a commercial standpoint, will undergo further toxicity testing to ensure their safe use. Additional compounds will be considered later.

The PAFT I and II programmes are expected to be completed in 1992 and 1993, respectively. The time requirement is the result of the size and complexity of the chronic toxicity studies. All of the information derived so far from the preliminary screening, and acute and short term studies is encouraging. It is expected that the long term exposure, developmental effects and carcinogenicity studies will progress on schedule. No dates are yet available for the completion of the work on the chemicals in PAFT 3.

Another group of 14 companies are collaborating in an "Alternative Fluorocarbon Environmental Acceptability Study" (AFEAS). These include: Akzo (Netherlands) Allied Signal (USA), Atochem (France), Daikin Industries (Japan), Du Pont (USA), Hoechst AG (Germany), ICI (UK), ISC Chemicals (UK), Kali Chemie AG (Germany), La Roche Chemical (USA), Montefluos Spa. (Italy), Pennwalt Corp. (USA), Racon (USA) and SICNG (Greece).

The AFEAS study is exploring the environmental effects of these substitute chemicals. Such effects include: ozone depletion potential (ODP); global warming potential (GWP); mechanisms for atmospheric decomposition; the atmospheric decomposition products and their potential environmental effects. Particular attention is being paid to HCFCs-123, -141b, -142b, -22, -124, and HFCs-134a, -152a and -125. The target is to produce a report by mid 1989 with publication in early 1990.

2.6) Status of Commercialisation of Substitute Chemicals

A number of chemicals or blends of chemicals have been identified that exhibit properties necessary to substitute for the current uses of the CFCs controlled under the Montreal Protocol. These include precommercial chemicals such as HCFC-141b, HCFC-123, HCFC-124, and HFC-134a and commercial chemicals such as HCFC-22, HCFC-142b, and HFC-152a. These chemicals are currently being evaluated for safety (non-flammability, low toxicity), energy efficiency (good thermodynamic properties, low thermal conductivities), performance (efficiency in use), environmental acceptability, and cost effectiveness.[11] For many uses, HCFCs and HFCs are the most promising chemical alternatives in the near term to replace CFCs. Unfortunately, these chemicals are usually not "drop in" replacements for CFCs. Products and processes that will use them will require redesign and in some cases, modification or rebuilding of production lines.

The steps to fully commercialise the production of the substitute chemicals include: process development, production of small test quantities, toxicity and application testing, and full-scale production. Production costs for the new chemicals are expected to be higher due in part to the product development expenditures, higher cost of ingredients, and more complicated production processes. Because of these high entry costs, initial capacity is likely to be relatively small until the producing and using technology has been proven, and there are clear indications that the market for these alternatives warrant further investment.[11]

The time scale for full scale commercialisation for some chemicals remains uncertain at this time but producers are working on many chemical substitutes. HFC-134a will be available in limited quantities in 1990/1991.[11]

2.7) Recovery and Recycling Programmes

In the major producing and consuming nations of the world, there is very little recovery and recycle of CFCs during maintenance, testing and training; from waste products or from decommissioned products containing these chemicals. However, recycling of halons has historically been practised in many applications principally because halon is more expensive and therefore recycling is more economical. Recycling is expected to increase dramatically in the very near future due to: environmental concern, reduced availability of supplies, increasing prices for virgin stock, and the design and implementation of collection and re-processing infrastructure.

Major recovery and recycle initiatives are now underway in both the public and the private sector. In the public sector, the Scandinavian countries have both announced or have adopted regulatory measures that mandate the recapture of CFCs from major equipment and major consumer items such as household refrigerators. Other countries are now considering similar measures. Many producers have announced that they are prepared to accept back used CFCs for reprocessing in their manufacturing facilities. However, global implementation of such programmes is not expected to occur immediately due to the lack of cost effective recycling infrastructure; inadequate economic or regulatory incentives; absence of market acceptance and purity standards product specifications that demand the use of virgin CFCs and halons; and, government regulations that restrict collection and transportation of used CFCs.

There are basically three methods used to facilitate capture or recovery: condensing units, liquid pumps, and, absorption techniques. Contaminated CFCs and halons are purified by filtration, dehydration, distillation, and reprocessing or remanufacturing.

Condensing units are suitable for low pressure liquefiable gases such as CFC-12 and CFC-502, HCFCs-22, -124, -142b, and HFCs-125, -152a, and -134a. The method consists of removing the chemicals as a vapour, compressing, condensing and collecting them in a receiver (fixed or portable). The recovery efficiency is poor for low vapour/air mixtures such as recovery from foam blowing.

Liquid recovery pumping techniques are suitable for liquids such as CFCs-11 and -113, and HCFCs-123 and -141b. The method consists of pumping the liquid in the system to a receiver (fixed or portable). This method leaves residual vapour at saturation vapour pressure in the system (which could be removed by vapour recovery pumps). For source liquids, this pressure will be atmospheric or less and no loss to the atmosphere will occur. For liquefied gases the residual pressure will be significant and a condensing unit will be needed for vapour recovery.

Adsorption techniques are suitable for CFCs, HCFCs and HFCs in air. The method consists of adsorbing the chemicals on activated carbon, desorption with steam, and then condensing and separating the organic and aqueous phases. New techniques are currently under development to recover CFC-11 from foams.

Equipment is available on the market to capture and recycle CFCs historically lost in the distribution, service use[8], and cleaning operations. The most simple equipment, often portable, remove most of the oil, water, solids, non-condensible gasses, and neutralise acidity. The driers, filters and acid acceptors need changing periodically. The more complex equipment are fixed installations which remove oil, water, solids, acids and inerts to a higher standard of purity.

Most CFC and halon manufacturers have the capability (and some have announced their willingness) to remove oil, water, acid, solids and inerts from refrigerants and to remove trace contaminants from foam blowing agents. The degree and nature of the contamination will determine whether chemicals can be reprocessed in this manner. Mixed grades of CFCs, HCFCs or HFCs generally would not be accepted by the manufacturer for fear of contamination. CFCs, HCFCs, and HFCs can all be re-used providing they have been reprocessed to a satisfactory quality.

Recycling of CFCs and halons offers a great potential for reducing emissions in the near term. CFC and halon recycling is technically feasible from solvent, mobile air conditioning, residential and commercial air conditioning, refrigeration, and some foam manufacturing.

It should be noted that the recycling infrastructure for CFCs and halons will undoubtedly prove useful in reducing the emission of HCFCs or other substitutes which will replace the controlled CFCs.

Recovery and recycle is important to the use of halons because there are few promising substitutes currently under test but the halon "bank" (reservoir of halons currently in existing equipment) is a viable source of supply for essential uses.

2.8) Destruction Technologies

The incentive of a credit for CFCs and halons that are destroyed as set out in the Montreal Protocol and the increasing desire to better protect the ozone layer are a driving force for the development of acceptable disposal or destruction practices or techniques.

In the near term, the price of the controlled chemicals is expected to rise due to restrictions on supply. This price increase will be a strong incentive to recover and re-use these substances. However, as more environmentally acceptable chemicals or substitute products come on stream the "banks" of stored chemicals will cease to be assets and could become surplus. These "banked chemicals" could be properly recovered and destroyed instead of released into the environment.

Separate studies in the United States and Japan have analyzed the current and potentially available destruction technologies, the potential environmental or health effects posed by destruction by-products, and the available methods to monitor destruction efficiency.[11, 14, 15]

CFCs and halons are very stable compounds. They are resistant to oxidation, thus making them difficult to destroy by incineration. Furthermore, CFCs and halons are non-flammable and do not support combustion by themselves (halons are primarily used as fire extinguishing agents). The stability of these chemicals is attributed to the presence of fully substituted halogens. Despite these difficulties there are many technologies that could be used to destroy CFCs and halons: thermal processes (thermal incineration, catalytic incineration, pyrolysis); chemical processes (metal and chemical scrubbing/destruction, wet air oxidation, super critical water oxidation); biological processes; and, electrical processes (corona discharge). Most of these technologies are at a preliminary level of development but look very promising. Only thermal incineration is both currently available and has been demonstrated for CFC and halon destruction.

CFCs and halons may be broken down by hydrolysis. Hydrolysis involves splitting the CFC with water as shown in the example below for CFC-12:

$$CCl_2F_2 + 2\ H_2O \dashrightarrow CO_2 + 2HCl + 2HF$$

This reaction occurs in the combustion chamber of an incinerator, where supplemental fuel is burned to create the high temperature (to increase the reaction rate) and also furnish some of the water for hydrolysis.

The primary products of CFC or halon destruction are carbon compounds such as CO_2 and potentially corrosive and dangerous halogen acids such as HCl and HF. Free halogen gases such as Cl_2 or F_2, which are also corrosive and hazardous chemical by-products, can also be formed.

Thermal destruction processes achieve destruction of the CFC or halon molecules by exposure to high temperatures for relatively long residence times (e.g., 1200°C and 5-7 seconds) in the presence of excess oxygen. Important factors[17] to be considered in determining the suitability of wastes for incineration include: BTU content of the waste, viscosity, water content, and ash content. About 5000 BTUs per pound is required to sustain combustion without the addition of a supplementary fuel; CFCs and halons do not have enough heat of combustion. The necessary heat must be supplied through firing a supplemental fuel or by co-firing other wastes that have a substantial net heat of combustion.

The thermal decomposition of CFCs and halons produces either halogen acids (HCl, HF, HBr) or free halogen molecules (Cl_2, F_2, Br_2). These decomposition products are very corrosive and pose one of the most significant problems in CFC/halons destruction. In particular, the attack on the refractory materials used to insulate and protect the incinerator walls has been a problem, requiring development of special refractory materials. The halogen acids or free halogens must also be scrubbed from the stack gases before emission. This can be done using a water scrubber for the acid species, but the free halogen species require an alkaline scrubbing liquor. The decomposition products can be forced towards the easier to scrub halogen acids by providing ample hydrogen in the incinerator. The hydrogen may be supplied by a high-hydrogen supplemental fuel (such as natural gas) or through steam or water injection. Equipment known as "fume abaters" can safely destroy compounds containing the halogens. The destruction products are routed to a scrubber where products formed are typically NaCl, NaF etc.

KEY OBSERVATIONS and TECHNICAL CONCLUSIONS

3.1) Key Observations

The key observations, in the context of amendments to the Montreal Protocol of this Technical Review Panel Report are as follows:

(1) Based on the current state of technology, it is possible to phase down use of the five controlled CFCs by over 95 percent by the year 2000. The remaining use after the year 2000 would be due to refrigeration and air conditioning in systems which were designed to use CFCs and are still in service, and in other minor uses. Figure 1, page vi, shows the technically feasible phasedown projections for each of the CFC use categories. The technically feasible reductions for any intermediate date (for example a 70 percent reduction from 1986 levels by 1995) can be read from Figure 1. Given the rate of technological development, it is likely that additional technical options will be identified to facilitate the complete elimination of the controlled CFCs before the year 2000.

The key technical sector observations are as follows:

-- The refrigeration, air conditioning, and heat pump sector represents approximately 25 percent of global consumption of the controlled CFCs of which 5-8 percent is used for food preservation, 1 percent being domestic refrigeration. It is necessary to distinguish between new and existing equipment. New designs using alternative refrigerants are possible now in most sub-sectors but existing equipment will have to be upgraded and replaced slowly with full substitution taking 15-20 years. A demand for CFCs after the year 2000 is expected for service of refrigeration and air conditioning (principally automotive) in systems that were designed to use CFCs and are still in service but are not amenable to "drop-in" substitutes. Note that based on a 30 percent annual growth rate in the manufacture of domestic refrigerators, the demand from developing countries, including India and the Peoples' Republic of China, for CFC-12 at the year 2000 will represent less than 2 percent annually of the 1986 global CFC consumption levels.

- Foam production represents approximately 25 percent of the global consumption of the controlled CFCs. It is technically feasible to reduce consumption by 60-70 percent by 1993 with a virtual phaseout by 1995. These reductions will be dependent on the availability of HCFCs-22, -141b, -123, etc.

- Solvent use of CFC-113 represents approximately 16 percent of global consumption of the controlled CFCs. The predominant use is in the electronics sub-sector. There is no single universal substitute for the various CFC-113 solvent uses. All application areas have a series of options available allowing all CFC-113 solvent uses to be phased-out by the year 2000. Alternatives exist and additional substitutes are under development for dry cleaning operations. The CFC-113 phaseout is only partially dependent on HCFCs due to the large variety of non-HCFCs alternatives including product and process substitutes, water cleaning, no-clean fluxes, terpenes, white spirits (dry-cleaning) etc.

- Aerosols in 1986 represented the largest global use of the controlled CFCs (27 percent). Sufficient technical options exist to phase out CFC use now in aerosols with the exception being some medical products and other minor uses. CFC-12 use in sterilisation can be substantially reduced using existing alternatives and can be phased out by 1995 in developed countries and somewhat later in developing countries. In food-freezing applications, CFC substitution is both technically feasible and commercially available through cryogenic techniques (liquid nitrogen).

(2) Once CFCs are phased out, the principal new sources of chlorine to the stratosphere will be methyl chloroform, carbon tetrachloride and to a much lesser extent HCFCs. Du Pont estimates that if HCFCs are allowed to satisfy new and expanding demands, including substitutes for CFCs, only 30 percent and 9 percent of the current demand for CFCs at the year 2000 will be satisfied by HCFCs and HFCs, respectively. The remainder will be satisfied by non-CFC alternatives. Furthermore, industry extrapolations of WMO data and USA/EPA estimates indicate that HCFCs will make a contribution of 2-10 percent of the global warming problem out to the year 2030.

(3) **There are currently no substitute chemicals with the equivalent performance of the halons in certain applications. There are however, current halon application areas where other fire protection techniques offer equivalent fire protection. Unless new alternatives are developed, this leaves the choice of continuing to use halon in essential uses with the concomitant adverse impact on the ozone layer or to accept the possibility of increased fire risk. It is recognised that conservation practices and use of other fire protection measures are important in reducing halon dependency. Some Halon Committee members are of the opinion that such measures alone are adequate to allow an orderly and complete phaseout of halon consumption by the year 2005. Other Committee members are of the opinion that these measures would allow a maximum consumption reduction of 60 percent within 5 years with the total phaseout possible if alternative chemicals are available. Other Committee members are of the opinion that it is premature to recommend any reduction until further experience with proposed alternative measures has been acquired but believe a total phaseout will be possible should substitutes become available.**

(4) If the fully halogenated CFCs now controlled by the Protocol were phased-out completely (with no controls on methyl chloroform, a carbon tetrachloride freeze at 1986 levels, and assuming HCFCs, with an average ODP of 0.05, captured 20 percent of what the CFC market would have been without the Protocol) chlorine concentrations would still increase by 3.7 ppb by 2100. If methyl chloroform was frozen at 1986 levels, chlorine levels would still increase by 1.7 ppb by 2020 before the concentrations would begin to decline. However, if methyl chloroform and carbon tetrachloride were phased-out chlorine concentrations could be stabilized at 1985 levels by about 2100. Substitutes currently exist for 90-95 percent of the methyl chloroform uses.

(5) With respect to carbon tetrachloride, substitutes also currently exist for the majority of its uses. However, carbon tetrachloride is needed as a chemical feedstock for the production of many of the substitute chemicals.

(6) This report describes the status of the technology for destroying both CFCs and halons but does not contain criteria for "approving" destruction techniques. There are many techniques currently available and many more under development but the establishment of approval criteria requires detailed technical consideration on a "per technique" basis.

Technical Conclusions

This section contains a synopsis of the key technical findings of the five sector groups. These findings plus many other issues are described in more detail in the individual reports. The executive summaries from these sector reports comprise the last section of this report.

3.2) Refrigeration, Air Conditioning, and Heat Pumps

The Refrigeration, Air Conditioning, and Heat Pump sector represents about 25 percent of the world's use of the controlled CFCs. In the near term, chemicals currently available in commercial quantities such as ammonia, HCFC-22, hydrocarbons, HCFC-142b, and HFC-152a can substitute for the controlled substances to varying degrees in certain applications. In the medium term there are additional chemicals currently available in very limited quantities but for which commercial process development is underway. These include HFC-134a, HCFC-123 and some azeotropic mixtures. In the long term, a series of potentially promising substitutes such as HCFC-124, and HFC-125, -134, -32, and -143a and perhaps fluorinated ethers could be used.

For a sophisticated design of refrigeration equipment, thermodynamic and transport refrigerant data must be available. At present, sufficient and accurate data is available only for HCFC-22, HCFC-142b, HFC-152a, ammonia, and hydrocarbons. Substantial work is now underway to collect the data for other substitutes. There remains a substantial quantity of data to be collected for fluids which are generally considered as candidate substitutes for the medium term.

The thermodynamic efficiency of a substitute and the resulting energy consumption of the equipment using the substitute are important aspects in the selection of substitute candidates. It may be desirable to tolerate the emission of a small quantity of ozone depleting substances (HCFCs) to avoid emissions of carbon dioxide that contribute to the greenhouse effect. Energy considerations play a very important role especially in the domestic refrigeration and heat pump sectors both of which are very reluctant to consider the use of substitute refrigerants with lower energy efficiencies compared to CFC-12. Some substitute chemicals or blends may offer higher energy efficiency.

The reduction in use of controlled CFCs in the refrigeration sector has to be viewed in the context of new and existing equipment. It is possible to introduce new refrigerants and new designs into newly manufactured equipment or installations in many applications starting now and accelerating after 1994 (due to the future use of chemicals now under test). However, in the near term, the very large global stock of existing capital equipment will have to be upgraded slowly, mainly through attrition and retrofitting new chemicals and designs. In the near term also, the major reductions will have to come through the implementation of emission control measures. This holds true especially for automobile air conditioning which accounts for 28 percent of the global consumption of CFC-12. A 25 percent reduction in consumption (relative to 1986 reference levels) and a 60 percent reduction in emissions through recycling during service, scrapping etc. is feasible in the near term through the implementation of rigorously applied conservation measures. Considering the fact that the current bank (refrigerant chemicals in existing equipment) of refrigerants amounts to some 1,000,000 tonnes worldwide, emission reductions take on an added degree of importance. "Tailor made" refrigeration systems where 80 percent of the current systems use CFC-12 pose an especially difficult problem. By 1994, <u>emission reductions</u> in the order of 45 percent appear feasible. By 1997-98, <u>use reductions</u> in the order of 50-60 percent may be realistic. However, the time needed for full market penetration and implementation of the new substitute refrigerants is estimated to be in the order of 15-20 years, mainly due to the long lifetime of the installations. This implies that, during this period, small amounts of controlled CFCs will have to remain available for servicing the needs of this equipment which has a very high societal and economic value. However, as substitutes are developed, that are virtual "drop-ins", or as retrofit capability develops, this situation will change.

One of the important substitutes that can serve to substantially lower controlled CFC demand in this sector in the near term is HCFC-22, both as a pure refrigerant and as an ingredient in blends. However, the availability of this chemical is uncertain over the expected lifetime of the equipment. This uncertainty must be resolved before suppliers and manufacturers will exercise this option.

