United Nations Environment Programme

Economic Panel Report

Montreal Protocol on Substances that Deplete the Ozone Layer

July 1989

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Final Report

of the

Economic Assessment Panel

August 1989

UNITED NATIONS ENVIRONMENT PROGRAMME

ECONOMIC PANEL REPORT

July 1989

ECONOMIC ASSESSMENT PANEL

NAME	AFFILIATION	COUNTRY
George Strongylis Chairman	Commission of the European Communities	Belgium
Stephen O. Andersen Vice-Chairman	U.S. Environmental Protection Agency	U.S.A.
John Hoffman Vice-Chairman	U.S. Environmental Protection Agency	U.S.A.
Christos Makridis Secretary to Chairman	Commission of the European Communities	Belgium
Stig P. Christensen Consultant to the Panel	COWIconsult	Denmark
Yusuf J. Ahmad	UNEP	Kenya
Alec Bouchitte	B.D.P.A.	U.K.
Daphne Lynn Coleman	Department of Trade and Industry	U.K.
John Corkindale	Department of Economics	U.K.
Stephen DeCanio	University of California	U.S.A.
Pascal Deschamps		France
Huib Jansen	Institute for Environmental Studies	Netherlands
Kazuo Katao	Ministry of International Trade and Industry	Japan
Wiel Klerken	Ministerie Van Economische Zaken	Netherlands
V.P. Kukhar	Ozone Committee	U.S.S.R.
Serge Langdau	Commercial Chemical Branch	Canada
Kai N. Lee	Universtiy of Washington	U.S.A.
Irving Mintzer	World Resources Institute	U.S.A.
Franz Nader	Verband der Chemischen Industrie e.V.	FRG
Gilbert Otieno	Division of Industry	Kenya
Dotun Philips	Nigerian Inst. of Social and Economic Research	Nigeria
Sylvain Rault	Universit de Caen	France
Masahiro Sato	Environmental Science Research Institute Inc.	Japan
Salah El Serafy	World Bank	U.S.A.
Peter Uhlenbrock	Hoechst AG	FRG

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PREFACE

The Montreal Protocol on Substances that Deplete the Ozone Layer entered into force on 1 January 1989. Article 6 of the Protocol: Assessment and Review of Control Measures requires that:

> Beginning in 1990, and at least every four years thereafter, the Parties shall assess the control measures provided for in Article 2 on the basis of available scientific, environmental, technical, and economic information. At least one year before each assessment, the Parties shall convene appropriate panels of experts qualified in the fields mentioned and determine the composition and terms of reference of any such panels. Within one year of being convened, the panels will report their conclusions, through the Secretariat, to the Parties.

On 17-18 October 1988, at The Hague, Netherlands, in compliance with Article 6 and in anticipation of the coming into force of the Protocol, an Ad Hoc Working Group of Legal and Technical Experts for the Harmonization of Data on Production, Imports, and Exports of Substances that Deplete the Ozone Layer established four review panels and outlined their terms of reference and timetables for completing reviews of available scientific, environmental, technical, and economic information. This process was approved by the Parties to the Protocol at their first meeting in Helsinki, Finland, on 2-5 May 1989. The Parties also confirmed UNEP as the Secretariat for the Vienna Convention for the Protection of the Ozone Layer and its Montreal Protocol.

This is the report of the Economic Assessment Panel chaired by Mr. George Strongylis (on the behalf of the European Economic Community) and co-chaired by Dr. Stephen O. Andersen and Mr. John Hoffman (on behalf of the United States of America). Twenty-four experts from 12 countries prepared the report, and it was peer reviewed by 25 experts from 18 countries.

CHAPTER 1

INTRODUCTION

The Montreal Protocol on Substances that Deplete the Ozone Layer incorporates a procedure to review and possibly amend its control measures. 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 Protocol was signed in Montreal on 16 September 1987 and entered into force on 1 January 1989.

This report is an economic evaluation of the Montreal Protocol prepared by international economic experts on the Economic Assessment Panel.