One of the leading candidates to ultimately replace CFC-12 use in this sector is HFC-134a. Assuming successful lubricant development, favourable toxicity test results, and adequate global supply, this refrigerant can be used in transport and retail refrigeration, and partially in industrial refrigeration and comfort air conditioning. The automotive industry has stated that HFC-134a could be introduced in new vehicles by 1994. If the existing fleet which uses CFC-12 is allowed to be phased-out gradually (through attrition), mobile air conditioning would be entirely converted to an environmentally acceptable refrigerant by the year 2010. Greater and quicker reductions in the use of CFC-12 in automotive air conditioning could be achieved in the near term by using mixtures based on HCFC-22. Given favourable toxicity results for blends which can be used as alternatives, USA/EPA studies forecast a possible total phaseout of the automotive use of CFC-12 by the year 2000.

3.3) Rigid and Flexible Foams

The foam industry now uses approximately 25 percent of all the CFCs consumed worldwide each year. The CFCs are used to make products of polyurethane, polystyrene, polyolefin and phenolic plastics. The technical options for reducing or eliminating CFC use varies with each foam type.

In the near term (by 1993), it is technically feasible to reduce the consumption of CFC-11, -12, -113, and -114 for foam manufacturing globally by approximately 150,000-175,000 tonnes (60-70 percent). Some foam subsectors such as manufacturers of polystyrene foam insulation and packaging, polyolefin foam, some integral skin and miscellaneous polyurethane foam products, moulded flexible foam, and most slabstock foam products, can begin to eliminate fully halogenated CFCs from manufacture immediately. Approximately 30 percent of the near term CFC reductions rely on the substitution of currently available HCFCs as replacements for CFCs.

Globally, it is possible to reduce 30 percent of all CFC consumption (on average) used in the manufacture of polyurethane rigid insulating foam by using increased water blowing. The actual percentage will vary regionally depending upon the type of foam, the application or use of the insulation, the presence of impermeable facers, flammability requirements, product quality etc.

The rate of substitution to near term options is dependent upon a number of factors, including the determination of environmental acceptability of the alternatives, sufficient worldwide supplies of the alternative blowing agents, smooth transition to new foam systems utilising alternatives, and the suitability of substitutes in all processes and product types.

Reductions in CFCs in the longer term (after 1993) will be dependent upon the availability and price of the HCFCs. Provided the HCFCs are environmentally acceptable and commercially available, the foam industry can begin to immediately substitute them for the fully halogenated CFCs currently used.

Under the assumption that HCFCs are available and commercialised around 1993, it is anticipated that a virtual elimination of CFCs in all foam uses is technically achievable around 1995. Without the HCFCs, foam manufacturers have few other options, given current technology. Foam manufacturers, particularly those that produce insulation products, would have to offer a product without CFCs or HCFCs. The product would have poor physical properties and/or insulating value compared to those that used CFCs. It would be difficult for such foam products to be cost-effective in the market with current non-CFC insulation materials.

3.4) Electronic, Degreasing and Dry Cleaning Solvents

CFC-113 is widely used as a solvent to clean printed circuit boards, delicate instruments and surfaces (defined as precision cleaning applications in the "Technical Options Report" for the Electronic, Degreasing and Dry Cleaning Solvents sector), and metal parts and surfaces. CFC-113 is also used to clean clothes in the dry cleaning industry.

There is no single universal substitute for all uses of CFC-113. However, every solvent application area has one or more available alternatives which can be adopted. In electronics cleaning, precision cleaning, and metal cleaning applications, for example, there are a wide variety of alternative solvents and processes available that offer equal or better cleaning performance at equivalent cost. The currently identified alternatives are environmentally acceptable in most jurisdictions if care is taken to use a properly designed cleaning system.

Methyl chloroform (1,1,1-trichloroethane) and carbon tetrachloride are technically able to replace CFC-113 in many cleaning applications, but methyl chloroform and carbon tetrachloride are more potent ozone depleting substances than the new HCFC solvents and the fully ozone-safe aqueous cleaning, terpene-based solvents, and other alternatives. Carbon tetrachloride is also toxic. Methyl chloroform and carbon tetrachloride will be considered for addition to the Montreal Protocol in 1990.

Carbon tetrachloride is not used as a solvent in the United States, Canada, Scandinavia, or the EEC countries because its use is restricted or prohibited because of carcinogenicity concerns. It is unlikely therefore, that carbon tetrachloride will be used as solvents in these countries in the future. However, carbon tetrachloride is used in other parts of the world. The existing use of carbon tetrachloride as a solvent should be reduced and eliminated because of the compound's carcinogenicity and its high ODP. The Committee does not recommend the use of carbon tetrachloride as a substitute for any cleaning application discussed in the "Technical Options Report" for the solvents sector.

All CFC-113 use in all application areas can be phased-out by the year 2000. Although the time-frame for a CFC-113 phaseout will vary among the different industry applications, CFC-113 will be replaced with the alternative processes and technologies described in the solvents Technical Options Report.

Alternative solvent blends based on hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) will become commercially available in the next decade. These will add to the growing list of CFC-113 alternatives for solvent cleaning. CFC-113 alternatives, including aqueous cleaning, terpene-based solvents, other organic solvents, solvent blends, combination cleaning, and no-clean alternatives, are currently being used by many companies.

As a first step in reducing CFC-113 use, companies can implement conservation and recovery practices to reduce CFC-113 consumption. Such steps are particularly important in the short-run while processes and equipment are re-designed, or other production changes are made to eliminate CFC-113 use altogether. Companies can improve operating practices, install engineering - controls, and recycle solvent. These measures would reduce solvent use by 50 percent or more at little or no net cost. Adopting alternative technologies such as aqueous cleaning, alcohol-based cleaning, inert gas wave soldering, and low solids no-clean fluxes can eliminate the remaining balance of uses. In the dry cleaning industry, which accounts for approximately 5 percent of worldwide CFC-113 use, alternative solvents such as white spirits are commercially available and the HFCs and HCFCs currently under development can serve also as viable alternatives to CFC-113. These substitutes are likely to be commercially available in the next three to five years.

The electronics industry uses the largest amount of CFC-113 worldwide of any industry application area. An estimated 80,000 metric tonnes of CFC-113 were used to remove flux from printed circuit board assemblies in 1986, representing 45 percent of worldwide CFC-113 consumption. Removal of fluxes and flux residues after soldering traditionally has been considered essential for high quality electronic assemblies to ensure electrical performance and adhesion of conformal coatings, to facilitate testing and inspection, and to prevent corrosion and electro-migration. CFC-113 solvents mixed with alcohols have been the solvents of choice for electronics cleaning because they effectively remove flux residues without damaging solvent-sensitive components on the printed circuit board assemblies.

An estimated 50 percent of current CFC-113 use in the electronics industry is dictated by military specifications. Industry experts agree that the use of alternative cleaning processes, such as aqueous cleaning, would increase if military specifications allowed manufacturers to meet performance criteria using a choice of flux and cleaning methods. The U.S. military has agreed to change military specifications based on a joint benchmark test program currently in progress. The U.K. Ministry of Defence has also accepted a new flux standard that will allow the elimination of CFC use in U.K. military productions.

Other promising cleaning alternatives include terpene-based solvents and low solids fluxes. Terpene-based solvents work effectively at close spacing and low temperatures. These solvents remove both polar and non-polar contaminants, and are non-corrosive. Low solids fluxes in some applications may eliminate cleaning altogether.

A second major use of CFC-113 as a cleaning solvent is in precision cleaning applications. Precision cleaning is used to clean delicate instruments and surfaces such as gyroscopes, computer disk drives, and optical components. Aqueous cleaning, alcohols and HCFC/alcohol blends, and biodegradable solvents are effective alternatives. Many alternative techniques are in the testing stage; as research and development increase in this area, use of alternatives should virtually replace CFC-113 use by the year 2000.

A third major application area is in metal cleaning applications. Conservation and recovery practices can reduce CFC-113 use substantially in the short-run. Additional reductions and elimination of CFC-113 use can be achieved by using a variety of aqueous and semi-aqueous cleaners, chlorinated solvents and terpene cleaners.

The dry cleaning industry is a relatively minor CFC-113 user (only five percent of the worldwide CFC-113 consumption in 1986). CFC-113 use as a dry cleaning solvent can be further reduced by the use of white spirits (in industrial facilities), possibly methyl chloroform and the HFCs and HCFCs under development. HCFC-225ca, and HCFC-225cb are particularly promising alternatives for dry cleaning.

3.5) Aerosols, Sterilants, and Miscellaneous uses of CFCs

There are a wide variety of alternatives available to substitute for CFCs in aerosols, the optimal choice of which varies with the product under consideration. Among the currently available chemicals, the most commonly used substitutes for CFCs in aerosols are the flammable hydrocarbons propane and butane. In some countries stringent regulations concerning the handling of flammable products have limited the possibility of using flammable propellants in aerosols. In at least some of these countries such legislation is now being reconsidered.

Currently available non-flammable chemical substitutes include: compressed gases and HCFC-22, alone or in mixtures. Compressed gases have, at present, only a minor share of the market but have potential for growth. From a technical perspective, HCFC-22 could probably work well in about 30 percent of the products now using CFCs and marginally well in another 15 percent. It is however, unlikely that HCFC-22 would achieve this degree of market penetration because it has a much higher price than hydrocarbons. Non-aerosol alternatives can also be used to apply, or administer, products that currently use CFCs. These include other spray dispensers, e.g., finger pumps, as well as non-spray methods such as roll-ons, brushes, powders, etc.

New chemicals such as HCFC-123, -124, -141b, as well as HFC-134a are, from a technical perspective, all considered to be possible substitutes for CFCs in aerosols. However, the high cost of these chemicals will likely limit their application to specialty products.

Medical products are recognised as the category where CFCs may be most difficult to substitute. Substantial reductions can be made within this category if CFCs are used only where no alternatives exist. Substituting CFCs in inhalant drugs poses a problem. New powder drug administration methods are being used in inhalant products which are already on the market. Such products may achieve a greater market penetration but will not be a substitute for all patients and drug products. Some of the new HCFCs and HFCs may also serve as a substitute in medical products. However, only limited testing has been conducted so far and it is still unclear to what extent substitution of these chemicals will be possible. All new medical products will need time for extensive testing and approvals from the appropriate authorities. A total phaseout of the use of controlled CFCs in medical products worldwide will therefore take several years. Some industrial and technical specialty aerosol products may have difficulty in substituting for the controlled CFCs.

In conclusion, the vast majority of the use of CFCs in aerosols - which in 1986 accounted for some 300,000 tonnes (approximately 27 percent of global consumption) - can be eliminated through chemical or product substitution using already available alternatives. The majority of aerosol producers are likely to switch to hydrocarbons. This switch will require time for reformulation, retrofitting and sometimes plant relocation (because of the increased explosion or fire risk associated with the use of those chemicals). In many countries the conversion to non-CFC aerosol products is, however, already well underway.

The amount of controlled CFCs used in medical products worldwide in 1986 is estimated to be 10-12,000 tonnes of which inhalant drug products consume 3-4,000 tonnes. Some fraction of this drug related use will likely remain until the second half of the 1990s. The quantities of CFCs consumed for industrial and technical specialty products in 1986 is difficult to assess but is estimated not to have been more than 40,000 tonnes worldwide. For these products it appears technically feasible to develop alternative chemicals or application methods to substitute CFCs within a few years. This substitution process is already underway.

By the end of this century, unless the use of hydrocarbons is curtailed, world aerosol use of HCFCs is not expected to exceed 25,000 tonnes per year.

With respect to sterilants, CFC-12 is used as a diluent for ethylene oxide (EO) in a mixture commonly known as "12/88" (12 percent EO, 88 percent CFC-12). EO is a widely used sterilant which, however, is toxic, mutagenic, a suspected carcinogen, as well as flammable and explosive. EO is often used pure (without any diluent) by industrial and larger commercial sterilisers, with due precautionary measures. Another diluent for EO is CO_2 which forms a non-flammable mixture when used in the ratio 10 percent EO and 90 percent CO_2 (commonly known as "10/90").

The total use of CFC-12 worldwide for sterilisation is estimated to be approximately 20-25,000 tonnes. "12/88" is used to some extent in at least 60 countries. The USA accounts for some 50 percent of the total use globally, or about 10-12,000 tonnes. Of this, some 30-40 percent (about 4,000 tonnes) is used in hospitals. In many other countries, especially in Europe, hospitals use formaldehyde instead of EO.

For products that can tolerate 121°C, steam sterilisation is widely used both in hospitals and by manufacturers, because it is non-toxic, economical, safe, and well accepted.

The main problem in eliminating CFC use in this area is the need for sterilisation of heat sensitive medical devices at hospitals. This problem can be reduced if heat sensitive devices are kept separate from non-heat sensitive devices. In countries where formaldehyde is accepted, devices that can stand 80-85°C (or in some countries even lower) can be sterilised with formaldehyde, leaving a small number of devices that require EO. These can be sterilised either at the hospitals with pure EO in small sterilisers, or by the manufacturer, or a third party sterilising facility. In countries where formaldehyde is not accepted, as is the case in the USA, the number of devices which need EO sterilisation at hospitals precludes the use of small sterilising units. These hospitals will have the choice to convert to "10/90" (which is not accepted by all), to pure EO (with full scale precautionary measures which is very expensive) or to sterilisation by a third party (also expensive).

One producer has recently announced his intention to commence commercial distribution (in the early 1990s) of a new mixture of HCFC-type substances with EO. This blend is claimed to be suitable as a "drop-in" replacement for "12/88" in existing equipment, and could also be used in "10/90" equipment with minimal changes.

Add-on engineering control systems are available for recycling a portion of the CFC-12 used in sterilisation equipment. Options for industrial and commercial users of "12/88" include existing sterilants such as pure EO, "10/90", in some cases radiation, and new HCFC-based chemicals.

In conclusion, by using a combination of possibilities the current use of CFCs for sterilisation can be substantially reduced using existing alternatives and can be phased-out not later than 1995 in developed countries. In developing countries the substitution will be slower unless special efforts are made.

CFC-12 is also used in food freezing. There are about 30 food freezing plants worldwide which used 3,400 tonnes of CFC-12 in 1986. Most of the equipment was installed before 1974, but has a long expected lifetime. This CFC consumption can be eliminated using currently available alternative methods such as cryogenic techniques (LIN) that use liquid nitrogen and air blast freezing with varying degrees of economic impact, (depending on the food sector). New chemicals such as HFC-134a may theoretically be possible to use, however, this option is unlikely due to the higher costs compared to LIN. There are also unresolved issues such as the safety approvals for use of HFC-134a in direct contact with food.

CFCs are also used for a variety of miscellaneous uses such as tobacco puffing, fumigation, leak detection, and cancer treatment. One use specifically worth mentioning is in relation to laboratory procedures. For example, standard methods for analyzing oil calls for either the use of CFCs or carbon tetrachloride. New standard methods are therefore required. The miscellaneous uses mentioned in this report are believed to consume, on a global basis, only a very small amount of CFCs. However, it is important to be aware of all of these miscellaneous uses when considering controls.

3.6) Halon Fire Extinguishing Agents

Halons are fully halogenated hydrocarbons that exhibit exceptional fire fighting effectiveness. They are electrically non-conductive, dissipate quickly leaving no residue, and have proven remarkably safe for human exposure. This unique combination of properties has led to their selection as the agent of choice for many fire protection situations including computer communications and electronic equipment facilities; museums; for engine spaces on ships and aircraft; for ground protection of aircraft; for general office fire protection; and for industrial applications. Recently, portable fire extinguishers using halons have achieved popularity in some countries for home use.

Total world production and use for the base year 1986 (in metric tonnes) is estimated as follows:

HALON	1301	1211	2402	Total
Banked	7,000	11,200	850	19,050
Test/Training	1,100	840	20	1,960
Unwanted Discharge	300	140	10	450
Service	900	420	20	1,340
Fires	700	1,400	100	2,200
Total	10,000	14,000	1,000	25,000
Percent Use	40%	56%	4%	100%

Annual halon consumption, on a tonnage basis, as defined in the Montreal Protocol (group II substances) is less than three percent that of the controlled CFCs (group I substances). However, the ozone depletion potential values (ODP 3-10) are high.

On a weight basis, it is estimated that over 70 percent of all halons produced annually are banked to provide stand-by fire protection. Studies have indicated that less than ten percent of annual production is used to extinguish fires. The remaining 20 percent of annual production is emitted to the atmosphere by test/training procedures, accidental or unwanted discharges or service procedures. These categories of emissions are considered controllable. Virtually all use of Halon 1301 as a test agent can be eliminated by other testing means and/or use of environmentally acceptable simulant testing gases. More efficient training techniques are being developed to reduce training related emissions of Halon 1211.

Global emissions can be reduced by:

-- restrictions on halon to ensure that use is limited to essential applications only;

-- improvements in procedures for servicing halon fire - equipment;

-- reduction of unnecessary discharges of fixed halon systems by more stringent requirements for detection and control equipment used with halon fire protection systems;

-- use of alternative, environmentally acceptable simulant gases for testing halon fire protection systems;

-- requirements to manage the existing bank of halons with the eventual re-allocation to satisfy the most essential applications; and

-- further development of means to destroy halons that have been contaminated to such an extent that recycle is not possible.

The Committee sought to quantify the reduction in halon dependency that can be achieved without jeopardising the provision of necessary fire protection. However, no consensus was reached. The majority of the members and technical advisors considered the following as a feasible and achievable schedule resulting in a complete phaseout:

YEAR	**HALON CONSUMPTION**
1992	Cap at 1986 level
1995	75% of 1986 level
1997	50% of 1986 level
2000	25% of 1986 level
2005	0% of 1986 level

Two members and one technical advisor considered the following as feasible and achievable:

Halon 1211 - The possible short term replacement of Halon 1211 by other existing products could achieve a 50-60 percent reduction in use within 4-5 years. If substitutes (which today are under preliminary study) turn out to be both acceptable and available it may be possible to phase out consumption and use of Halon 1211 by the year 2000.

Halon 1301 - Restricting use to essential applications could achieve a reduction of 30-50 percent within 4-5 years. A total phaseout may be difficult to achieve, recognising that development of replacement agents with the very low toxicity of Halon 1301 for use in total flooding systems for occupied enclosures may not be a realistic expectation.

Two other members of the Committee were of the opinion that it is premature to determine and quantify levels of possible halon reductions or availability as more experience is required in working with the proposed alternative measures outlined in the full report. These experts, however, support a complete phaseout when viable substitutes become available.

The existing global bank of halon has been estimated at approximately 110,000 tonnes. This bank can be considered as both an important fire protection asset and an environmental threat. The quantities of halons banked in extinguishing systems containers, portable extinguishers, and mobile units is greater than the quantities emitted each year for extinguishing fires, discharge testing, training, and unwanted discharges. For the year 1986, an estimated 70 percent of Halon 1301 and 80 percent of Halon 1211 produced were stored in cylinders or containers installed on end-users premises.

Managing this bank at a national level is desirable for the following reasons:

- to recover the highest possible quantities for recycling and re-use in new systems for critical applications;
- to eliminate controllable emissions associated with periodic maintenance of pressure vessels or dismantling of installations;
- to provide a precise means of evaluating the quantities of halon emitted to the atmosphere and to pursue efforts;
- to reduce unnecessary emissions; and
- to destroy quantities, that cannot be recovered due to contamination, in an environmentally acceptable manner.

Halon producers worldwide and a new consortium consisting of USA/EPA, U.S. Department of Defense, and Industry have research programs underway to examine and develop alternative agents. Preliminary, unpublished, reports indicate that development of application specific alternative agents are a realistic possibility for Halon 1211 and Halon 2402 replacement. Alternatives that offer the same high degree of human tolerance as Halon 1301 for use in total flooding systems for occupied enclosures will be a difficult task to accomplish.

The choice of other means to reduce fire risk to acceptable levels, of improved procedures to effectively reduce halon emissions, and management of the existing halon bank are important steps to reduce dependency, achieve conservation, and reduce potential ozone destruction. Means to destroy halons at the end of useful life, in the event alternatives are found or should scientific evidence make it necessary, appear to be relatively simple. Major programs to develop alternatives to extinguishing agents have begun. The development of clean agents with high extinguishing capability and low ozone depletion potential appear possible. Human tolerance is of concern and development of replacement agents with the very low toxicity of Halon 1301 for use in total flooding systems for occupied enclosures may not be a realistic expectation.

3.7) Anticipated End-of-Use Dates

Table I, page 42, outlines our best estimates as to the time periods when substitute products, technology or chemicals will be available in commercial quantities throughout the world and thus permit a total phaseout. A range is shown to indicate that sufficient quantities of chemicals or other alternative products will not be available in adequate commercial quantities throughout the world at the same time. These data have been considered in arriving at our overall observations relating to the technically feasible phasedown schedule (Figure 1, page vi). These are also the global dates that are realistic based on our knowledge at this time. However, technological development is progressing rapidly and it may therefore be possible to accelerate these global dates and this schedule by the time of the next technical review. Many countries, of course, will be able to end use in advance of these dates.

3.8) Methyl Chloroform, and Carbon Tetrachloride

Methyl chloroform is a versatile all purpose solvent used extensively because of its low cost, powerful cleaning properties, non-flammability (under normal conditions of use) and low toxicity. Estimates for 1984 were that the USA, Western Europe and Japan alone consumed 545,500 metric tonnes. The report of the first meeting of the Parties to the Montreal Protocol (Helsinki, May 1989), concluded "in order to reduce the atmospheric levels of chlorine below those of today it will be necessary to phaseout all the substances controlled under the Protocol, together with strict limitations on carbon tetrachloride and methyl chloroform". As was noted in the "Key Observations" section of this report, this chemical would need to be controlled in order to accelerate global efforts to reduce the large sources of Clx to the stratosphere. Substitutes exist for almost all of the uses of methyl chloroform. However, some time may be required for the orderly transition away from the use of this chemical. Annual reporting on consumption would assist future technical evaluations.

Carbon tetrachloride was not considered for inclusion in the Montreal Protocol because it was erroneously believed that the only significant uses were as a feedstock transformed in the production of other chemicals. However, scientific measurements have found significant quantities (increasing with time) of carbon tetrachloride in the stratosphere suggesting continuing use in ways that result in emissions to the atmosphere. Technical alternatives and substitutes exist, for carbon

TABLE I

Anticipated End-of-Use Dates -- Worldwide

SECTOR	DATE
Refrigeration	1989-2015
Domestic Refrigeration	1995-1999
Commercial/Retail Refrigeration	1989-1999
Refrigerated Transport	1989-2010
Cold Storage	1989-2005*
Comfort Air Conditioning	1991-2015
Industrial Refrigeration	1989-2010
Heat Pumps for Heating	1989-2005*
Mobile Air Conditioning	1994-2010*
Flexible Foams	1989-1993
Rigid Foams	
Polyurethane	1993-1995
Polystyrene	1989-1993
Phenolic	1993-1995
Polyisocyanurate	1993-1995
Polyolefins-Polyethylene Polypropylene	1989-1993
Solvents	
Electronic	1995-1997
Metal Cleaning	1993-1996
Dry Cleaning	1993-1995
Miscellaneous Uses	
Aerosols-Non-Medical	1990-1995
-Medical	1995-2000
Sterilisation	1990-1995

* Some refrigeration uses may be able to reduce sooner if retrofitted to accept HFC and HCFC blends now under development

tetrachloride. Consumption reporting on an annual basis would assist future evaluations.

3.9) Status of Recovery and Recycling Programmes

Recycling programmes for CFCs and halons offer a tremendous potential for reducing emissions in the near term. Two classic candidates for recycle are CFC-113 used as a solvent and CFC-12 used in automotive air conditioning.

Major recycling programmes are now under development in many countries. Several producers have announced that they are prepared to take back used CFCs for reprocessing in their facilities. The global implementation of such recycling programmes can not occur immediately due to the lack of infrastructure, economic incentives, etc.

One important application area for recovery and recycle is in relation to the use of halons where there are few, if any, environmentally benign substitutes and where the industry themselves are committed to a phaseout in production of these chemicals.

Assistance to many developing countries in the area of recovery and recycle programmes, including institutional frameworks and infrastructure etc., will be required.

Whereas the recycling and re-use of CFCs can only be viewed as a short term measure as we pursue total elimination, the infrastructure developed will prove useful in facilitating the reclaiming and recycling of the HCFCs or any other chemicals that see use and continue to exert an appreciable ODP. Recovery of CFCs at the time of equipment disposal is technically feasible, and in some cases, already practised. The challenge will be to find practical and cost effective ways of recovering small quantities of CFCs from household appliances, as well as industrial products and equipment.

3.10) Status of Destruction Technologies

Thermal incineration is the only technology for CFC or halon destruction that is currently available on a commercial scale. CFC incinerators exist as well as general hazardous waste incinerators that can co-fire CFCs with other wastes.[19] Halon has been decomposed thermally into HF and HBr gases. CFC-113 has also been successfully incinerated in a cement kiln over a 3 hour period at 1050°C and 4 seconds residence time. Other promising technologies are:

- Catalytic incineration;
- Pyrolysis;
- Active metals scrubbing;

- Chemical scrubbing;
- Wet air oxidation;
- Supercritical water oxidation; and
- Corona discharge.

A common measure of the performance of a chemical destruction technology is its destruction and removal efficiency. Although there is limited test burn data on CFCs (CFC-11 and 12), the available data show high destruction efficiencies (99.9998 percent). Since these are two of the most stable CFCs, it is anticipated that other CFCs (like CFC-113) would have similar, or possibly better destruction efficiencies.

Environmental concerns of CFC and halon destruction include the possible formation of potentially hazardous products of incomplete destruction (PICs), and acid and/or halogenated gas emissions. Thermal destruction of CFCs produces acid gases (HCl, HF, or HBr) and/or free halogen gases (Clx, F_2, or Br_2) when the halogen-containing parent compound is broken down in the incinerator. Acid gases can be scrubbed with either a water or with a caustic solution to react with the acid/halogen gases. Both water and caustic scrubbers are used for cleaning CFC destruction flue gases.

In addition to products of incomplete combustion and the formation of acid gases, destruction of CFCs will also produce combustion products such as CO_2, NO_x, and CO. Some of these combustion products are greenhouse gases; however, the amount relative to other man-made sources would be very small.

In conclusion, several promising technologies exist for destroying both CFCs and halons. Establishing criteria for "approving" destruction techniques will require further detailed consideration on a "per technique" basis by a dedicated Working Group. What appears to be needed is a "total management system" for ensuring the appropriate cradle-to-grave management of these chemicals -- not simply criteria. Such a management system which could be developed in conjunction with, or under the auspices of, UNEP (perhaps via a Working Group) could provide invaluable information and guidance to Parties, especially developing countries. This management system description could provide guidance on assignment of responsibility and liability for collecting and disposing of the banked chemicals (both CFCs and halons) and criteria for siting and approving the various destruction technologies or techniques. Such criteria could include[5]:

-- performance standards for incinerators or other destruction techniques (e.g., temperature, retention time, combustion and destruction efficiency) and pollution control systems (e.g., HCl removal);

-- tracking procedures (feed records and requirements for certificates of destruction for each load);

-- sampling and analytical methods specification;

-- process, environmental and emission monitoring requirements;

-- emission and/or effluent standards;

-- ash/residue disposal requirements;

-- wastewater treatment/disposal requirements;

-- operating procedures;

-- handling and storage of waste inventory;

-- emergency shut down procedures; and

-- contingency plans.

EXECUTIVE SUMMARY of the TECHNICAL OPTIONS REPORT
for
REFRIGERATION, AIR CONDITIONING and HEAT PUMPS

4.1 Introduction

Refrigerant Data

The properties of refrigerants for use in the vapour compression cycle have been considered. The vast majority of present equipment utilizes the vapour compression cycle because of its simplicity and good efficiency. The dominance of this cycle is not likely to change simply due to the need to replace CFCs.

A refrigerant must satisfy a set of criteria, including nonflammability and low toxicity, the need for favourable thermophysical properties, and other more practical considerations. Although many fluids and fluid types have been used as refrigerants in the past, halocarbons dominate today because their unique combination of properties best satisfy these sometimes conflicting requirements.

Because of the success of CFC refrigerants, most of the efforts to develop replacement refrigerants have focused on a set of hydrogen-containing, but otherwise similar, compounds. This choice is confirmed by theoretical studies which indicate that simple molecules of relatively low molecular weight and with normal boiling points similar to present working fluids are the ideal refrigerants. These fluids include HFCs-134a, -152a, -125, and -23 and HCFCs-123, -22, -141b, -142b, and -124. Mixtures of these fluids are also good candidates. These fluids are the most likely choices for the near- to mid-term replacement of CFCs. Although receiving little attention, HFCs-134, -32, and -143a also deserve consideration; and for applications where highly flammable fluids can be used, propane, iso-butane, butane and dimethylether deserve attention. Additional classes of fluids, such as the fluorinated derivatives of dimethylether, show some promise as refrigerants; such fluids, however, present many difficulties and would not be available for many years, if ever.

The thermophysical (i.e., thermodynamic and transport) properties of a fluid determine its energy efficiency and capacity in refrigeration machinery and thus thermophysical property data is required to select the best refrigerant for a particular application. The required thermodynamic properties vary according to the level of development of a fluid. Only simple parameters such as normal boiling point and molecular structure are needed to conduct a coarse screening among many candidates. The minimum data to estimate cycle efficiency are: the critical point parameters and vapour pressure; saturated liquid density; and, ideal gas heat capacity over the temperature range of interest. Single-phase, pressure-volume-temperature, measurements and calorimetric information are needed (in addition to the above) to develop an accurate formulation of the properties; this is the minimum desired level for equipment design purposes. Much more extensive data is needed to define a reference fluid which would be the basis for fluid property models. Transport property information is somewhat lower in priority than the thermodynamic data. Isolated measurements of thermal conductivity and viscosity can be used to screen among fluids, but as a minimum, measurements along the saturation line over a range of temperatures are required for equipment design. Similar data are required for mixtures.

The available property data for the candidate replacement refrigerants are summarized. Priorities identified in this area are the completion of work underway to measure the thermodynamic properties of the leading "new" refrigerants (HFC-134a and HCFC-123); the measurement of transport properties for HFC-134a, HCFC-123, and HCFC-141b; development of HFC-134a to the level of a reference fluid; and measurement of at least skeleton data for the remaining candidate pure fluids and mixtures.

Domestic Refrigeration

For small domestic equipment, good manufacturing processes, exploiting the potential of recycling, and refining current products and processes are important aspects. Reductions in CFC emissions, taking into account the bank of installed equipment, will very much depend on the percentage of recycling.

Domestic refrigerators and freezers use roughly 1.0 percent of all controlled CFCs in the refrigerant loop (roughly another 4.0 percent is used in the insulation which is not considered further here). An increase or decrease in the efficiency of any CFC-12 substitute of even 5 percent would result in a difference in electricity demand growth of 200 Mw/year. Therefore, efficiency is an important consideration in finding CFC substitutes for refrigerator and freezer use.

Different options exist for the replacement of CFC-12 in domestic equipment:

- Application of CFC-500 would lead to a 40 percent ODP reduction, but the high CFC-12 content of this mixture makes this an unattractive substitute;

- Use of NARMs, preferably non-flammable, could result in extremely low ODP values (between 0 and 0.5). Reliable functioning of many products has to be investigated, however, as would energy improvement potential exploited by sophisticated design refinements; the NARMS could lead to short to mid-term CFC savings;

- Choosing HFC-134a would result in an ODP of zero but result in energy consumption increases estimated to be 8-12 percent initially and 5-10 percent after optimization of designs (this makes HFC-134a a less suitable candidate);

- Applications of flammable refrigerants (such as HFC-152a and DME) offer prospects for reducing energy consumption if their "acceptability" problem can be overcome and accompanying problems in design and manufacturing solved; but this must be considered a mid- to long-term option;

- The recently introduced ternary mixture may offer "drop-in" advantages and better efficiency possibilities if system tests prove satisfactory and toxicity testing has an acceptable outcome; but this must be considered a mid- to long-term option; and

- HFC-134 may prove to be an acceptable long-term option but no testing has been performed so far.

In conclusion, small refrigeration equipment is characterized by the highest requirement for reliability and energy efficiency. Testing of new substances will take time. A considerable time period is needed to make the "best" long-term choice for this type of equipment.

Retail Refrigeration

Retail systems are assembled on site. Unit capacities range from lower than one kW to several hundred kW. Refrigerants used are CFC-12, HCFC-22, and CFC-502. Other refrigerants are used only in small amounts and in special applications.

CFC-12 is used for medium temperature systems only. HCFC-22 is used for evaporation temperatures down to -35°C, and CFC-502 is used for temperatures down to -45°C. CFC-502 is also used in medium temperature systems, if the same refrigerant for low and medium temperature cooling is to be used. Small amounts of CFC-13, CFC-503, CFC-14, and Halon-1301 (R13B1) are used for low temperature systems in two or more stage cascade systems.

It is estimated that about 5 to 6 percent of the total CFC consumption is used in retail refrigeration. There are numerous system designs in the field of retail refrigeration depending on their use. Leakages are the most important source of CFC emissions in retail refrigeration.

As long as HCFC-22 is accepted as a possible alternative, nearly all the CFC-12, CFC-502, CFC-13, and Halon-1301 consumption in retail refrigeration could be displaced as far as initial charges for new systems are concerned. Costs will be about US$15 million worldwide (US$8 million for the U.S. alone) for a savings of about 3 percent of the total use of CFC-12 and CFC-502 combined.

The change-over from CFCs in existing systems will only be possible for a few of the CFC 502-systems (HCFC-22) and for virtually all the few CFC-13 systems (HFC-23) with costs of about the same magnitude as required for a new charge.

It may be possible to reduce CFC consumption in retail refrigeration to about 20 percent in the near future. These savings would be from the change-over to HCFC-22, HFC-23, and mixtures in new systems, personnel education for good practice in service, leak testing and disposal in already existing systems, improved leakage control.

Transport Refrigeration

Currently there are about 1,300 refrigerated cargo and container ships, representing 10,500,000 cubic meters of refrigerated space. Most of these use HCFC-22, representing a pool of about 2,600 tonnes of HCFC-22. Maintenance and repairs are set to a high standard, requiring the use of about 50 tonnes per year. The continuing availability of HCFC-22 is important, as conversion costs to an alternative (if available) would be very high.

In addition to cargo refrigeration, there could be as many as 35,000 ships with "domestic" refrigeration systems, representing a pool of a further 3,500 tonnes of refrigerant.

Refrigerated containers use CFC-12, and there is no suitable alternative in this very demanding application. The estimated fleet of 300,000 units in late 1990 holds a pool of 1,650 tonnes of refrigerant. Ongoing maintenance and manufacturing require 245 tonnes of refrigerant per year, which is 0.06 percent of 1986 world production. Should CFC-12 be unavailable beginning 1996, it would involve scrapping US$2,000 million worth of equipment, and would pose formidable problems for manufacturing capacity. Equipment purchased today has an expected economic lifetime of 15-20 years.

Road vehicles currently use CFC-12, but in the short term some change-over to CFC-500 or CFC-502 are expected. Once proven alternatives are available, further changes will be possible as vehicles have a relatively short life of 7-12 years. There is a world fleet of about 800,000 refrigerated vehicles (220,000 in the EC) with a pool of 3,500 tonnes of refrigerant and a maintenance requirement of 800 tonnes per year. Although the industry is making every effort, reduced CFC use through improved maintenance and handling procedures is difficult to achieve with large numbers of small mobile units.

On a world scale, transport refrigeration is a small but important user of CFC and HCFC refrigerants which may merit special attention.

Cold Storage/Food Processing

Cold storage covers storage of food products both above freezing (0°C to +10°C) and below freezing (-10°C to -28°C), both for in-processing storage and for storage and distribution of finished products. Food processing covers chilling from -3°C to +10°C and freezing from -18°C to -28°C.

Most large scale industrial chilling, freezing, and cold storage plants utilize ammonia. However, certain areas and countries use CFC-12, HCFC-22, and CFC-502. Most small scale chilled and cold storage operations use CFCs and HCFCs rather than ammonia. The principal exception is in Eastern Europe, where ammonia is the primary refrigerant.

A significant portion of very large site-built plants contain several tonnes of CFC-12 or HCFC-22. These plants have greatly decreased their need for recharge in recent years. For example, 5 or 10 years ago these plants had an average loss of 10 percent of charge per year; today many report yearly losses down to 1 or 2 percent. Where these plants 5 or 10 years ago had an average loss of 10 percent of the charge per year, many today report yearly losses down to 1 or 2 percent. Because these plants represent a very high investment and are expensive and difficult to rebuild, additional methods for reducing their charge should be encouraged.

The existing alternatives are:

- Ammonia

- HCFC-22 and other CFC's where required for operation, safety or climatic reasons; and

- Greater use of indirect refrigeration for all refrigerants.

Ammonia is quickly biodegradable and is not harmful to the environment. It is toxic to humans in concentrations above 100 ppm after eight hours of exposure. Ammonia is flammable in concentrations of 16 to 25 percent by volume in air. Codes, regulations, and laws have been developed to deal with the toxic and flammable characteristics of ammonia, which if followed, provide a high degree of safety.

Ammonia is recommended for freezing operations; close-coupled, confined compressor-evaporator systems; and frozen goods storages where the systems are well-managed and not far-flung geographically. Unitized designs can reduce ammonia charge and risk in many applications.

HCFCs and CFCs should still be used where dense populations, public buildings, severe earthquake zones, and special climatic situations prevail. Wherever possible, HCFC-22 should be utilized as it has the least effect on the ozone layer.

A greater use should be made of indirect systems. These systems can use either ammonia or HCFC/CFC refrigerants in a close-coupled arrangement to cool/chill water or a brine solution (glycols, calcium chloride, alcohols, etc.) in a heat exchanger. Indirect systems provide a reduced refrigerant charge in most applications. Indirect systems are theoretically less efficient than direct systems due to the extra heat transfer step to cool the water or brine solution. Practical experience, however, shows that because of simultaneity many indirect systems have better performance characteristics than direct systems.