The terms of reference for the Economic Assessment Panel were determined during the Science Review Meeting and the Technical Workshop convened by UNEP at The Hague, the Netherlands, in October 1988. This report assembles available information on the economic costs and benefits of the Protocol measures. This information will help guide the revision of the Protocol envisaged for early 1990.

The first Conference of the Parties to the Protocol at Helsinki in May 1989 confirmed the membership and terms of reference of the Panel.

The Panel was chaired by George Strongylis of the European Community and had two Vice-Chairpersons, Stephen Andersen, U.S.A, responsible for coordination with the Technical Panel, and John Hoffman, U.S.A., responsible for coordination with the Environmental Effects Panel. The list of members of the Panel is in Appendix I. UNEP and the chairpersons contacted many countries on several different occasions and encouraged them to send experts to the Panel in order to obtain the widest possible international participation.

The Panel met three times: 7 March 1989 in Brussels, Belgium, 21-22 April 1989 in Washington D.C., U.S.A., and 29-30 May 1989 in Tokyo, Japan.

The Panel report presents historic and current production and consumption patterns and trends of the relevant chemicals affecting the ozone layer. It discusses a framework for a global and national benefit-cost analysis and its limitations, and it reviews the present and expected future technical possibilities for substitution of CFCs and halons in each application area.

1.1 ORGANIZATION OF THE REPORT

The report contains eight chapters. Chapter 1 contains an introduction discussing the organization of the report and some of its key findings. Chapter 2 presents historic and current production and consumption patterns and trends of chemicals depleting the ozone layer.

Chapter 3 discusses a framework for a global and national benefit-cost analysis and its limitations. It also reviews country studies for the U.S.A., the Nordic countries, and the Netherlands.

Chapter 4 reviews the present and expected future technical alternatives and substitutes for CFCs and halons in each application area. Information from the Technical Options Reports and the Technology Assessment is reviewed for its:

- availability and expected market potential,
- potential for reducing CFC/halon use, and
- energy efficiency and costs.

Furthermore, the chapter presents some example calculations in the refrigeration and solvents areas that indicate the order of magnitude of the costs of replacing CFCs.

The benefits of avoiding ozone depletion are analyzed in Chapter 5. The chapter summarizes the environmental and health effects expected from increased ultraviolet radiation. The problems associated with uncertainties of the scientific "dose-response functions" and the difficulties of quantifying the benefits are discussed. Some estimates made in Japan are also included.

Chapter 6 discusses the issue of technology transfer, which is important to consumer nations and especially to developing countries.

Chapter 7 includes a review of industry policies around the world as they were known as of June 1989.

Chapter 8 summarizes all the findings of the Economic Review Panel. The principle under which the Panel has operated has been that of consensus on all issues brought before it. In their deliberations the Panel members have sought to act as the representatives of all the countries that could not participate directly in the review.

1.2 CONSUMPTION OF CFCS AND HALONS

In the absence of regulation such as the Montreal Protocol, demand for products and services based on CFCs and halons would continue to grow, especially in developing countries.

North America, Europe, and Japan are responsible for about 80 percent of total consumption of controlled chemicals. The per capita consumption in developed economies is in many cases more than 10 times the per capita consumption in the developing nations.

1.3 ASSESSMENT FRAMEWORK

There are significant health, agricultural, productivity, and environmental benefits arising from the elimination of CFC and halon emissions. However, only very few of these benefits can be quantified in economic terms.

Assessments of the costs of reducing or eliminating CFCs and halons must consider a variety of factors. These include capital costs, research and development costs, operational costs (such as energy and labour costs), and safety and toxicity risks.

Differences in stages of national development and in the extent of development of CFC and halon producing and using industries from country to country result in very different transition costs for each country.

The development of new options for replacing CFCs and halons is progressing very rapidly. A static cost analysis based on current knowledge therefore might overestimate the costs and underestimate the reduction in use achievable in the transition to CFC-free technologies.

Several national studies have been conducted and these have concluded that substantial reductions of CFC and halon use are technically and economically feasible. These studies estimate that the benefits realized from avoiding ozone depletion will be higher than the associated costs.