New refrigerants are being developed to provide comparable economic benefits to ammonia and HCFCs and CFCs without the toxic qualities of ammonia and the environmental disadvantages of the HCFCs and CFCs. They can be phased in as appropriate when and if they become available, and the machinery and accessories can be adapted to their characteristics.

Refrigeration for food processing, chilling, freezing, storage, and distribution represents a large portion of installed refrigeration tonnage, and it will increase faster than population growth for both chilled and frozen products. The existing plants using CFC-12, HCFC-22, and CFC-502 should be allowed to remain but with targets for lower recharge levels. New installations and major retrofits or modernization should consider the use of ammonia where acceptable on a safety basis followed by HCFC-22 for medium temperature applications and CFC-502 for freezing applications (maybe HFC-32 in the long-term). Use of indirect refrigeration and unitized, factory-built equipment should be encouraged for all refrigerants to reduce refrigerant charges and to minimize potential for leaks.

Industrial Refrigeration

Industrial refrigeration systems include applications within: the chemical, pharmaceutical, and petrochemical industries; the oil and gas industry; the metallurgical industry; civil engineering; sports and leisure facilities; industrial ice making; and, other miscellaneous uses.

All types of refrigerants are used: CFCs; HCFCs; ammonia; and hydrocarbons. The controlled refrigerants account for approximately 25 percent of the total refrigerant consumption. The global consumption of CFCs is estimated to be 3,500 tonnes per year, of which more than 80 percent is believed to be CFC-12. The increase in CFC consumption since 1986 has been negligible. The usage of HCFC-22 is approximately twice that of CFCs.

First charge of new plants is believed to account for 30 percent of the annual consumption. Most of the rest of refrigerant consumption is used for replenishment after leakages and release during service. A small amount is also used for leak testing, etc.

Options for reduction of CFC usage in existing plants are refrigerant conservation, and, to a lesser extent, change-over to alternative refrigerants. In new plants, alternative refrigerants will replace the CFCs gradually. Complete phase-out of regulated refrigerants in new plants is expected to be possible by 1998. Small quantities of CFCs must be available until approximately 2015 for service purposes.

Estimates concerning possible consumption reductions, according to a realistic scenario, appear in Table J. The figures given are relative to CFC consumption in 1986 (3,500 tonnes).

The impact on the local environment is considered negligible. The global impact includes a calculated 20 percent reduction in ozone depleting potential (ODP) of emitted refrigerants (CFCs and HCFC-22) by 1994, increasing to approximately 50 percent before 1998. About one-third of the reduction is due to refrigerant reclamation.

The economic impact is estimated to be a 13-14 percent investment increase in 1994, which amounts to nearly US$35 million. The corresponding figures for 1998 are 22 percent and US$55 million respectively. Maintenance costs for the stock is supposed to increase by 12.5 percent (1998), i.e., by US$13 million per year. This expense will, to some extent, be compensated for by reduced leakage and less refrigerant released

TABLE J

Possible Reduction in CFC Consumption
Industrial Refrigeration (Reference Table 8-2)

Measure	Estimated Reductions (percent) 1994	1998
Retrofitting existing plants to use alternative refrigerants	2	5
Alternative refrigeration in new plants	26	38
Refrigerant conservation	15	32
Total	43	75
Refrigerant reclamation	7	17
Total, Including Reclamation	50	92

during service, which is estimated to represent a value of approximately US$4 million a year at the current price level.

Calculations indicate that the energy consumption will remain fairly constant, provided that no significant efficiency improvements in compressor or plant performances are developed during the period (0 percent in 1994, +2 percent from 1998 on). Accordingly, the impacts on energy costs are not important.

Unrestricted availability of HCFC-22 is an absolute prerequisite for the results and conclusions presented here. These scenarios imply a 15-20 percent increase in the usage of this refrigerant by 1998. Regulations on the use of HCFC-22 will delay the possible phase-out of CFCs considerably, and lead to adverse cost and energy effects.

Comfort Air Conditioning

The portion of comfort air conditioning equipment which is affected by the ban on fully halogenated refrigerants is the very large chilled water systems, which are predominantly centrifugal compressor driven. The problems posed and the remedies being considered can be categorized as either existing equipment or new designs. The former of these poses the more difficult challenge, particularly in finding a "drop-in" alternative refrigerant which will require only a reasonable amount of hardware alterations. In fact, it is likely that some cost in performance (i.e., capacity and/or efficiency decrease) will occur even after expensive alterations are carried out. New designs are, of course, possible for new systems. Those presently being studied are systems that will employ HCFC-123 and HFC-134a. Also HCFC-22 systems are being studied for possible expansion into a higher capacity range than currently used.

CFCs and refrigerants, in general, can be conserved by improving the equipment handling process throughout. Normal system leakage, servicing, manufacturing, shipping, and installation procedures can be "tightened up" and recovery and recycling procedures can also be implemented. It is estimated that the current CFC usage would be cut in half if such procedural changes were implemented. New designs for both new and existing systems would reduce CFC usage another 23 percent. The remainder would be phased out gradually by the year 2025 by replacement with non-CFC chillers.

Mobile Air Conditioning

Mobile air conditioning (MAC) currently utilizes CFC-12 exclusively as the refrigerant in a vapour-compression refrigeration cycle. The compressor is engine-driven via a drive belt and associated electromagnetic clutch. The compressor is mounted on the engine while the remaining system components are attached to the vehicle chassis. Thereby requiring the use of flexible refrigerant lines to dampen relative engine/chassis movements. In addition to reliably providing for passenger comfort and driving safety over a wide range of ambient conditions, the system must not put the occupants of the vehicle or the public at risk due to exposure to toxic or flammable materials.

Current annual MAC usage of CFC-12 is estimated to be 120,000 metric tons or 28 percent of global CFC-12 production. Original manufacture uses approximately 29,900 metric tons while 89,700 metric tons are used for servicing existing vehicles.

Current CFC-12 emissions to the atmosphere result from using CFC-12 as a leak detection gas, losses during system charging, system leaks, recharging leaky systems without having to fix the leak, service venting prior to repairs, vehicle scrapping, and poor handling practices in general. Emissions from these sources can be minimized or eliminated. Alternate leak detection gases are available (e.g., HCFC-22). Service venting can be significantly reduced by implementing CFC-12 recycling during service and vehicle scrappage. Resulting annual savings would be on the order of 28,000 metric tons. Elimination of over-the-counter small service cans of CFC-12 would minimize the ability of the general public to recharge leaky systems without repairing them and result in an annual estimated savings of 12,000 metric tons. The practice of MAC system flushing with CFC-11 after component failure can be eliminated by the use of as add-on-filter which would contribute to overall CFC savings.

Because no direct "drop-in" replacement for CFC-12 in MAC systems exists, conversions to another refrigerant is a very major undertaking. Presently, the most viable candidate to replace CFC-12 is HFC-134a, a non-ozone depleting chemical. MAC system changes required for HFC-134a use are relatively modest since HFC-134a's thermodynamic properties are similar to those of CFC-12. Given successful lubricant development, favourable final toxicity test results, and adequate global supply, HFC-134a could be introduced in new vehicles in 1993. Full implementation (a 3-5 year task) will result in a CFC-12 savings of some 29,900 metric tons annually.

Novel mixtures of refrigerants have been offered as potential replacements for CFC-12 in original equipment and all have been found to be unacceptable, generally due to incompatibility with existing and/or available system materials. Candidates proposed to date for retrofitting existing systems all require significant system changes and, in many cases, flushing with CFC-11 to remove the existing lubricant.

The technology of reducing leakage, recycling CFC-12 and full conversion to HFC-134a in new vehicle manufacture, properly applied, will effect an annual reduction in CFC-12 usage of approximately 70,000 metric tons during the course of the next 7-9 years (Table II). The conversion of new MAC systems to HFC-134a by the mid-late 1990s will leave only the existing CFC-12 fleet in need of CFC-12. This need will diminish with time and can be minimized by timely leak repair, preventative maintenance and CFC-12 recycling. With conversion to HFC-134a and aging of the existing CFC-12 fleet, mobile air conditioning could be entirely converted to an environmentally acceptable refrigerant by the year 2010.

Heat Pumps for Heating Only

Heat pumps for heating only, cover heat demands from a few kW up to several MW, both in the residential/commercial sectors and in the industrial sector.

CFC-12 and HCFC-22 are the most commonly used refrigerants. CFC-114 is used in industrial applications where high temperatures are required. Roughly it can be stated that HCFC-22 is used for heat delivery temperatures up to 60°C, CFC-12 for temperatures up to 85°C, and CFC-114 up to 130°C.

The annual consumption of CFCs is estimated to be 800 tonnes, evenly divided between first charge in new plants and for recharging of the existing stock.

Conservation is the most promising option to reduce the CFC-consumption in existing plants. Change-over to alternative, non-regulated refrigerants, is not believed to occur to a great extent.

Today, no alternatives exist for the CFC-refrigerants in new plants with standard components, when the heat delivery temperatures exceed the maximum obtainable, using HCFC-22 or ammonia. Therefore, only a gradual change-over to non-CFCs in 15 percent of the new plants is expected to be possible before 1994. In 1998 it is considered to be possible to use alternative refrigerants in all new plants.

The reduction relative to the expected consumption without any remedial actions to reduce consumption is expected to be about 25 percent in 1994 and 80 percent in 1998.

The heat pump market is anticipated to increase by 10 percent annually. This implies a 45 percent increase in CFC consumption by 1994 compared to 1986. In 1998 a CFC consumption reduction of about 45 percent is expected, with reference to the same year.

The net additional cost for the reduction scenario described is roughly estimated to be US$42 million in 1994 and US$76 million in 1998.

The energy effect of introducing equipment which does not use CFCs is considered to be small. In the long-term, more efficient equipment and system designs will probably be introduced due to further research and development. This might also refer to absorption heat pumps.

Heat pumps reduce both energy consumption and emission of greenhouse gases and other polluting gases from combustion of fossil fuels. Even if they produce a limited emission of CFCs to the atmosphere, they are assumed to have a net positive effect on the global and the local environment.

Refrigerant Recycling

Refrigerant recycling means a process whereby contaminated used refrigerant is recovered, recycled, and, possibly, reclaimed so that the refrigerant can be reused in air conditioning and refrigeration equipment. Recycling can be done on-site with potable recycling equipment while reclaiming is usually done off-site. Off-site refrigerant recycling is performed by CFC manufacturers, independent reclaimers, and individual service companies.

The air conditioning and refrigeration industries are exploring reusing CFC refrigerants by issuing standards for acceptable levels of containments in reclaimed refrigerants. Using the recycled refrigerants which meet these specifications will not void manufacturer warranties, an important step in the widespread use of recycling.

Current servicing practices result in unnecessary emissions of CFCs. Refrigerant is released when manufacturing, repairing, and testing equipment. These releases of CFCs can be reduced with recycling equipment and improved practices.

Recharging of leaky systems without proper repair must be eliminated. This will result in the refrigerant escaping to the atmosphere in a short period of time. Elimination of small cans of refrigerant will reduce the ability of the non-professionals to recharge leaky systems.

Under proper recycling practices, roughly 92 to 99 percent of used refrigerants can be recycled, and may cost about the same as new refrigerant. However, few facilities and portable recycling equipment are available today for recycling refrigerants.

EXECUTIVE SUMMARY of the CONTROL OPTIONS REPORT
for
RIGID and FLEXIBLE FOAMS

4.2 Introduction

The foam plastics manufacturing industries, the markets their products serve and their use of fully halogenated chlorofluorocarbons (CFCs) is extremely varied. CFCs-11, -12, -113 and -114 are all used to some extent in the manufacture of foam plastic products, which include building and appliance insulation, cushioning foams, packaging materials, flotation devices and shoe soles.

The following summary describes the foam industry, its use of CFCs, technical options available in each foam segment to reduce or eliminate CFCs, and the overall reductions in CFC consumption which can be achieved.

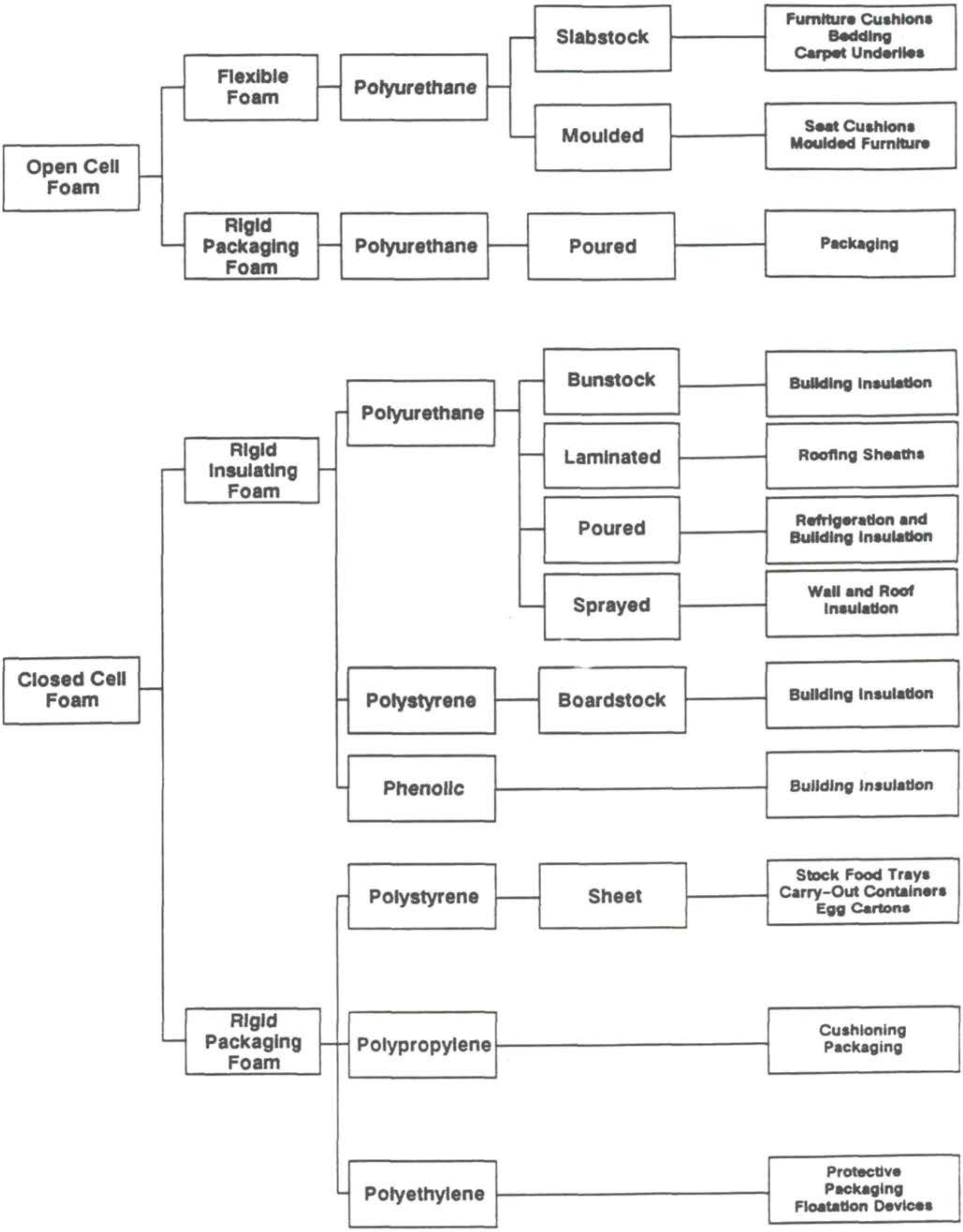
The profiles of technical options are quite different in each foam application and market sector. A few foam industries can reduce CFC usage with minimal cost or energy penalties, whereas other foam subsectors have more limited choices.

Description of the Foam Industry

The foam industry used approximately 267,000 tonnes (metric tons) of CFCs worldwide in 1986. This represents approximately 25-30 percent of the total annual global use of controlled CFCs. The CFCs are used to make products of polyurethane/polyisocyanurate, polystyrene, polyolefin and phenolic plastics that are rigid or flexible. Foams can be classified according to their manufacturing type as thermosets (polyurethanes and phenolics) or thermoplastics (polystyrene and polyolefins) or according to their application/use (Figure 9).

CFCs are used as blowing agents in the foam manufacturing process because they have suitable boiling points and vapour pressures, low toxicity, they are non-flammable, non-reactive, cost effective and have a very low thermal conductivity. In insulating foams, CFCs are retained in the cell structure, giving the foam excellent insulation characteristics. CFCs are commonly used as an auxiliary blowing agent in flexible foams to decrease foam density, and to increase the softness of cushioning foams. For combustion modified high resilience foams, CFCs are needed to obtain necessary physical properties. In flexible and rigid slabstock polyurethane foams, CFCs act to cool the exothermic

Figure 9
Types and Major Uses of CFC-Blown Foam



Source: ICF Incorporated, 1989

reaction that occurs during the production process, thus protecting foam products from scorching.

Technical Options by Foam Type

The technical options for reducing or eliminating CFC use in foam are dependent upon each foam type, since each has a distinct set of process and product application needs. Discussion of options and CFC reductions will be divided into near term (before 1993) and longer term (after 1993). The 1993 time frame was chosen for two reasons:

1. 1993 is the expected availability date for commercialisation of the partially halogenated chlorofluorocarbons (HCFCs), the longer term option for most rigid foam applications.

2. 1993 is the date of the first set of reductions under the current Montreal Protocol.

Reductions of CFC use in foam manufacture can potentially be accomplished in three ways:

1. Substitution with alternative blowing agents for CFCs;

2. Modification of the present process or use of alternative technologies; or

3. Substitution of foams with alternative products.

Table K highlights the technical options under development for each foam segment. The estimated amount of CFC reductions achievable by each foam subsector is also presented.

Scheduled Reductions

In the near term, it is technically feasible to reduce the amount of CFC-11, -12, -113 and -114 used in foam manufacturing by approximately 60 percent (140,000-185,000 tonnes) per annum by 1993. Some foam subsectors can begin to eliminate CFCs from manufacture immediately, including manufacturers of extruded polystyrene foam insulation and packaging, polyethylene foam, some integral skin and miscellaneous polyurethane foam products, moulded flexible foam, and most slabstock foam products. Approximately 30 percent of near term CFC reductions relies on the substitution of currently available HCFCs (HCFC-22 and HCFC-142b) as replacements for CFCs. Globally, it may be possible for manufacturers of rigid polyurethane foam insulation to reduce CFCs by about 30 percent through increased water blowing. The actual percentage, however, will vary between 15 and 50 percent regionally depending upon the type of foam, the application or

TABLE K

Summary of Technical Options Available for CFC Reductions

Type of Foam	Tonnes of CFC Used (1986)	Near Term Options	Possible Global Reductions by 1993	Longer-Term Options	Possible Global Reductions After 1993
Polyurethanes:					
Flexible Slabstock	45,600	New polyol technology Increased Foam density/increase water "AB" technology CFC recovery Methylene chloride Product Substitutes (Fibrefill, latex foam)	80-100%	HCFC-141b	0-20%
Flexible Moulded	13,700	New polyol technology Increased water/ increased densities	80-100%	HCFC-141b HCFC-123	0-20%
Rigid Insulation:					
Appliance	37,200	Increased water substitution	30%[b] (15-50%)	HCFC-141b HCFC-123 Product substitutes Vacuum panel insulation	Remaining CFC use
Laminate	51,000	Increased water substitution Product substitutes (EPS, perlite, fibreboard)	28%[b] (15-50%)	HCFC-141b HCFC-123 Product substitutes	Remaining CFC use
Spray, Slabstock, and Poured-in-place	44,200	Increased water substitution Product substitutes	15-50%	HCFC-141b HCFC-123 Product substitutes	Remaining CFC use

TABLE K (Continued)

Summary of Technical Options Available for CFC Reductions

Type of Foam	Tonnes of CFC Used (1986)	Near Term Options	Possible Global Reductions by 1993	Longer-Term Options	Possible Global Reductions After 1993
Integral Skin and Miscellaneous	17,700	Increased water Total water blowing HCFC-22 Hydrocarbons Methylene chloride Air loading Product Substitutes	50-100%[c/]	HCFC-141b HCFC-123	0-20%
Sub-total Polyurethane	(209,400)				
Phenolic	6,900	Capture/recycle Product substitutes	50%	HCFC-141b HCFC-123	Remaining CFC use
Extruded Polystyrene Sheet	20,000	HCFC-22 Hydrocarbons Blends of these two alone and with other atmospheric gases Product substitutes	100%	HCFC-141b HCFC-123 HCFC-124 HFC-125 HFC-134a Modified resins/ atmospheric gases	N/A
Extruded Polystyrene Boardstock	17,600	HCFC-22 HCFC-142b Hydrocarbons Blends of the above Product Substitutes	100%	HCFC-124 HFC-134a	N/A
Polyolefin	13,000	HCFC-22 HCFC-142b Hydrocarbons (butane) Product Substitutes	100%	HCFC-141b HCFC-123 HCFC-124 HFC-134a	N/A
Total	266,900				

TABLE K (Continued)

Summary of Technical Options Available for CFC Reductions

[a] The actual amount of water substitution possible will vary geographically by 15-50 percent according to the choice of raw materials, initial energy efficiency value of the insulation and energy efficiency standards. The following table illustrates the average reductions expected worldwide:

Region	CFC Consumption (Tonnes)	% Reduction	Total (Tonnes)
N. America	9,400	15-30	1,410-2,820
W. Europe	9,900	50	4,950
Japan	4,700	15	705
Other	13,200	15-30	1,980-3,960
Total	37,200		9,045-12,435

[b] The actual amount of water substitution will vary geographically by 15-50 percent according to the type of facers, polyurethane or polyisocyanurate foam chemistry, energy efficiency, and combustibility requirements.

Region	CFC Consumption (Tonnes)	% Reduction	Total (Tonnes)
N. America	21,700	15	3,255
W. Europe/ Other	29,300	25-50	7,325-14,650
Total	51,000		10,580-17,905

[c] In polyurethane rigid packaging, rigid integral skin, and other miscellaneous polyurethane applications, it is technically possible to reduce CFCs by 80 to 100 percent by 1993. For flexible integral skin foams, the level of CFC reductions worldwide is expected to be around 50 percent.

use of the insulation, the presence of permeable or impermeable facers, combustibility requirements, product quality, the initial energy efficiency value of the foam, and energy efficiency standards.

The world's polystyrene insulation board industry, assuming acceptability of HCFCs, can technically achieve the elimination of the use of CFCs in its products by 1993. This total phase-out is achievable with capital investment and increased cost, whilst the performance of the product, especially long-term insulation performance, remains virtually unchanged.

The world's polystyrene foodservice and packaging industry is also striving for total elimination of CFCs immediately. CFCs have been or are being phased out by foam packaging manufacturers in Australia, Asia, Canada, Europe, Hong Kong, Japan and the Far East, South America, and the United States.

The polyurethane slabstock and moulded cushion foam industries can reduce CFC consumption by 80 to 100 percent by 1993, by using a combination of technical options, including formulation and processing modifications and alternative blowing agents. The ability of the flexible slabstock industry to eliminate its CFC use will vary according to region and will be dependent on the continued acceptability of methylene chloride which has become subject to increasingly stringent local environmental and health regulations.

In polyurethane rigid packaging, rigid integral skin, and other miscellaneous polyurethane applications, it is technically possible to reduce CFCs by 80 to 100 percent by 1993 as well. For flexible integral skin foams, however, the level of CFC reductions will be around 50 percent.

The extruded polyethylene foam industry whose products are used in special insulation and cushioning packaging applications can also achieve a total elimination of CFC use by 1993, by using available HCFCs and hydrocarbons. The same conversion by polypropylene manufacturers may not be possible until a non-flammable alternative to CFC is available.

While the polystyrene, polyethylene and some polyurethane industries can successfully eliminate their dependency on fully halogenated CFCs by 1993, the rigid polyurethane insulation and phenolic industries have more limited near term technical options for CFC reductions.

One option the polyurethane foam insulation industry can implement to achieve immediate CFC reductions is to increase the substitution of water for CFC-11. Water reacts with the isocyanate to generate carbon dioxide as a blowing agent. Variables affecting the substitution of water include the type of foam produced and its intended application, the permeability of any facers attached, energy efficiency requirements and the baseline energy efficiency of the foam, foam density and thickness, choice of raw materials, and combustibility requirements.

In the case of polyurethane insulating foam for appliances, the amount of water substitution will be dependent upon the choice of raw materials, the initial energy efficiency value of the insulation and energy efficiency standards. Structural requirements, foam dimensional stability and foam adhesion to the cabinet and liner are other factors limiting the use of water in the appliance industry. In Europe, appliance manufacturers have achieved reductions in CFC use as high as 50 percent, with a slight energy impact, by adopting new foam technology. In Japan, where new foam technology has already been introduced, appliance manufacturers will only be able to reduce CFC-11 by about 15 percent. In the United States, where strict energy efficiency standards are enforced, the maximum amount of water substitution has been estimated to be up to 30 percent.

The ability to increase the use of water to generate carbon dioxide as a blowing agent in building and industrial insulation applications will also vary. For insulation products like spray foams or slabstock with a permeable facing or unfaced, water substitution is more limited due to gaseous diffusion of carbon dioxide. At most, water could substitute for 25 percent of CFCs for these uses, with no significant change in foam quality. For foam-in-place applications, where the foam insulation is protected by impermeable facings (insulated doors, refrigerated transport, cold storage panels), water substitution could be as high as 50 percent in some applications and regions.

In North America, laminated polyisocyanurate foam boards, used mainly as building insulation, could reduce CFC-11 use by a maximum of 15 percent via reformulation with water-carbon dioxide blowing. These reductions will be achievable without adversely affecting foam properties. In Europe, where most laminated foam products are based on polyurethane chemistry, reductions of 25 to 50 percent may be accomplished through the use of water. In any case, the type of facers (i.e. permeable or impermeable) will greatly affect the level of CFC replacement with water.

Raw material suppliers are also working on developing a foam insulation based solely on water blowing, but the substantial energy efficiency penalties now associated with these will require changes in the product that may not be possible for some applications. Some polyurethane district heating pipe insulation manufacturers have been able to successfully eliminate CFCs from their product. To compensate for energy efficiency losses resulting from the substitution of the CFC blowing agent with water, the thickness of the insulation must be increased to result in a pipe of larger external diameter.

Annual operating costs due to water substitution in the various polyurethane foam insulation products will increase by approximately 5 to 20 percent. The increased cost can be attributed to the need for increased amounts of isocyanate in the formulation. If the thickness of the foam was adjusted to compensate for any effects on energy efficiency, raw material usage will further increase.

The use of water in phenolic foam is not technically possible.

After 1993, the complete elimination of CFCs will be dependent upon the successful commercialisation of the HCFCs, principally HCFC-141b and HCFC-123, but also, HFC-134a, HCFC-124 and others.

One long term option is to develop a total carbon dioxide blown foam used in combination with vacuum panels, an insulation technology currently under development. While extensive research is still necessary to determine a cost effective way to commercialise vacuum panel technology and develop long term panel reliability, such technologies could eliminate CFCs from polyurethane foam insulation and potentially provide significant increases in energy efficiency. Their application has been targeted at appliance applications. There have been attempts in Japan and the U.S. to market appliances using vacuum panel technology, however, problems were experienced with loss of the vacuum as the appliance aged. Further concentrated research efforts are essential to determine the viability of this option.

Issues Affecting the Reduction in CFC Use

The scheduled reductions of CFCs described for the foam plastic industry assumes worldwide availability of substitutes. It also assumes that there will be no future regulations which could restrict the ability of substitutes from being adopted on either a global or regional basis. Issues which could affect the substitution of CFCs include: HCFC availability, product substitutes, energy impacts, and recycling.

HCFC Availability

Research and development conducted by CFC producers, raw material suppliers and foam manufacturers have identified HCFCs, HFCs and other low ozone depleting compounds as longer term solutions in the foam industry. In the near term, it is estimated that slightly more than 30 percent of the achievable reductions in CFCs can be attributed to use of HCFCs (HCFC-22 and HCFC-142b) by the polystyrene, polyethylene and some polyurethane industries.

Factors such as environmental acceptance, favourable toxicity evaluation and eventual commercialisation of HCFCs will dictate the technically feasible schedule for a CFC phase out by the foam industry.

Provided these HCFCs are commercially available, foam manufacturers are expected to be able to begin to eliminate CFCs at the time of their commercialisation, after 1993. Without HCFC and HFC substitution, many subsectors of the foam industry, at this time, have not identified other substitute blowing agents or process modifications for eliminating CFCs.

Product Substitutes

Non-CFC containing product substitutes currently compete in all subsectors of the foam market, with the possible exception of appliance insulation. The appliance manufacturing production system is based on direct automated injection of polyurethane foam raw material into the appliance cabinet, which facilitates the manufacturing process. The foam-in-place technology utilised is a major factor in the structural integrity of the appliance cabinet.

Alternative materials currently are available that provide low density cushioning (natural and synthetic fibre materials), packaging protection and insulation value.

In some uses of flexible slabstock foam, notably the outer layers of furniture cushions and mattress upholstery backing (quilting foam), fibrefill materials such as polyester batting are competitive with flexible foam. These materials have the potential to replace at least some portion of slabstock use, principally the supersoft foams, in response to regulatory and/or economic pressures.

Whilst products such as paper, cardboard and expanded polystyrene can be used in many packaging applications, there are a number of special applications (such as electronic equipment packaging) where protective foam products are the most cost effective choice. Polyurethane, extruded polystyrene and polyolefin packaging materials offer better moisture barrier protection, increased durability and better cushioning protection than more conventional materials.

Foam insulation use in buildings has significantly increased because of its high energy efficiency combined with other physical properties, including excellent combustibility test performance, waterproof characteristics, low density, thin profile and ease of handling. Some polyurethane foam insulation products can be sprayed or poured in-situ. Non-CFC insulation products can achieve some of these properties, but not all. In all instances, the substitution of non-CFC products would require increases in the thickness of the product to provide equivalent energy efficiency.

Building design constraints, local building code requirements, and construction costs dictate the choice of insulation material. Because of these factors, it is difficult to generalise the potential substitution of non-CFC insulation for foam insulations currently containing CFCs. In the majority of instances, there are non-CFC materials available which can provide acceptable performance. For some applications, however, there is no obvious alternative which would not involve considerable changes in design and construction practice. (Curwell, 1988).

Energy Impact

Energy impacts from CFC restrictions could occur in two ways: from use of substitute CFC blowing agents or from use of alternative non-CFC insulation materials. Initial tests indicate that HCFC-141b and HCFC-123 cannot be used as "drop-in" replacements for CFCs in polyurethane insulation foams for a variety of reasons. Research and development work is currently underway by raw material suppliers and foam manufacturers to overcome adverse foam properties which have been detected in trial foam samples containing HCFC-141b and HCFC-123. In particular, a reduction in insulating value has been attributed to the higher thermal conductivity of the HCFCs. There is optimism that reformulation can partially overcome the thermal performance deficiencies, and minimize any energy impact.

However, in extruded polystyrene boardstock production, with process changes and formulation modification, the use of HCFC-142b and mixtures of HCFC-22 and HCFC-142b can provide foam products with equivalent long-term insulation performance. It should be recognised that only HCFC-142b contributes to the long term insulation performance because HCFC-22 readily permeates out of the foam product.

Any worldwide energy impacts from use of non-CFC insulating products will vary by end use application, energy efficiency standards and type of building design. It is not possible to quantify actual global impacts because of the large number of factors involved with choosing different insulating products, as well as the ability and cost-effectiveness of increasing insulation thickness of non-CFC insulation products to compensate for their lower insulating values.

There is a potential to develop and commercialise highly efficient, reliable insulation products in the future. Such products, like vacuum panels, if reliability and commercialisation problems can be overcome, could offer both increased energy efficiency and elimination of CFCs.

Recycling

Capture and recycle of CFC emissions from the manufacturing process may only be technically feasible in flexible slabstock production, where CFC emissions at the pouring conveyor are approximately 40 to 50 percent of the total volume of CFC used. Carbon adsorption technology is available and has been used on both pilot scale tests and full size plant tests. Approximately 40 percent of the CFC emissions have been successfully captured. This technology requires a substantial capital expenditure. Still being evaluated are the questions of carbon bed contamination with isocyanate or other by-products and the regeneration of carbon beds.

In West Germany, there is a programme evaluating the recovery of CFC from foam insulation in refrigerators at disposal. The refrigerator has to be disassembled. CFC is extracted by compressing and breaking up the foam insulation. The CFC is captured and recycled using condensation and carbon adsorption technologies. Further work is needed to evaluate the effectiveness of this program.

The phenolic foam industry in Europe is evaluating the technical feasibility of recycling CFCs from foam scrap. Scrap pieces of boards are compressed and CFCs are captured using small compact carbon adsorption units. It is estimated that between 50 to 80 percent of the CFC from the foam put into the system has been captured. The feasibility of capturing CFCs by this technique is dependent upon the foam scrap rate. Further work is being conducted to evaluate this technical option.

Summary and Conclusions

The foam plastics industry used approximately 267,000 tonnes of CFCs worldwide in 1986. In the near term, it is technically feasible to reduce the amount of CFC-11, -12, -113 and -114 used in foam manufacturing by approximately 60 percent (140,000-185,000 tonnes) per annum by 1993. Some foam subsectors can begin to eliminate CFCs from manufacture immediately, including manufacturers of extruded polystyrene foam insulation and packaging, polyethylene foam, some integral skin and miscellaneous polyurethane foam products, moulded flexible foam, and most slabstock foam products. Approximately 30 percent of near term CFC reductions relies on the substitution of currently available HCFCs (HCFC-22 and HCFC-142b) as replacements for CFCs. Globally, it may be possible for the manufacturers of polyurethane rigid insulating foam to reduce CFCs by about 30 percent through increased water blowing. The actual percentage, however, will vary between 15 and 50 percent regionally depending upon the type of foam, the application or use of the insulation, the presence of permeable or impermeable facers, combustibility requirements, product quality, the initial energy efficiency value of the foam, and energy efficiency standards.

The rate at which near term options can be adopted is dependent upon a number of factors, including the determination of environmental acceptability of the alternatives, sufficient worldwide supplies of the alternative blowing agents, smooth transition to new foam systems utilising alternatives and the suitability of substitutes in all processes and product types.

Reductions in CFCs in the longer term (after 1993) will be dependent upon the availability and cost of the HCFCs. Provided the HCFCs are toxicologically and environmentally acceptable and are commercially available, the foam industry can begin to immediately substitute them for the fully halogenated CFCs currently used.

Under the assumption that HCFCs are available and commercialised around 1993, it is anticipated that a virtual elimination of CFCs worldwide in all foam uses is technically achievable around 1995. Without the HCFCs, many foam manufacturers have few other options, given current technology.

Foam manufacturers, particularly those that produce insulation products, would have to offer a product without CFCs or HCFCs. The product may have poorer physical properties, poorer fire performance properties, higher cost, and poorer insulating value compared to those that used CFCs. It would be difficult for such foam products to be cost-effective in the market with current alternative insulation materials.

EXECUTIVE SUMMARY of the UNEP SOLVENTS TECHNICAL OPTIONS COMMITTEE REPORT for ELECTRONICS, DEGREASING AND DRY CLEANING SOLVENTS

4.3 Introduction

The Montreal Protocol on Substances that Deplete the Ozone Layer restricts the production and consumption of some ozone-depleting chemicals. Chlorofluorocarbon 1,1,2-trichloro-1,2,2-trifluoroethane, commonly referred to as CFC-113, is one of these chemicals. CFC-113 is used widely as a solvent to clean electronics assemblies, delicate instruments and surfaces (defined as precision cleaning applications in this report), and metal parts and surfaces. CFC-113 also is one of the solvents used to clean clothes and other fabrics and materials by the dry cleaning industry. This report discusses the solvent uses of CFC-113 and the feasibility of replacing CFC-113 with alternative cleaning agents or processes to reduce and eventually eliminate the need for CFC-113.

This report also addresses the potential use of 1,1,1-trichloroethane[1] and carbon tetrachloride as substitutes for CFC-113. While technically feasible as a substitute for CFC-113, the use of 1,1,1-trichloroethane already contributes significantly to atmospheric chlorine levels. While this report identifies and evaluates the technical potential of 1,1,1-trichloroethane as a CFC-113 substitute, it also notes the market uncertainty over the international acceptability of 1,1,1-trichloroethane (e.g., whether this chemical will be added to the Montreal Protocol to protect the ozone layer). Because of toxicity and ozone depletion concerns, carbon tetrachloride is not considered an acceptable substitute for CFC-113.

Feasibility of a CFC-113 Phaseout

This report is organised according to the major industry application areas which use CFC-113, 1,1,1-trichloroethane, and carbon tetrachloride as cleaning solvents. For each application area, the UNEP Solvents Review Committee examined the extent of CFC-113 and 1,1,1-trichloroethane use, alternatives, environmental aspects associated with the alternatives, and the extent to which the alternatives can replace CFC-113 and 1,1,1-trichloroethane in solvent cleaning worldwide. The UNEP Solvents Technical Options Committee's consensus is that all CFC-113 use in solvent applications can be phased out by, or before, the year 2000.

---

[1] 1,1,1-Trichloroethane is also referred to as methyl chloroform, TCA, and CH_3CCl_3.

Table L presents the earliest technically feasible reduction schedule for CFC-113 use as a solvent. A complete phaseout of the use of CFC-113 is technically feasible by or before the year 2000. This phaseout would require a combination of options including rationalized cleaning for performance, not cosmetic purpose; no-clean and low-clean solutions such as controlled atmosphere soldering and low solid flux; containment, recovery, and recycle; aqueous and hydrocarbon/surfactant blends; alcohol and petroleum solvents; new HCFC solvents; chlorinated solvents and CFC blends (while available). This phaseout depends upon prompt world-wide response by user and supplier industries, adequate capital, engineering skills, access to accurate information and availability of new technologies.