1.4 THE COSTS OF TECHNICAL SUBSTITUTION

With the exception of some foam products, CFCs and halons constitute only a small part of the final consumer price.

Technical options to phase out production and use of CFCs within the next 10 to 15 years and to phase down the production and use of halons have been identified by the UNEP Technical Panel. The Technical Options Reports estimate the approximate costs and the eventual problems of transition to CFC- and halon-free technologies for each application. Detailed estimates of the changeover costs, however, cannot at present be made for many potential options. Consequently, global cost estimates are difficult to make with accuracy.

Different technical options will be available in the short, medium, and long term. The actual costs of each of these options will depend on the outcome of technical development and the speed with which the options are adopted.

Analysis of options in the domestic refrigerator sector demonstrates that the costs of reducing CFC and halon use vary greatly. Net costs increase if less energy-efficient options are selected, while net cost savings can be achieved if the most energy-saving options are selected. The ability to achieve maximum energy and cost savings will depend on the resources and the time available to review and test options and redesign products.

An example of a solvent replacement option demonstrates that some technical options are interdependent in implementation. This means that a technical option that is cost effective when used alone may not be economically justified when other technical changes are undertaken.

There has been a rapid increase in the availability of technologies to reduce CFC and halon use. These new technologies have generally lower costs and increase the capability to reduce total use.

The total costs for the world of reducing or phasing out CFCs and halons cannot be precisely estimated at this time. However, current evidence suggests that net costs for the first 50 percent of the global reduction will be low. Cost estimates for the remaining reduction -- mainly in the fields of industrial refrigeration, rigid foam, solvents and halons -- vary widely and depend mainly on the availability of drop-in substitutes, re-engineering costs of equipment and products, and the (higher) price and energy efficiency of the substitutes.

The time-path for phasing out CFCs is critical with respect to costs. A too rapid transition may raise costs due to capital abandonment. Individual governments and industries face significant opportunities to save money if the best reduction strategy is chosen.

1.5 ECONOMIC/ENVIRONMENTAL BENEFITS OF REDUCED CFC/HALON USE

Reducing the use of CFCs and halons could have enormous beneficial impacts on human health and the environment. In many instances, the current state of scientific knowledge makes it very difficult to quantify the magnitude of many of these impacts. Nevertheless, mounting scientific evidence predicts that stratospheric ozone depletion will cause increased levels of skin cancer, cataracts, immune suppression and other adverse health effects, as well as adverse effects on plants and animals.

In attempting to value these impacts there are many issues associated with proper valuation procedures varying from one region of the world to another and between people alive today and generations to come. These issues make it inherently difficult, if not impossible, to assign a monetary worth to the harmful impacts avoided as a result of reduced CFC and halon use.

Notwithstanding the problems of quantifying the benefits, the basic conclusion is that the monetary value of the benefits is undoubtedly much greater than the costs of CFC and halon reductions. However, some developing nations may not have sufficient resources to make the change to new ozone-safe technologies or may have other economic, environmental, or human health concerns that are more immediate and pressing than protection of the ozone layer.

1.6 TECHNOLOGY TRANSFER

Global diffusion of CFC and halon replacement technology (including recovery and recycling) is crucial for protecting the ozone layer and is in the interests of both developed and developing countries alike.

Priority should be given to reducing demand by CFC/halon-using industries. This can be accomplished in many ways, for example, through a tax on production or use, restrictions on productions, public education, or regulation of the use of CFCs and halons.

Developed countries may also assist in activities to educate people on the importance of ozone layer protection and may provide information to guide industries toward phase-out of CFCs. Current information and financial resources of developing countries are inadequate for adoption of CFC replacement technologies and for defining and implementing the national options for the transition to CFC-free technologies.

Some CFC replacement technologies will be adopted in the usual course of economic growth but at a slow rate. Development assistance will be required in other cases. Means are needed to implement the Montreal Protocol commitment to prevent the transfer of discarded CFC/halon-producing and CFC/halon-using technologies to developing countries.

Developed countries that have signed the Protocol may choose different methods to financially assist developing countries. These methods vary, from increasing overseas development assistance, to raising funds by charging for CFC use or contributing a small percentage of their GNP as a contribution to an international fund. Substantial financing can be generated using any of these techniques. These arrangements can be bilateral or as a contribution to an international fund.

Multilateral development institutions, which include organizations such as the World Bank, the Inter-American Development Bank, the Asian Development Bank, and the African Development Bank, can, by virtue of their development activities and established connections with developing countries, play a crucial role in facilitating the transfer of technology needed during the transition period. Special funding mechanisms or arrangements are needed for this purpose because currently available resources are already strained as a result of the world debt problem and the dire economic situation of many countries. Such institutions should be urged to develop internal guidelines in support of explicit policies to facilitate the implementation of the Montreal Protocol.

MEMBERS OF THE ECONOMIC ASSESSMENT PANEL

George Strongylis, Chairman Commission of the European Communities	Belgium
Stephen O. Andersen, Vice-Chairman U.S. Environmental Protection Agency	U.S.A.
John Hoffman, Vice-Chairman U.S. Environmental Protection Agency	U.S.A.
Christos Makridis, Secretary to Chairman Commission of the European Communities	Belgium
Stig P. Christensen, Consultant to the Panel COWIconsult	Denmark

MEMBERS

Yusuf J. Ahmad UNEP	Kenya
Alec Bouchitte B.D.P.A.	France
Daphne Lynn Coleman Department of Trade and Industry	U.K.
John Corkindale Department of Economics	U.K.
Stephen DeCanio University of California	U.S.A.
Pascal Deschamps	France
Huib Jansen Institute for Environmental Studies	Netherlands
Kazuo Katao Ministry of International Trade and Industry	Japan
Wiel Klerken Ministerie van Economische Zaken	Netherlands
V.P. Kukhar Executive Secretary, Ozone Committee	U.S.S.R.
Serge Langdau Commercial Chemical Branch	Canada

MEMBERS OF THE ECONOMIC ASSESSMENT PANEL
(Continued)

MEMBERS (Continued)

Kai N. Lee University of Washington	U.S.A.
Irving Mintzer World Resources Institute	U.S.A.
Franz Nader Verband der Chemischen Industrie e.V.	FRG
Gilbert Otieno Division of Industry	Kenya
Dotun Philips Nigerian Inst. of Social and Economic Research	Nigeria
Sylvain Rault Universit de Caen	France
Masahiro Sato Environmental Science Research Institute Inc.	Japan
Salah El Serafy World Bank	U.S.A.
Peter Uhlenbrock Hoechst AG	FRG

OBSERVERS

John Mills ICI	U.K.
Joachim Von Schweinichen Montefluos S.p.A.	Italy

CHAPTER 2

CONSUMPTION OF CFCs AND HALONS

2.1 INTRODUCTION

Chlorofluorocarbons (CFCs) are chemical compounds derived from the simple hydrocarbons (methane, ethane, etc.) by substitution of halogen atoms for hydrogen. The chemicals have been known since the 1890s, but significant use began in the 1930s. Since then the use of CFCs has increased rapidly in a growing number of applications. The CFCs have been an effective, non-toxic, non-flammable, and inexpensive production input in refrigeration, aerosols, foams and other products.

In 1974 a theory of ozone depletion was presented, which stated that CFCs would diffuse into the stratosphere where they would be broken down by photolysis to release chlorine atoms which would catalytically destroy ozone. There is now an international consensus that CFCs play the decisive role in the Antarctic ozone "hole" and the decline in stratospheric ozone observed for the rest of the world. A reduction in the ozone layer will allow a higher quantity of the harmful UV_b radiation from the sun to pass through the stratosphere and reach the earth. An additional effect from the atmospheric release of CFCs, halons, and fluorinated compounds is their potential to absorb infrared radiation and contribute to the wider problem of global warming.