Industries have already tested the new alternatives but this information is not yet publicly available. Cooperative efforts could quickly verify the performance and economy of new technologies to provide the basis of choices that maintain or improve product quality and durability, preserve capital investment, and are cost effective. Large companies have announced their intentions to lead the phaseout and to share the information they gain through rapid innovation. Small companies will wait for proven technologies that will be made available from their suppliers. There is a substantial opportunity to speed this process by coordinating the needs of small users and the producers of technical options. This would capture economies of scale.

There is no single substitute for all uses of CFC-113. However, every solvent use area has one or more available alternative(s) which can be adopted. In electronics cleaning, precision cleaning, and metal cleaning applications, there are a variety of alternative solvents and processes available that offer cleaning performance equal to, or better than, CFC-113 and that have equivalent net costs. With the freeze on production and subsequent reduction of CFC availability in the Montreal Protocol signatory countries, the price of CFC-113 will increase. This higher price will, consequently, increase the number of alternative solvents and technologies that are cost competitive with CFC-113.

Carbon tetrachloride is technically able to replace CFC-113 in some cleaning applications. However, carbon tetrachloride is toxic and has an ozone depletion potential of 1.1. These concerns make carbon tetrachloride an unacceptable substitute. Furthermore, it is possible that carbon tetrachloride will be added to the list of substances controlled under the Montreal Protocol in 1990. Carbon tetrachloride is not used as a solvent in the United States or Western Europe, because its use is restricted or prohibited as a carcinogen.[2] It is unlikely, therefore, that carbon tetrachloride will be used in these countries in the future. However, carbon tetrachloride is used

---

[2] The U.S. EPA has classified carbon tetrachloride in Category B2 as a "probable human carcinogen."

TABLE L

Technically Feasible Reduction Schedule

	CFC Consumption
1989/1990	50-60%
1991/1992	30-50%
1993/1994	20-40%
1995/1996	10-30%
1997/1998	5-20%
1999/2000	0-10%
2001	0%

NOTE: This schedule assumes that:

- their will be a prompt response by governments, producers and users to the requirements of the protocol;
- adequate engineering skills and information is available to develop application process to evaluate alternatives and to obtain market and regulatory approvals for the use of selected alternatives; and
- adequate capital resources are available to evaluate and procure alternatives and that necessary equipment is commercially available.

as a solvent in other parts of the world. The existing use of carbon tetrachloride as a solvent should be reduced and eliminated because of the compound's carcinogenicity and its high ODP. The Committee does not recommend the use of carbon tetrachloride as a substitute for any cleaning applications discussed in this report.

1,1,1-trichloroethane is also a technically viable substitute in some cleaning applications. It has an ODP of 0.10-0.16 and can be an attractive substitute if it is not regulated under the Montreal Protocol or by national and/or regional legislation. It is technically feasible to freeze or substantially reduce the production and use of 1,1,1-trichloroethane without affecting a timely phaseout of CFC-113.

Some of the HCFC products under development have ODPs similar to 1,1,1-trichloroethane and massive future use of them as a general substitute for CFC-113 may reduce the effect of restrictions; they would be better reserved for applications where there is no other technically feasible substitute.

Other potential solvents, including CFC-112 and CFC-113a, currently are not regulated under the Montreal Protocol but have high ozone depletion potential. CFC-112 and CFC-113a are being marketed as substitutes for CFC-113 despite high ODPs. Parties to the Protocol may want to consider specific measures to anticipate and avoid unwanted development of chemical substitutes that are allowed under the Protocol but are as damaging to the ozone layer as controlled substances.

Environmental Risk of Options is Uncertain

This document is primarily a technical and economic assessment of alternatives to replace the use of CFC-113, 1,1,1-trichloroethane, and carbon tetrachloride used as solvents. It is not a risk assessment and therefore only contains a general description of some of the environmental health and safety issues. The health and environmental effects of these technical options needs further investigation. The UNEP could coordinate and distribute health and environmental studies of the use of cleaning options.

Many of the soils removed by cleaners are themselves toxic. Some commercially available solvents like carbon tetrachloride are generally recognised as toxic while other solvents are suspected but not confirmed as toxic. Other cleaners including aqueous and hydrocarbon/surfactant cleaners may also be hazardous; however, only limited testing of these chemicals has been completed.

Nonetheless, the use of some toxic chemicals is permitted in certain cases by governmental authorities with workplace controls and waste treatment and/or disposal. However, regulatory measures are not available in all locations. In these circumstances it may be prudent to select cleaning options that do not depend on workplace controls and waste treatment.

The carcinogenicity, mutagenicity (genotoxicity), acute, chronic, and developmental toxicity, neurotoxicity, and ecotoxicity of the alternative compounds that could be used in cleaning applications must be evaluated prior to their use. Waste solvent or waste water should be properly treated, disposed of or destroyed to prevent creating new environmental problems in solving concerns about stratospheric ozone depletion.

There are governmental and industry projects underway to study the human health and environmental implications of alternatives and substitutes to CFCs. For example, international manufacturers of new chemical alternatives to CFCs have formed three separate research consortia to conduct toxicity studies on partially-halogenated substitute chemicals (HFCs and HCFCs). The consortia, Program for Alternative Fluorocarbon Toxicity Testing (PAFT-1, -2, and -3) are developing toxicity profiles on HCFC and HFC substitutes with broad commercial potential. Acute toxicity tests will be completed for the PAFT 1 & 2 chemicals by September 1989. The final analysis of these test results will be issued in January 1990. Long term testing (two-year bioassays for these same chemicals) has begun or will soon begin with results of these tests available by 1992-3. Acute and chronic tests, including the two-year bioassay for both methyl chloroform and carbon tetrachloride, have been available for some time.

There is also a consortium called Alternative Fluorocarbon Environmental Acceptability Study (AFEAS) to estimate ozone depletion potential (ODP); to calculate global warming potential (GWP); to study mechanisms for atmospheric decomposition; and to evaluate the atmospheric decomposition products and their potential health and environmental effects. Individual manufacturers are also undertaking toxicity studies of other potential chemical alternatives.

Alternative Solvents and Processes

Major CFC producers have taken steps to provide users with solvent blends that use less CFC-113 in the formulations. Solvent blends using 1,1,1-trichloroethane also are available which technically can be used as substitutes. Low CFC-113 blends, some HCFC blends and 1,1,1-trichloroethane are uncertain long-term substitutes because CFC-113 may be phased out and 1,1,1-trichloroethane may be regulated in the future. Alternatives such as aqueous cleaning, hydrocarbon/surfactant blends (e.g., terpene-based solvents), other organic solvents and blends (e.g., isopropanol), inert gas soldering, and no-clean alternatives are the ozone-safe CFC-113 alternatives. Some of these in use by many companies in the industry applications are discussed in this report. Others, such as HCFCs with relatively low ODPs, are either under development or undergoing toxicity trials. Table M is a list of alternative materials and processes announced to date and their physical/chemical properties, including their ODP values. This list is likely to grow substantially over the next few years. Table N summarises some of the advantages and disadvantages of the CFC-113 alternatives discussed in this report.

TABLE M

Comparison of CFC-113 Solvent Alternatives Considered in the Report*

	Potential CFC-113 Substitutes										
Physical Properties	Pentafluoro-propanol	HCFC-225ca	HCFC-225cb	HCFC-141b/ HCFC-123/ methanol	Carbon Tetrachloride	Isopropanol	1,1,1-Trichloro-ethane	Trichloro-ethylene	Perchloro-ethylene	Methylene Chloride	CFC-113[j]
Ozone Depleting Potential	0	<0.05**	<0.05**	0.08	1.1	0	0.15	0	0	~0	0.8***
Chemical Formula	$CF_3CF_2CH_2OH$	$CF_3CF_2CHCl_2$	$CClF_2CF_2CHClF$	CH_3CCl_2F/ $CHCl_2CF_3$/ CH_3OH	CCl_4	CH_3CH_3CHOH	CH_3CCl_3	$CHClCCl_2$	CCl_2CCl_2	CH_2Cl_2	CCl_2FCClF_2
Molecular Weight	150	202.94	202.94	Not Appl.	153.82	60.09	133.5	131.4	165.9	84.9	187.38
Boiling Point (°C)	81	51.1	56.1	30-32	76.5	82	72-88	86-88	120-122	39.4-40.4	47.6
Density (g/cm^3) @ 25 °C	1.51	1.55	1.56	1.28	1.59	0.787	1.34	1.46	1.62	1.33	1.56
Surface Tension (dyne/cm)	19	16.3	17.7	18.5-19.0	27.0	22.6	25.4	29.3	31.3	N/A	17.3
Kauri Butanol Value	36	34	30	N/A	113	N/A	124	130	91	132	31
Toxicity	Incomplete+	Incomplete+	Incomplete+	Incomplete+	High	Medium	Low	Medium	Medium	Medium	Low
Carcinogenicity	Unknown	Unknown	Unknown	Unknown	Yes	No	Inconclusive[a]	See Note[b]	See Note[c]	See Note[d]	No
VOC[e]	N/A	N/A	N/A	No	N/A	N/A	No[f]	Yes[g]	Yes[h]	No[i]	No
Flash Point (°C)	None	None	None	None	None	12	None	None	None	None	None

* Hydrocarbon/surfactant blends, aqueous cleaners, and no clean technologies are considered viable alternatives to CFC-113 in this report. However, because hydrocarbon/surfactant blends and aqueous cleaners have a large number of formulations, they are not included in this particular table. No-clean technologies are processes rather than materials, and also are not included in this table.

** Manufacturer's estimate.

*** Montreal Protocol Value. The UNEP technical assessment lists a probable range of 0.8 tp 0.9.

\+ Toxicity testing is in progress.

TABLE M

Comparison of CFC-113 Solvent Alternatives Considered in the Report*

[a] Tests concerning the carcinogenicity of 1,1,1-trichloroethane have proven inconclusive (NTP 1984).Table ES-1 (Continued)

[b] The U.S. EPA (1989b) has not formally classified trichloroethylene in Category B2 as a "probable human carcinogen," while the International Agency for Research on Cancer (IARC) has classified this solvent in Group 3, a substance not classifiable as to its carcinogenicity in humans (HSIA 1989c).

[c] The U.S. EPA (1989a) has not formally classified perchloroethylene in Category B2 as a "probable human carcinogen." IARC has classified perchloroethylene in Group 2B as a substance considered "possibly carcinogenic to humans" (HSIA 1989a).

[d] The U.S. EPA (1989b) has classified methylene chloride in Category B2 as a "probable human carcinogen," while IARC has classified methylene chloride in Group 2B as a substance considered "possibly carcinogenic to humans" (HSIA 1989b).

[e] VOC = Volatile Organic Compound. These are constituents that will evaporate at their temperature of use and which, by a photochemical reaction, will cause atmospheric oxygen to be converted into a potential smog-promoting tropospheric ozone, under unfavourable climatic conditions.

[f] 1,1,1-Trichloroethane is exempt from the U.S. EPA classification of VOCs (HSIA 1987).

[g] Trichloroethylene is regulated in the U.S. as a VOC in many states (HSIA 1989c).

[h] Perchloroethylene is regulated in the U.S. as a VOC in most states (HSIA 1989a).

[i] The U.S. EPA has indicated that methylene chloride may be exempted from regulation as a VOC under state regulations (HSIA 1989b).

[j] In addition to the blends containing over 90 percent CFC-113, CFC manufacturers have also introduced "low" CFC-113 blends containing 60 percent to 70 percent CFC-113. These blends are excellent temporary substitutes.

Sources: Asahi Glass 1989; Ashland Chemical 1988; Basu and Bonner 1989; Daikin 1989; HSIA 1989a, 1989b, 1989c, 1987; IPC 1987; NTP 1984; Rodgers 1989; and U.S. EPA 1989a, 1989b.

TABLE N

Advantages and Disadvantages of Alternatives to CFC-113

Alternative	Advantages	Disadvantages
Chlorinated Solvents		
Methylene Chloride	Effective cleaner	Probable carcinogen[a] Waste disposal
Trichloroethylene	Effective cleaner	Probable carcinogen[b] Waste disposal
Perchloroethylene	Effective cleaner	Probable carcinogen[c] Waste disposal
1,1,1-Trichloro-ethane	Effective cleaner	Ozone depleting substance Waste disposal
Aqueous Cleaners	Effective cleaner	Waste disposal, Energy consumption
Water only	No additional chemicals	Limited effectiveness
Hydrocarbon/Surfactant Blends[d]	Effective cleaner	Toxicity uncertain Waste disposal, Combustible[e]
Alcohol	Effective cleaner	Flammable[e] Waste Disposal Fiscal concerns[f]
No-Clean Technologies	Less or no residue to be cleaned	Not yet approved for many applications including military
HCFCs	(Under development)	

[a] The U.S. EPA (1989b) has classified methylene chloride in Category B2 as a "probable human carcinogen," while the International Agency for Research on Cancer (IARC) has classified methylene chloride in Group 2B as a substance considered "possibly carcinogenic to humans" (HSIA 1989b).

[b] The U.S. EPA (1989b) has classified trichloroethylene in Category B2 as a "probable human carcinogen," while the IARC has classified this solvent in Group 3, a substance not classifiable as to its carcinogenicity in humans (HSIA 1989c).

[c] The U.S. EPA (1989a) has classified perchloroethylene in Category B2 as a "probable human carcinogen." IARC has classified perchloroethylene in Group 2B as a substance considered "possibly carcinogenic to humans" (HSIA 1989a).

[d] This includes solvents based on terpenes.

[e] In this report a combustible substance is defined as one which has a flash point under 37.8°C, while a flammable substance is defined as one which has a flash point over 37.8°C.

[f] Some countries impose duties on all alcohols, including methanol, propanols and some butanols, as well as ethanol. Other countries require a license for any still capable of distilling alcohols (Ellis 1989c).

Sources: HSIA 1989a, 1989b, 1989c, 1987.
U.S. EPA 1989a, 1989b.

The Committee believes that companies, as a first step, can implement conservation and recovery practices to decrease CFC-113 consumption. Such steps are important while processes and equipment are modified, redesigned, or other production changes are made to eliminate CFC-113 use altogether. They can improve operating practices, install containment features, and recycle solvent to reduce consumption by up to 50 percent. The further addition of activated carbon adsorption will reduce solvent use by 30 to 40 percent. For one company, the payback period on an activated carbon adsorption system is two years. The use of carbon adsorption systems is optimal only at certain minimum concentrations of solvent in the exhaust stream entering the adsorber. If alternative technologies such as aqueous cleaning, alcohol-based cleaning, inert gas (controlled atmosphere) wave soldering, and low solids-no clean fluxes are adopted, then all uses of CFC-113 in the electronics cleaning, precision cleaning, and metal cleaning application areas can be eliminated. In the dry cleaning industry, which accounts for less than five percent of worldwide CFC-113 use, alternative solvents such as white spirits are commercially available and the HFCs and HCFCs currently under development can be a viable CFC-113 alternatives. These new substitutes are likely to be commercially available in the next three to five years. Each alternative dry cleaning chemical will have to be used according to safety precautions concerning flammability and/or toxicity.

Electronics Cleaning

The electronics industry is the largest worldwide user of CFC-113. An estimated 8.00×10^7 kilograms of CFC-113 were used to remove flux from printed circuit board assemblies[3] in 1986, representing 45 percent of worldwide CFC-113 consumption. Removal of fluxes and flux residues after soldering traditionally has been considered essential for high quality electronic assemblies to ensure electrical performance and adhesion of conformal coatings, to facilitate inspection and electrical testing, and to prevent corrosion and electro-migration. CFC-113 solvents mixed with alcohols have been the solvents of choice for electronics cleaning because they effectively remove flux residues without damaging solvent-sensitive components on the printed circuit board assemblies, are nonflammable, and have low toxicity levels.

An estimated 50 percent of current CFC-113 use in the electronics industry results directly or indirectly from military specifications. Industry experts agree that the use of alternative cleaning processes, such as aqueous cleaning, could increase if military specifications allowed manufacturers to meet performance criteria using a choice of flux and cleaning methods. The U.S. military has agreed to change military specifications based on a joint U.S. Department of Defense, U.S. Environmental

---

[3] A wide variety of products are built with printed circuit board assemblies including computers, satellites, avionics, and home entertainment electronics.

Protection Agency, and U.S. industry benchmark test program currently in progress. The U.K. Ministry of Defence also has pioneered a new flux standard that will allow elimination of CFC use in U.K. military production. In Europe, two cleaning evaluation programmes are also examining alternative electronics cleaning processes. A cooperative government/industry cleanliness and reliability evaluation programme of candidate solvents is also being undertaken in Scandinavia. This programme is evaluating aqueous alcohol and derivatives, chlorinated, and terpene-based alternatives.

Alternative solvents that are demonstrated to clean as well as, or better than, the benchmark cleaning performance of CFC-113 will be accepted as candidate materials by the U.S. military for use in manufacturing military electronics equipment. This change is likely to take effect within the next year. Aqueous cleaning, alcohols and HCFC/alcohol blends, hydrocarbon/surfactant blends (including terpene-based formulations), and chlorinated solvents are effective cleaning alternatives.

Other promising cleaning alternatives include hydrocarbon/surfactant blend-based solvents, including terpenes, and low solids fluxes. Hydrocarbon/ surfactant blend-based solvents work effectively in close geometry spacings and at room or slightly higher temperatures. These solvents remove both polar and non-polar contaminants, and are noncorrosive. The use of low solids fluxes in some applications may eliminate the need for cleaning altogether.

Precision Cleaning and Displacement

A second major use of CFC-113 as a cleaning solvent is in precision cleaning applications and water displacement/drying. Precision cleaning is used to clean delicate instruments and surfaces such as gyroscopes, computer disk drives, miniature bearings, medical equipment and supplies, and optical components. Aqueous cleaning, alcohols and HCFC/alcohol blends, hydrocarbon/surfactant blends (including terpene-based formulations), and chlorinated solvents are effective alternatives. Many alternative techniques are in the testing stage; as research and development increase in this area, use of alternatives could virtually replace CFC-113 use by, or before, the year 2000. Alternatives include alcohols and HCFC/alcohol blends, 1,1,1-trichloroethane and other chlorinated solvents, hydrocarbons, aqueous cleaning processes, and biodegradable solvents.

Metal Cleaning

A third major application area is in metal cleaning applications. CFC-113 use in metal cleaning has grown out of concern about the adverse human health effects of some chlorinated solvents, particularly in the U.S. and Japan. Conservation and recovery practices and the use of other chlorinated solvents can reduce CFC-113 use substantially in the short-term. Additional reductions and elimination of CFC-113 use can be achieved by using a variety of aqueous and semi-aqueous cleaners, and hydrocarbon/surfactant blend cleaners.