In 1981 the United Nations Environment Programme (UNEP) Governing Council passed a resolution requiring the Executive Director to set up a working party to draft a "Convention for the Protection of the Ozone Layer." The convention was finalized and adopted in 1986 in Vienna and entered into force in 1988. Parallel to the work on the Vienna Convention, deliberations on a protocol to enforce control measures were initiated in 1984. The Montreal Protocol was finalized and approved in Montreal in September 1987 and entered into force in January 1989.

Section 2.2 presents the Montreal Protocol in terms of consumption coverage, substances regulated and the specific regulations imposed by the Protocol. Trends in the consumption of CFCs and halons are reviewed in Section 2.3 along with the regional distribution of the consumption and the major applications for the substances.

Section 2.3 also describes the relationship between CFC and halon consumption and the pace of the atmospheric release of the CFC and halon compounds. Finally, Section 2.4 contains a general assessment of the economic importance of CFCs and halons as production inputs and the trend in the markets for the major applications.

Statistics on the production, trade, and consumption of CFCs and halons on a world scale are incomplete. The most reliable statistics are supplied for CFCs -11 and -12 by world producers through the U.S. Chemical Manufacturers

Association (CMA), though excluding centralized economy countries, and for CFCs -11, -12, -113, -114, and -115 by the EEC Producers through EFCTC published by the EEC Commission. Data from a number of sources, therefore, have been combined to produce estimates for the presentation in this chapter.

2.2 THE MONTREAL PROTOCOL

Consumption Coverage

The Montreal Protocol specifies a reduction in the production and consumption of the five most important CFCs and a freeze on the production and consumption of the three major halons.

Thirty-six countries, which together account for around 80 percent of the global consumption of the regulated CFCs and halons, have now ratified the Protocol.

The Protocol's coverage is most extensive in North America and Europe (including USSR) where most countries have joined the Protocol. Outside North America and Europe relatively few countries have yet ratified the Protocol. Two countries have joined the Protocol in Latin America, four in Africa, two in Asia and one in the Oceanic region.

The 20 percent of the world consumption of CFCs and halons which is not covered by the Protocol is mainly consumption in the newly industrialized countries and other developing countries. As of June 30, Australia, Austria, Belgium, Canada, Denmark, Egypt, Finland, France, German Dem. Rep., Germany, Fed. Rep., Ghana, Greece, Hungary, Ireland, Italy, Japan, Jordan, Kenya, Liechtenstein, Luxembourg, Maldives, Malta, Mexico, Netherlands, New Zealand, Nigeria, Norway, Panama, Portugal, Singapore, Spain, Sweden, Switzerland, Thailand, Uganda, USSR (including Ukraine and Byelorussia), United Kingdom, United States, and Venezuela have ratified, and Argentina, Burkina Faso, Chile, Congo, Indonesia, Israel, Morocco, Philippines, Senegal, and Togo have signed but not yet ratified.

Substances Regulated

Five CFCs and three halons are regulated by the Montreal Protocol. The ozone-depleting potential (ODP) and global warming potential (GWP) of the individual substances vary. The relative ODP and relative GWP of the controlled substances have been established at the levels shown in Table 2-1, where the ODP and GWP of CFC-11 equal 1.00.

The Protocol Regulations

Ratification of the Protocol places an obligation on each of the Parties (individual countries or communities) to reduce CFC consumption to the 1986-level in July 1989, to 80 percent of the 1986-level by July 1993, and to 50 percent of the 1986-level of consumption by July 1998. Developing countries having a per capita consumption of the controlled substances of less than 0.3 kilogrammes may delay reductions in use to satisfy basic domestic needs for 10 years.

Table 2-1. ODP and GWP of Controlled Substances

Compound[a]	ODP (Montreal Protocol)	GWP (CFC-11=1)
CFC-11	1.00	1.0
CFC-12	1.00	2.8-3.0
CFC-113	0.80	1.3-1.4
CFC-114	1.00	3.7-4.1
CFC-115	0.60	7.4-7.6
Halon 1211	3.00	-
Halon 1301	10.00	-
Halon 2402	b)	-

a) A large number of substances not controlled by the Montreal Protocol also deplete the ozone layer and contribute to the global warming, including 1,1,1-trichloroethane and CCl_4. Relative ODPs and GWPs of these substances are shown in Table 2-2.

b) Not yet determined.

Source: UNEP, Technology Review Panel, Draft Report, 1989.

Table 2-2. ODP and GWP of Non-Controlled Substances

Compound	ODP	GWP
Other CFCs[a]	0.45-0.96	-[g]
HCFCs[b]	0.03-0.1	0.017-0.65
Methyl Chloroform	0.10-0.16	0.022-0.026
Carbon Tetrachloride[c]	1.0 -1.2	0.34 -0.35
Other HCs[d]	-[g]	-[g]
HFCs[e]	0.00	0.026-0.76
FCs[f]	0.00	-[g]

[a] Fully halogenated chlorofluorocarbons; none are in commercial production.

[b] Partially halogenated chlorofluorocarbons.

[c] Also used in the production of CFC-11/12.

[d] Includes chloroform, methylene chloride, methyl chloride, perchloroethane, pentachloroethane, perchloroethylene, acetylene tetrachloride, ethylene chloride and ethyl chloride.

[e] Halocarbons with no chlorine.

[f] Fluorocarbons; the only FC in commercial production is CF_4 (carbon tetrafluoride).

[g] Not yet determined.

Source: UNEP, Technology Review Panel, Draft Report, 1989.

The regulatory impact of the Protocol on the world CFC consumption is illustrated in Figure 2-1. It is assumed that a continued growth in global CFC consumption would have taken place without the Protocol and that all nations will participate in the Protocol.

Protocol parties have agreed to limit consumption of halons to the calculated 1986 level after January 1992.

The ODP-weighted consumption of CFCs and halons is calculated as the sum of the quantity of each of the controlled substances multiplied by its ozone-depleting potential. Consumption of the substances in each group is further defined as production, minus destruction, plus import, minus export. However, after January 1993, exports to non-parties may no longer be subtracted in the calculated consumption level.

For parties producing regulated CFCs and halons, the Protocol establishes a parallel reduction in production level but allows a 10 percent increase over the 1986 production level until July 1993 to satisfy the basic domestic needs of the developing countries and for the purpose of industrial rationalization between parties. Similarly, the 80 percent CFC production may be exceeded by 10 percent from July 1993 to July 1998; after 1998, the 50 percent CFC production may be exceeded by 15 percent.

Parties not qualified as low-use developing countries may increase their 1986 calculated production level if new plants have been documented in national plans and contracted for before September 1987. Such plants must be completed by December 1990, and the additional production may not raise the party's annual consumption of the controlled substances above 0.5 kilogramme per capita.

If a party has annual production of CFCs below 25,000 tonnes per year, it may transfer its production rights to any other party and then import the chemical.

In addition to the regulation of consumption and production of CFCs and halons, the Protocol also imposes control on trade with non-parties. After January 1990, each party will ban the import of controlled substances from non-parties. After January 1993 parties are not allowed to export any controlled substances to non-parties.

Before January 1992 the parties shall establish a list of products containing controlled substances, and within the following year ban the import of those products from non-parties. The Protocol also urges the parties to determine before January 1994 the feasibility of import control measures for products produced with, but not containing, controlled substances. The Protocol also discourages parties from transferring technology for production and utilization of controlled substances to non-parties.

2.3 WORLD CONSUMPTION

Table 2-3 shows the estimated world consumption of the controlled CFCs and halons and the three major non-controlled substances that have an ozone-depleting potential. The parties to the Montreal Protocol report annual