Dry Cleaning

The dry cleaning industry is a relatively minor CFC-113 user. There are numerous operating and maintenance procedures that can be implemented to reduce use in existing machines. Alternative solvents have been identified and their use on specific fabric types approved in some countries. White spirits, for example, are an alternative to CFC-113 for cleaning most fabrics. These must be used with caution in industrial facilities, however, due to their flammability. CFC-113 use as a dry cleaning solvent can be reduced further by using 1,1,1-trichloroethane and the HCFC substitutes currently under development. Pentafluoropropanol, HCFC-225ca, and HCFC-225cb are promising alternatives for dry cleaning. CFC-113 use in this area also could be reduced by establishing centralised cleaning facilities at which technical and procedural controls on solvent use could be implemented.

Corporate Positions for Protection of the Ozone Layer

Protection of the stratospheric ozone layer has become an important policy objective for companies that now use CFC-113 solvents. These companies are acting out of concern for the environment and in response to economic incentives (e.g., price increases, chemical shortages, and prudent investment criteria) resulting from national and global regulation. These corporate policies confirm that large markets exist for substitutes and alternatives and reinforce the judgment of the Committee that phaseouts are technically and economically feasible. Many of these corporate policies also offer assistance in technology transfer to developing countries.

Several multinational corporations have announced prompt goals to reduce and eliminate CFC and halon use. In January 1988, AT&T announced a goal to reduce solvent use of CFC-113 by 50 percent by 1991. Sharp Corporation forecasts that they will achieve a 40 percent reduction in solvent use from 1988 levels by the end of this year. Table O presents the Sharp Corporation's CFC phaseout plan. Digital Equipment, Hitachi, Matsushita, NEC, Northern Telecom, Seiko-Epson, Siemens, Toshiba, and other major electronics manufacturers have announced similar policies to reduce the use of CFC-113.

Northern Telecom has established a goal to eliminate CFC-113 and Halon purchases by the end of 1991, and Seiko-Epson has announced their intention to completely phase out all CFC use by 1993. AT&T has a new goal of 1994. In each case, top management was involved in setting this policy. For example, the full board of directors of Seiko-Epson voted on the phaseout policy and appointed a board member who was given primary responsibility to supervise the phaseout.

TABLE O

Measures for Phase Out of CFCs: One Company's Plan

	Montreal Protocol Schedule	Target	Measures for Phase-Out of CFCs by Manufacturing Group							
			TV and Video Systems Group CFC-113	Audio Systems CFC-113	Information Systems CFC-113	Integrated Circuits CFC-113	Electronic Components CFC-113	Appliance Systems		
								CFC-11	CFC-12	CFC-113
1986	Base Year		• Re-use waste solvents • Install solvent recovery systems	• Non-cleaning technology of circuit boards[a]	• Improve cleaning equipment • Non-cleaning technology of circuit boards[a]	• Reduce cleaning processes • Alternatives • Aqueous cleaning	• Alternatives • Reduce exchange frequency • Improve cleaning conditions • Improve cleaning equipment		• Investigate alternatives	• Use alternative substances for wiping
1987	Adoption (Sept.)									
1988										
1989	Freeze at '86 Level	20% Reduction								
1990			• Improve open tray cleaning • Non-cleaning technology of circuit boards	• Improve cleaning equipment • Non-cleaning technology of circuit boards[a]	• Non-cleaning technology of circuit boards[a]	• Add cooling equipment • Non-cleaning technology[a] • Add solvents recovery systems • Improve cleaning equipment • Alternatives • Aqueous cleaning	• Improve cleaning equipment • Adopt new cleaning processes • Reduce exchange frequency • Aqueous cleaning	• Alternatives (50%)	• Alternatives (60%)	• Install solvent recovery equipment
1991										
1992										
1993	20% Reduction	50% Reduction								
1994			• Alternatives	• Non-cleaning technology of circuit boards[b] • Alternatives	• Non-cleaning technology of circuit boards[b] • Alternatives	• Renew equipment • Non-cleaning technology[b] • Alternatives • Improve wire bonding machines	• Switch to isopropyl alcohol • Switch to low solids fluxes • Aqueous cleaning • Alternatives	• Alternatives	• Alternatives	• Alternatives
1995										
1996										
1997										
1998	50% Reduction	Phase-out								
1999										
2000										

[a] Partially substituted.
[b] Fully substituted.

Source: Sharp Corporation 1989.

All the electronics manufacturing companies that met with the Committee are implementing corporate policies to phase out use of CFCs and halons at all their facilities, including facilities in nations not yet party to the Protocol. These policies should reassure developing countries that they will be at the forefront of new technology development and implementation and, furthermore, that corporate financing will be available in their countries.

New corporate and government procurement policies also have begun to discourage purchase of products dependent on CFC-113 use. The U.S. Defense Department, AT&T and Siemens have new policies that set a high priority on ozone layer protection. The U.S. Secretary of Defense has directed U.S. Armed Forces to reduce the use of CFCs and halons as well as to avoid the purchase of products that depend on these chemicals. This policy is primarily in support of environmental protection, but recognises the strategic importance avoiding dependence on chemicals that may be unavailable or expensive. This policy will be implemented through prompt changes in procurement specifications and through other innovative management practices. Because the military is such an important customer and its procurement standards are industry guidelines, new, ozone-safe solvents should be readily available and easier to use because of this policy change.

AT&T recently notified their international suppliers that ozone layer protection was a top corporate priority. AT&T asked their suppliers to notify them of whether their products were made with CFCs and also to identify their proposed actions to eliminate the use of CFCs. Furthermore, AT&T warned suppliers that soon they may have to provide a Supplier Warranty certifying that products sold to AT&T are not made with and do not contain CFCs, and otherwise conform to government requirements established to comply with the Montreal Protocol. This bold announcement puts suppliers on notice that future markets will be dominated by companies that do not use CFCs.

Siemens' production facility in Erlangen, Germany is one of the largest of electronic manufacturing plants in the world, producing goods valued at one billion U.S. dollars annually. Siemens made a corporate decision to replace some CFC-113 solvent cleaning with an alcohol solvent. This decision confronted Siemens with the technical necessity that all circuit board components be compatible with alcohol. Siemens notified all suppliers that the parts they furnished must be fully compatible with alcohol. Due to the enormous amount of business Siemens provides, the suppliers responded promptly. As a result, Siemens has sources to supply every component used in their company with materials compatible with alcohol. Not only was this change important to Siemens' strategy, it is also valuable to smaller manufacturers who can now take advantage of Siemens' initiative and buy alcohol-compatible components.

These phaseout policies by large CFC-113 customers who produce vital computer, communication, and defense products serve as an indicator to other companies that CFC-113 alternatives and substitutes are currently available and that the range of alternatives should continue to increase in the future.

Conclusions

In summary, the Committee has drawn the following conclusions regarding the technically feasible reduction of CFC-113 and 1,1,1-trichloroethane, and carbon tetrachloride use by the year 2000:

- CFC-113 use <u>can</u> be phased out by, or before, the year 2000;
- Inevitable price increases in CFC-113 as production drops may create a <u>de facto</u> situation in which CFC-113 becomes economically less desirable and a more rapid phase out of CFC-113 may occur than is currently foreseen;
- Up to 50 percent of current CFC-113 use can be reduced with minimal net cost; for some users of CFC-113, the addition of activated carbon adsorption systems may reduce solvent use by up to a further 30 to 40 percent with a reasonable payback;
- Opportunities exist for improved cleaning and innovation through the use of substitutes for CFC-113;
- No-clean and aqueous processes as well as alcohol and hydrocarbon/ surfactant blend substitutes are the most promising alternatives;
- A number of multinational and national electronics manufacturers have announced new corporate policies to promptly phase-out CFC use. These efforts will speed development, verification, and commercialisation of new technology and may reduce costs of phase-out.
- New technology currently under development will help smaller companies successfully switch to CFC-113 cleaning alternatives;
- Ozone-depleting HCFCs under development should be continually monitored if they become commercially available in large quantities so that they are reserved for those applications where their special qualities are essential.
- 1,1,1-Trichloroethane will be an attractive substitute for CFC-113 if it is not regulated as an ozone

depleting substance under the Montreal Protocol or by new national and regional regulations;

- Many of the alternatives for CFC-113 also are alternatives to the use of 1,1,1-trichloroethane;
- 1,1,1-Trichloroethane production can be frozen or substantially reduced without affecting a timely phaseout of CFC-113;
- Industry will select alternatives based on the best technology for each application;
- Parties to the Protocol may consider specific measures to anticipate and avoid unwanted development of chemical substitutes that are allowed under the Protocol but are as damaging to the ozone layer as controlled substances. CFC-112 and CFC-113a are two such substances;
- The human health and environmental effects of the alternative compounds that could be used in cleaning applications must be evaluated prior to their use. Waste solvent or waste water should be properly treated, disposed of or destroyed to prevent creating new environmental problems in solving concerns about stratospheric ozone depletion. More evaluation is needed; and
- Workplace controls and effective waste treatment and/or disposal services for certain alternatives may not be available in all locations. In these circumstances it may be prudent to select cleaning options that do not depend on workplace controls and waste treatment.

EXECUTIVE SUMMARY of the TECHNICAL OPTIONS REPORT
for
AEROSOLS, STERILANTS AND MISCELLANEOUS USE of CFCs

4.4 Introduction

CFCs have been used extensively in aerosol products, mainly as a propellant but also as solvents and as the active ingredients in these products. In the mid 1970s the use of CFC-11 and 12 in aerosols accounted for about 60 percent of the total use of these chemicals worldwide. Due to mandatory and voluntary reduction programmes in various countries this use has been substantially reduced. In 1986, aerosol use was still substantial, accounting for some 300,000 tonnes (approximately 27 percent of the total use of controlled CFCs). The reduction in use of CFCs in aerosols has accelerated since that time.

There is a wide variety of alternatives available as substitutes for CFCs in aerosols. The optimal choice depends upon the product under consideration. Each alternative has its own unique set of properties such as solvency, performance characteristics, costs, etc.

Among currently available chemicals, the most commonly used substitutes for CFCs in aerosols are the flammable hydrocarbons propane and butane. The use of flammable chemicals requires that precautionary measures be taken during production, storage and transportation. When used by the general public no special precautions are needed except those noted on the label.

In some countries stringent regulations concerning the handling of flammable products have substantially limited the possibility of using flammable propellants in aerosols. Such legislation is now being reconsidered in some of these countries. On the other hand, some countries require, for safety reasons, that hydrocarbons are "stenched" before shipment -- this makes them unsuitable for aerosol filling purposes unless subsequently purified.

The cost of converting to hydrocarbons depends on whether the plant facilities are already designed for flammable gas filling or need to be retrofitted or relocated. In both developed and developing countries, some smaller filling plants which have operations designed to handle only non-flammable propellants may not have the investment funds or the expertise to change over to explosion proof storage and filling equipment. The hydrocarbon cost per kilogram is, however, substantially lower than that of the CFCs (20-30 percent of the current cost of CFCs). In most cases, a conversion to hydrocarbons will therefore result in a net gain for the producer and a cheaper product for the consumer. The lower cost of hydrocarbons, where suitable supplies of these propellants exist, may be especially important to developing countries.

Other flammable gases, currently with a limited availability, include: dimethyl ether, HCFC-142b and HFC-152a. Because of the higher price of these gases, they are used primarily when their special properties are required.

Currently available non-flammable chemical substitutes include: compressed gases (such as CO_2) and HCFC-22, alone or in certain mixtures. If the product concentrate is flammable, a non-flammable propellant may not yield a non-flammable aerosol.

Compressed gases have at present only a minor share of the market but they have a potential for growth. From a technical perspective, HCFC-22 could probably work well in about 30 percent of the products now using CFCs and marginally in another 15 percent. Because of the much lower price of hydrocarbons, it is unlikely that HCFC-22 would achieve this degree of market penetration.

There are many traditional solvents, including 1,1,1-trichloroethane (methyl chloroform) and methylene chloride, that could be used as a solvent substitute for CFCs in aerosol products, from a technical perspective.

Non-aerosol alternatives can be used to apply or administer products that currently use CFCs. These include: other spray dispensers such as finger pumps, trigge pumps, mechanical pressure dispensers, as well as non-spray methods such as solid sticks, roll-ons, brushes, pads, shakers, powders, etc.

Such future chemicals as HCFC-123, -124, -141b and HFC-134a are considered to be possible substitutes for CFCs in aerosols. However, their high cost will limit application to speciality products.

Within the category of aerosols medical products are recognised as the most difficult to substitute. Substantial reductions can, however, also be made within this category if CFCs are used only where no alternatives exist. Among the medical products inhalant drug products are the most difficult to substitute. New powder administration methods are already on the market and may achieve wider market penetration but will not be suitable for all patients or drug products. Some of the new HCFCs and HFCs may also serve as a substitute in medical products. However, only limited testing has been conducted so far and it is still unclear as to what extent substitution will be possible. All new medical products will need time for extensive testing and approval from the appropriate authorities. A total phaseout of the use of controlled CFCs in medical products worldwide may therefore not be possible until close to the end of the century.

Certain industrial and technical speciality aerosol products, based on the state of technical progress to date, may also have difficulty in substituting the controlled CFCs. The most commonly mentioned products in this category are aerosol sprays used in the manufacture or servicing of electrical or electronic equipment. For these, it may be possible to use HCFC-22 or HFC-134a as a substitute for CFC-12. Alternatives for CFC-113 are separately considered in the UNEP Technical Options Report on Solvents. For other industrial products substitution with hydrocarbons, dimethyl ether, compressed gases, HCFCs or HFCs should be possible; however, flammability risks must be fully considered.

In conclusion, the vast majority of CFCs used in aerosols can be eliminated through chemical or product substitution with existing alternatives.

The majority of aerosol producers are turning to hydrocarbons. This requires time for reformulation, retrofitting and sometimes plant relocation (because of the increased explosion or fire risk associated with the use of certain chemicals). In many countries conversion to non-CFC propellant products is already well under way.

The amount of controlled CFCs currently used in medical products worldwide has been estimated to be 10-12,000 tonnes of which inhalant drug products consume 3-4,000 tonnes. In all likelihood some fraction of this drug related use will likely remain until the second half of the 1990s. It is expected that a proportion of the medical market will be able to convert from CFCs in the short term. Due to the expected growth in demand for medical products, however, no net reduction in their CFC use is foreseen before the second half of the 1990s.

The quantity of CFCs consumed for industrial and technical speciality products in 1986 is thought not to have exceeded 40,000 tonnes worldwide. For these applications, it appears technically feasible to develop substitutes within the next few years. This process is already under way.

By the end of this century, unless the use of hydrocarbons is curtailed, world aerosol use of HCFCs is not expected to exceed 25,000 tonnes per year.

Sterilants

Ethylene oxide (EO) is widely used by medical device manufacturers, contract services and hospitals for gas sterilization of medical equipment and devices. EO has the ability to penetrate a wide variety of packaging materials, which is vital to the handling, storage and transport of products sterilized prior to their use. EO is especially useful for sterilizing heat sensitive products. With recent developments in medical surgery, the quantity of such products has increased dramatically.

EO can be used in pure form or diluted with other gases. EO is toxic, mutagenic, a suspected carcinogen, flammable and explosive. The use of pure EO, therefore requires stringent safety precautions. In order to reduce flammability and explosion risks EO is often diluted with CFC 12 to form a mixture of 12 percent (by weight) EO and 88 percent CFC-12 (commonly known as "12/88").

Another well known diluent for EO is CO_2 used in various proportions. The only commercially available non-flammable mixture with CO_2 is a mixture of 10 percent EO and 90 percent CO_2 (commonly known as "10/90"). This ratio can, however, change during use due to differences in vapour pressure between CO_2 and EO. "10/90" requires equipment tolerating a much higher pressure than a comparable "12/88" process.

CFC Use for Sterilization Worldwide

Methods for sterilizing medical equipment/devices have developed differently in different countries due to codes and regulations on fire protection and occupational safety, liability considerations, local suppliers of sterilization equipment, medical traditions, etc.

The total use of CFC-12 worldwide for sterilization is estimated to be approximately 20-25,000 tonnes. "12/88" is used to some extent in at least 60 countries. The USA accounts for approximately 50 percent of the total use globally, or about 10-12,000 tonnes. 30-40 percent of the use in the USA (about 4,000) tones is used in hospitals. The vast majority of hospitals in the USA use the "12/88" mixture. In Europe, formaldehyde is extensively used instead. Pure EO is also used, in small sterilizers. Several European countries do not use "12/88" at all in hospitals. The pattern differs from country to country.

For non heat-sensitive products, steam sterilization is widely used both in hospitals and by manufacturers because it is non-toxic, economical, safe, and well accepted.

Larger medical device manufacturers and contract sterilization services often prefer to use pure EO for products that cannot withstand steam sterilization instead of "12/88" or "10/90", because of a lower cost. Whenever product compatibility can be achieved industry also favours radiation sterilization techniques, because this process is reliable, simple to control and readily validated. Many materials are, however, damaged when exposed to radiation.

Alternatives to Reduce and Replace Current Use of CFC-12

Most industrial and commercial users of "12/88" could convert to pure EO. Existing "12/88" sterilization chambers can be used. Such a conversion would require extensive retrofitting for safety (including possible relocation within the plant). There will, on the other hand, be cost savings from not having to buy CFC-12 or its potential replacement chemicals. Small and medium size industrial and commercial facilities may, in some cases, prefer to convert to "10/90", because of a lower overall investment cost. It is estimated that half of the "12/88" sterilizers in use today are certified to work at the higher pressure needed for "10/90".

Radiation facilities are costly to build and operate. The percentage of medical products currently being sterilized with "12/88" that could be reformulated to be compatible with radiation is believed to be small. In some instances, however, the costs to convert medical products to be compatible with a radiation sterilizatin process may be less expensive than retrofitting existing facilities.

The main problem is sterilization of heat sensitive medical devices in hospitals. Until recently, medical device manufacturers and users had no reason to avoid dependence on EO and particularly "12/88". Temperature tolerance may be used to separate items to be sterilized. Those devices which tolerate temperatures above 121°C can be steam sterilized. Devices tolerating temperatures above 80°C may be sterilized with formaldehyde. Devices (catheters, some fibre optics, etc.) not tolerant of those temperatures have EO as the only effective, well established sterilant.

Surgical instruments and devices are often prepackaged in trays or sets for specific surgical procedures. Separating devices that can withstand steam sterilization (working at or above 121°C) from heat sensitive items can decrease the number of products to be EO sterilized.

In countries where formaldehyde is accepted, devices that can withstand 80-85°C (or in some countries even lower) can be sterilized with formaldehyde, leaving a small number of devices that require EO sterilization. These can be sterilized either at the hospitals with pure EO in small sterilizers; or, by the manufacturer; or, a third party sterilizing facility.

In countries where formaldehyde is not accepted, as is the case in the USA, the number of devices which need EO sterilization at hospitals precludes the use of small sterilizing units. One choice for these hospitals is to convert to "10/90" sterilization (with adequate training of personnel and proper equipment). This alternative is rejected by some as being a short term solution involving safety risks for personnel and patients or complex logistic problems to deal with single charge cylinders, as well as potential problems with polymerization and product compatibility. Another, rather expensive, alternative is to convert to pure EO with the same type of precautionary measures as those used by manufacturers. A third option, which also can be expensive, is increased use of presterilized disposable devices (moving the sterilization to the manufacturer) or off-site contract sterilization.

One producer has announced his intention to commence commercial distribution of a new mixture of HCFC-substances with EO. Other producers are investigating similar products. These blends are claimed to be suitable as a "drop-in" replacement for "12/88" in existing equipment, and could also be used in "10/90" equipment with minimal changes. Product performance, validation and stability studies have been started. Field tests have been encouraging. Health authority approval procedures will be run in parallel with the construction of the new plant. The substitute is planned to be on the market in the early 1990s, well before 1995. It will cost more than today's price of "12/88" and may be subject to future controls due to the HCFC content.

Add-on engineering systems are available for recycling CFC-12 and EO. These systems require handling of pure EO (with the necessary safety precautions) to replace lost amounts. All of the CFC could be reclaimed using a cryogenic system. This could be cost effective on a large scale.

In conclusion, by using a combination of possibilities the current use of CFC-12 for sterilization can be substantially reduced using existing alternatives and can be phased out not later than 1995, at least in developed countries. In developing countries the substitution will be slower unless special efforts are made.

Co-operative international efforts could also be made to reduce dependence on materials for medical devices that have to be sterilized with EO.

Food Freezants

There are about 30 food freezing plants worldwide which used 3,400 tonnes of CFC-12 in 1986. The USA used about 3,000 tonnes of this total. The process, called "Liquid Freon Freezant (LFF)", is primarily used to freeze seafood, corn-on-the-cob, and to a lesser extent, raspberries. Corn and seafood freezing account for approximately 1,500 tonnes of use each. Most of the equipment was installed before 1974, but has a long expected lifetime. This CFC consumption can be totally eliminated using currently available alternative methods such as cryogenic techniques (LIN), which use liquid nitrogen, and air blast freezing. These methods are competitive for most products, except for some grades of raw shrimp. Many shrimp processors are small enterprises and may have difficulty absorbing the cost of further process development and equipment changeover. New chemicals such as HFC-134a may be usable in modified LFF equipment. This option is very unlikely however, due to the higher costs compared to LIN. In addition, unresolved issues such as the safety approvals for use of HFC-134a in direct contact with food, and potentially adverse public reaction make this option less attractive.

Other Miscellaneous Uses

CFCs are also used for a variety of other miscellaneous uses such as tobacco puffing, fumigation, leak detection and cancer treatment. One use specifically worth mentioning is in relation to laboratory procedures. For example, standard methods for analyzing oil call for either the use of CFCs or the use of carbon tetrachloride. New standard methods are therefore required.

The miscellaneous uses mentioned in this report are believed to consume, on a global basis, only a very small amount of CFCs. However, it is important to be aware of these and other miscellaneous uses when considering controls.

EXECUTIVE SUMMARY of the REPORT
of the
HALONS - TECHNICAL OPTIONS COMMITTEE

4.5 Introduction

Halons are fully halogenated hydrocarbons that exhibit exceptional fire fighting effectiveness. They are electrically nonconductive, dissipate quickly, leave no residue, and have proven remarkably safe for human exposure. This unique combination of properties has led to their selection as the agent of choice for many fire protection situations: computer, communications, and electronic equipment facilities; museums; engine spaces on ships and aircraft; ground protection of aircraft; general office fire protection and industrial applications. Recently, portable fire extinguishers using halons have achieved popularity in some countries for home use.

Annual halon (Group II Substances) consumption, as defined by the Montreal Protocol, is less than 3% of the CFCs'(Group I Substances), however Ozone Depletion Potential (ODP) values are high. Recognizing the environmental threat posed by the halons, this report offers technical options intended to reduce or eliminate dependency on halons. The use of halons as a substitute for other fire protection measures is unacceptable. Social benefit and human safety considerations are considered to be the only justifications to offset the environmental risk associated with halon use.

The Halons - Technical Options Committee recognizes that global halon emissions can be reduced by:

- Restrictions on halon usage to ensure that use is limited to essential applications only;
- Improvements in procedures for servicing halon fire equipment;
- Reduction of unnecessary discharges of fixed halon systems by more stringent requirements for detection and control equipment used with halon fire protection systems;
- Use of alternative, environmentally acceptable simulant gases for testing halon fire protection systems;
- Requirements to manage the existing bank of halons with the eventual re-allocation to most essential applications;

- Development of means to destroy halons that have been contaminated to such an extent that recycle is not possible.

The Halons - Technical Options Committee has sought to quantify the reduction in halon dependency that can be achieved without jeopardizing the provision of necessary fire protection. The majority of our members and technical advisors consider the following as a feasible and achievable schedule, resulting in a complete phase-out:

Year	Halon Consumption[1]
1992	Cap at 1986 level
1995	75% of 1986 level
1997	50% of 1986 level
2000	25% of 1986 level
2005	0% of 1986 level

[1] - As defined by the Montreal Protocol

Two of our members and one of our technical advisors consider the following as feasible and achievable:

Halon 1211 - Possible short term replacement by other existing products (reduction of 50...60 % ? of the usage in 4...5 years). Then phasing out procedure if acceptable substitute (today under study) is available (year 2000 ?).

Halon 1301 - Focusing on the essential use (to be defined) could lead to a reduction in the usage of (30...50 % ?) within (4...5 years?) keeping in mind that phase-out seems difficult to achieve if as stated in this report the "development of replacement agents with the very low toxicity of halon 1301 for use in total flooding systems for occupied enclosures may not be a realistic expectation".

Two other members are of the opinion that:

It is premature to consider quantifiable levels of possible reduced halon availability as more experience is required in working with the proposed alternative measures outlined in the full report. These members support a complete phase-out when viable substitutes become available to the market.

There are three types of halons in general use in the world today, halons 1211, 1301, and 2402. Ozone Depleting Potential (ODP) factors or the three halons identified in Group II of the Montreal Protocol are as follows:

Halon	ODP
1211	3
1301	10
2402	6

The extinguishing mechanism by which the halons extinguish fires is not yet fully understood. However, it is believed that halons interfere with the complex chain reaction that occurs during a fire.

Halon 1301 has a boiling point of -57.75°C and a vapour pressure of approximately 15 Bars at 20°C. As a result, it can be discharged rapidly, mixing with air, to create an extinguishing concentration. Halon 1301 is, therefore best suited for use in total flooding fire protection systems. Most fires extinguished by halon 1301 are put out by a 5% concentration by volume. At this concentration human exposure for up to 10 minutes is generally acceptable. Thus halon 1301 is most often used to protect occupied enclosures that house equipment or property having high value.

Halon 1211 has a boiling point of -3.4°C and a vapour pressure of approximately 2.5 Bars at 20°C. As a result, it can be discharged in the form of a liquid stream. Therefore halon 1211 is suited for use in portable fire extinguishers; by large capacity handline equipment and in local application fire protection systems. Human exposure of up to 4% concentration by volume for one minute has been studied and found to produce minimal, if any, effects on the central nervous system. Nevertheless halon 1211 is not generally used in occupied areas where the resultant residual concentration by volume could exceed 2% by volume if the area or enclosure is normally occupied.

Halon 2402 has a boiling point of 47.3°C. It can be discharged in the form of a liquid stream and is therefore best suited for use as a manually applied fire extinguishant in portable fire extinguishers or hand hose line equipment. Halon 2402 is also used in fire protection systems for specialized applications. Human exposure of 0.2% after two minutes has been found to produce definite central nervous system effects such as dizziness and impaired coordination. Halon 2402 is generally used outdoors.

Current Use

Halon 1301 fixed fire protection systems are typically provided for the protection of computer rooms, tape libraries, telephone exchanges, defense facilities, ship machinery spaces, pipeline pumping stations, aircraft engine nacelles and repositories of cultural heritage. The committee estimates halon 1301 usage as follows:

Electronic Equipment Facilities	65%
Records Storage	5%
Cultural Heritage	5%
Pipeline pumping stations and Other Flammable Liquids Hazards	10%
Aviation	2%
Ships	10%
Miscellaneous	3%

Halon 1211 applications include use in portable fire extinguishers for protection of electronic equipment, important records and cabin protection of aircraft. Handline systems using halon 1211 are used to protect aircraft during ground maintenance operations and for crash rescue purposes. Local application systems have been provided for printing presses used to produce currency or other important documents.

The committee estimates halon 1211 usage as follows:

Transportation (Aviation, Ships and Vehicles)	25%
Electronic Equipment	35%
Other Commercial/Industrial/Institutional	30%
Residential	10%

Halon 2402 is used in portable fire extinguishers, handline equipment and fixed systems. Halon 2402 fixed systems have been used to protect off-road mobile equipment and the seal areas of floating-roof petroleum storage tanks. The committee lacks sufficient data to estimate percent usage of halon 2402.

Total world production and usage for the base year 1986 is estimated (in metric tonnes) as follows:

Halon	1301	1211	2402	Total
Banked	7,000	11,200	850	19,050
Test/Training	1,100	840	20	1,960
Unwted. Disch.	300	140	10	450
Service	900	420	20	1,340
Fires	700	1,400	100	2,200
Total	10,000	14,000	1,000	25,000
% Use	40%	56%	4%	100%

Known Fire Protection Alternatives

The provision of a fire suppression system is only one part of an adequate fire protection scheme for a particular installation or facility. Other fire protection features include, but are not limited to: detection systems; fire resistive enclosures; smoke control systems; manual fire fighting equipment; provision of high ignition resistance, low flammability, cable and wire insulation, furnishings and interior finish, and "smoke resistant" electronics components. The total fire risk of a facility is also reduced by such methods as: redundant facilities, backups of records and other media, proper planning, minimizing of single point failures (relative to the facility mission or objective) and adequate post fire reclamation procedures and contingencies.

Halogenated fire suppression systems have been installed primarily to provide a very high level of property protection with minimal secondary damage and minimal disruption to resumption of operations. This has been accomplished by the actuation of the system at very early stages in the fire development and through the application of a clean agent with development and through the application of a clean agent with minimum secondary damage.

Additional positive aspects of halon 1301 are: low toxicity at typical flame extinction concentrations, low space and weight requirements and electrically non-conductive (hence non damaging to energized electrical and electronic equipment). Halon systems are used to meet very limited and specific property protection objectives.

The requirement for a fire protection system is also driven by the risk posture of the organization. Obviously as the exposure increases, the justification for fire protection increases. Fire loss is very rarely entirely born by the property owner but is spread through the use of insurance. The fire protection cost includes expected losses, installed cost of fire protection systems and maintenance. Most specific fire safety analyses are not quantitative in nature.

In the final analysis the decision is financial but many uses of halons make purely financial decisions very difficult. Military systems and public safety systems (e.g., air traffic control, aircraft avionics, etc.) are especially difficult to evaluate in this way.

For this reason, it is useful to concentrate on the engineering aspects of protecting a particular hazard. That is, assume that a computer room operator has evaluated the fire risk and has decided that a fire suppression system is required, that the fire suppression system must be of low toxicity, cause minimum collateral damage, and that the total direct and indirect fire damage must not exceed one cabinet. In the past, the system of choice would have been a total flooding halon 1301 system. Use of a clean agent is obviously desirable; however, use of a high secondary damage agent results only in increased damage and perhaps increased downtime or business interruption. It is a matter of balancing costs including environmental cost.

More difficult choices lie in the consideration of more toxic fire suppression agents. Suppose that carbon dioxide could be used as a replacement for halon 1301 except for the increased risk of accidental death caused by discharge of the system. How does this risk balance against the fire risk and/or the environmental risk? These are not technical issues - they are political, social and economic questions and to some extent, independent of the desirable features of any particular fire suppression system/agent combination.

The concept of a selection matrix is that the benefits of halon total flooding systems, given in terms of low toxicity, permeability, low space/weight requirements, minimum collateral damage, minimum down time etc., are not equally important in all applications. The primary disadvantage of halon considered in these selection matrices is its environmental risk.

An important consideration is that the system, not the agent, impacts the relative benefits of a particular choice. The system in this context is limited to the fire suppression system. It does not include such important factors as the existence of other fire protection features, the fire hazard, and the risk associated with a particular facility. The full report of the Halons - Technical Options Committee outlines a matrix approach and shows alternative fire protection means reviewed by the committee. The matrix enabling other choices is somewhat driven by the weighting factor assigned to the halons as ozone depleting substances. Other factors in the matrix include: space and weight, secondary damage, direct damage, reliability, downtime and clean-up, tri-dimensional fire suppression capability, use on energized electrical equipment, and installed cost.

Detection systems, halon systems, carbon dioxide systems, dry chemical systems, foam systems and water sprinkler systems are compared in various configurations and combinations.

Halon Emission Reductions

On a weight basis, it is estimated that over 70% of all halons produced annually are banked to provide stand by fire protection. Studies have indicated that less than 10% of annual production are used to extinguish fires. The remaining 20% of annual production is emitted to the atmosphere by test/training procedures, accidental or unwanted discharges or service procedures. These categories of emissions are considered controllable. Major research programs and training programs have been undertaken within the worldwide fire protection community to significantly reduce these emissions.

Research program results indicate that virtually all use of halon 1301 as a test agent can be eliminated by other testing means and/or use of environmentally acceptable simulant testing gases.

Trade associations within the largest user nations have developed training programs and procedures to significantly reduce service related emissions. More efficient training techniques are being developed to reduce training related emissions of halon 1211.

Management of the Banked Halons

The existing bank of halons has been estimated at approximately 150,000 tonnes. This bank can be considered as both an important fire protection asset and an environmental threat.

The quantities of halons banked in extinguishing systems containers, portable extinguishers, and mobile units is greater than the quantities emitted each year for extinguishing fires, discharge testing, training, and unwanted discharges. For the year 1986, an estimated 70% of halon 1301 and 80% of halon 1211 produced were stored in cylinders or containers installed on end-users premises.

Managing this bank at a national level is desirable for the following reasons:

- to recover the highest possible quantities for recycling and reuse in new systems for critical applications.
- to eliminate controllable emissions associated with periodic maintenance of pressure vessels or dismantling of installations.
- to provide a precise means of evaluating the quantities of halons emitted to the atmosphere and to pursue efforts to reduce unnecessary emissions.
- to destroy quantities, in an environmentally acceptable manner, which cannot be recovered due to contamination.

Bank management consists of keeping track of halon quantities identified at each stage: initial fill, installation, recovery, recycle (or destruction) and recharge. This management is possible through the companies which are in charge of these various operations. A national organization would have to be authorized to certify these companies and to centralize the data and information necessary to assume the responsibility of this bank management.

The possibilities of creating a procedure, within individual countries, which is flexible and sufficiently motivating must be analyzed separately for fixed systems and for portable extinguishers.

In the event that replacement agents are developed or other considerations make it necessary, it would be possible to destroy the banked halons by high temperature incineration.

Alternative Agent Research

Halon producers have research programs to examine and develop alternative agents. In the United States, research consortia with the United States Environmental Protection Agency and Department of Defense have been formed as a means to provide further funding, optimize efforts, and hasten the process.

General purpose, "direct" replacements having attributes equal to those of the present halons are unlikely in the foreseeable future. However, clean alternative agents, with lower ODP's for specific uses are a realistic goal, particularly for use in manually applied equipment and local application systems, if trade-off's in fire extinguishment capabilities, toxicity and/or other characteristics are acceptable.

Conclusions

The choice of other means to reduce fire risk to acceptable levels, improved procedures to effectively reduce halon emissions and management of the existing Halon bank are important steps to reduce dependency, achieve conservation and reduce potential ozone destruction. Means to destroy halons at the end of useful life, in the event alternatives are found, or should scientific evidence make it necessary, appear to be relatively simple. However destruction facilities and procedures could require appreciable time to construct and implement. Major programs to develop alternative extinguishing agents have begun. The development of clean agents with high extinguishing capability and low ozone depletion potential appear possible. Human tolerance is of concern and development of replacement agents with the very low toxicity of halon 1301 for use in total flooding systems for occupied enclosures may not be a realistic expectation.

BIBLIOGRAPHY

1) United Nations Environment Programme, Document - UNEP/W.G.172/CRP 9 (Ad Hoc Working Group Meeting - Geneva 27-30 April 1987).

2) Personal communication G.V. Buxton with Dr. Paul A. Cammer, President, Halogenated Solvents Industry Alliance (HSIA).

3) Donald J. Wuebbles, "The relative efficiency of a number of halocarbons for destroying atmospheric ozone". UCID - 18924 (January 1981).

4) Du Pont Canada Ltd., "Fluorocarbon/Ozone Update" (March 1987).

5) Environment Canada National Guidelines for Hazardous Incineration Facilities, Volume I, Design and Operating Criteria (document under preparation).

6) Correspondence from T. David Dougherty, Hazardous Materials Specialist, Western Research, Bow Valley Resource Services Ltd. to Ms. Kathleen Demoissac, Northern Telecom Canada Ltd. Calgary, Alberta, Canada.

7) Douglas G. Cogan, Stones in a Glass House - CFCs and Ozone Depletion, Investor Responsibility Research Center, Washington D.C., 1988.

8) "Strategies to Reduce the Consumption and Emissions of Ozone Depleting Substances", Second Report of the Government/Industry Working Groups, Australian Association of Fluorocarbon Consumers and Manufacturers, March 1989.

9) "Relative Effects on Stratospheric Ozone of Halogenated Methanes and Ethanes of Social and Industrial Interest" Fisher et al, prepublication 4/14/89.

10) "A Review of 1,1,1 Trichloroethane (methyl chloroform)", hand out by Dr. John Mills, ICI Chemicals & Polymers Limited, presented at the third meeting of the Technology Review Panel, Stockholm, Sweden, 7-9 May 1989.

11) "Response to UNEP Technical Review Panel", hand out by Dr. J. Von Schweinechen CEFIC/EFCTC, Stockholm 7-9 May, 1989.

12) "The Occurrence of Chlorinated Solvents in the Environment", Chemistry and Industry, December 15, 1986, prepared by a workshop of the European Chemical Manufacturers Federation (CEFIC).

13) "Use and Substitutes Analysis of Methyl Chloroform", preliminary draft report prepared by ICF Incorporated for USA/EPA.

14) "Technologies for CFC/Halon Destruction", a report by the Radian Corporation prepared for the USA/EPA, April 1989.

15) "Destruction Technologies of CFCs", unpublished interim report of the Chemical Product Council, Ozone Layer Protection Committee, Destruction Technology Subcommittee, Japan (April 1989).

16) Personal memorandum from Farzan Riza, Trish Koman, Mike Barth, ICF Incorporated Re: Carbon Tetrachloride Notebook (March 27, 1989).

17) "Destruction Technologies for Ozone Depleting Halocarbons", unpublished paper by Nimitz and Tapscott, New Mexico Engineering Research Institute, University of New Mexico, (May 1989).

18) "Fluorocarbon/Ozone Update" Du Pont USA Newsletter, July 1988.

19) Telecommunication from Dr. J. von Schweinichen, Montefluous (Italy) to G.V. Buxton, Environment Canada, June 15, 1989.

ISBN 92 807 1247 0