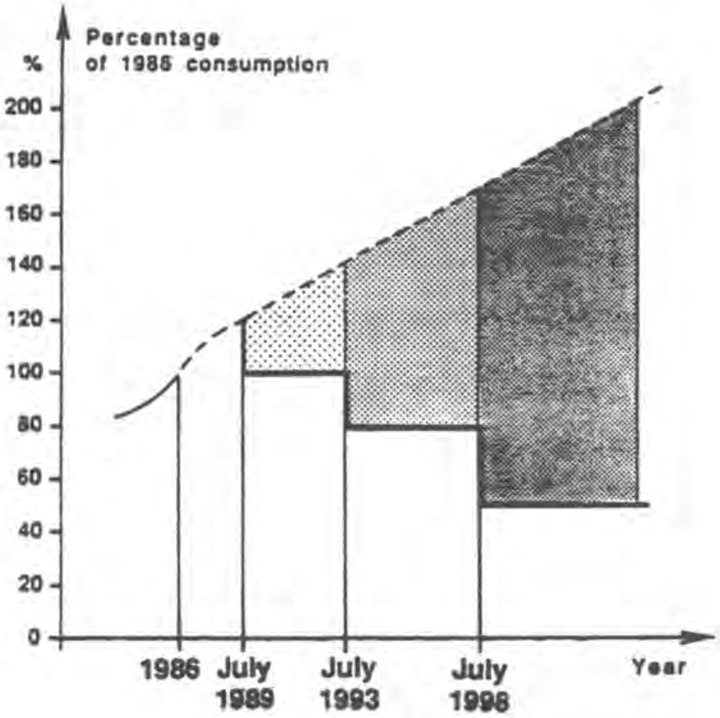

Figure 2-1. Illustration of the Montreal Protocol's Regulation of the CFC Consumption

Table 2-3. Estimated World Consumption of Substances with an Ozone Depleting Potential, 1986

Compound	Consumption Tonnes	ODP-Weighted Tonnes	Percent
Controlled			
CFC-11	411,000[a)]	411,000	33.0
CFC-12	487,000[b)]	487,000	40.0
CFC-113	182,000	146,000	12.0
CFC-114	15,000	12,000	1.0
CFC-115	15,000	6,000	0.5
Halon 1211	18,000	54,000	4.0
Halon 1301	11,000	110,000	9.0
Halon 2402	1,000	6,000	0.5
TOTAL	1,140,000	1,232,000	100.0
Non-Controlled			
HCFC-22	140,000[c)]	7,000	
Methyl Chloroform	609,000[c)]	81,000	
Carbon Tetrachloride	1,116,000[d)]	21,000[e)]	

On world scale annual production is assumed to equal annual consumption (no change in stocks).

[a)] CMA production reported at 350,000 tonnes. The production of other nations is estimated at 61,000 tonnes.

[b)] CMA production reported at 398,000 tonnes. The production of other nations is estimated at 89,000 tonnes.

[c)] UNEP, Technology Review Panel Report, 1989. This estimate is probably low since the U.S.A. alone produced 122,700 tonnes in 1986.

[d)] Carbon tetrachloride is used as a production input in the manufacturing of CFC-11 and CFC-12. This application has been estimated to account for some 1,097,000 tonnes (technical conversion factors are 1.138 for CFC-11 and 1.293 for CFC-12). Based on the EC share of carbon tetrachloride used as solvent (8,000-10,000 tonnes; 1.7 percent of total production) world solvent application was estimated by the Economics Panel at 19,000 tonnes, but CEFIC estimates that total world use is much higher than this, particularly in Eastern Europe.

[e)] Estimated only for solvent application (see note d above).

production and consumption data to UNEP. The Chemical Manufacturers Association (CMA)[1] and the Commission of the EC are also important sources of data on production and consumption of CFCs and halons.

Among the controlled substances CFC-11 and CFC-12 together account for 73 percent of the total ozone-depleting potential of these substances. The world consumption of halons represents around 14 percent of the ozone-depleting potential of all the controlled substances. CFC-113 consumption represents 12 percent of the total ODP.

Figure 2-2 shows the estimated world consumption of CFC-11 and 12 from 1971 to 1987 (CMA figures). World consumption of CFC-11 and CFC-12 peaked in 1974 when production in the CMA countries reached some 813,000 tonnes of CFC-11 and CFC-12. After 1974 consumption declined to a level of 600,000 tonnes in 1982. This represents a reduction of more than 25 percent compared with the 1974 production level. Production grew after 1982 and probably exceeded 1974 production in 1988 and 1989.

The reduction in the consumption of CFC-11 and CFC-12 between 1974 and 1982 was brought about by regulations on the use of CFCs in aerosols in the U.S., the Nordic Countries, and the EC, by a global slow down in economic growth, and by changes in consumer preferences.

Regional Consumption

There are limited data on the consumption of CFCs and halons on a regional basis. Table 2-4 presents an estimated regional distribution of the total world production of CFCs and halons in 1986. Table 2-4 shows that around 37 percent of total CFC/halon production takes place in Western Europe. Twenty-nine percent of total world production is located in USA and Canada. Eastern Europe and USSR produce some 12 percent of total world production. Asia, Pacific and Latin America combined account for 22 percent of the total CFC/halon production.

Because CFCs are traded, production data in Table 2-4 is not the same as consumption data in Figure 2-3. It is known that West Europe and North America are net exporters of CFCs and halons; East Europe and "Other countries" are net importers. Data on CFC-11/CFC-12 exports are limited, but EEC statistics collected by EFCTC for 1986 give 134,309 tonnes of exports from EEC to non-EEC countries. This suggests a total world export of some 150,000 tonnes, of which the EC countries account for some 110,000 tonnes.

Since 1982 the consumption of CFC-11 and CFC-12 has increased rapidly, and by 1987 total consumption had again reached the level of the 1974-peak of more than 800,000 tonnes. The areas of growth in consumption have been rigid foam and refrigeration.

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[1] The companies reporting to CMA cover the following countries: Argentina, Australia, Brazil, Canada, England, France, F.R. Germany, Greece, Holland, India, Italy, Japan, Mexico, Netherlands, Spain, USA, and Venezuela.

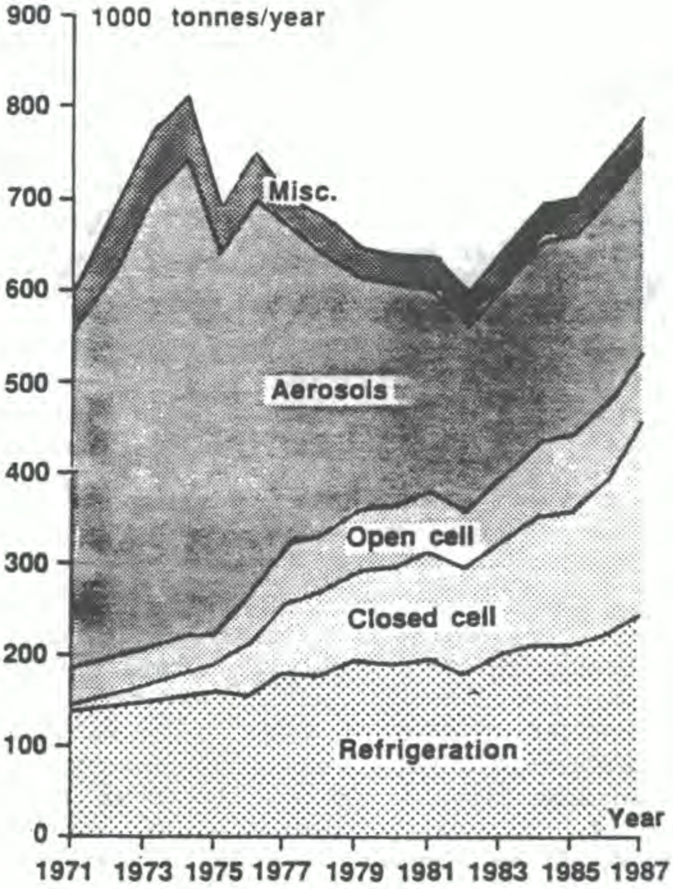

Figure 2-2. Estimated World CMA Consumption of CFC-11 and CFC-12

Table 2-4. Estimated Regional Production of CFCs and halons in 1986 (tonnes per years)

	Regions				
Substance	North America	West Europe	East Europe	Asia + Pacific + Latin America	World Total
CFC-11	85,000	185,000	55,000	85,000	410,000
CFC-12	155,000	185,000	85,000	65,000	490,000
CFC-113	70,000	45,000	0	65,000	180,000
Halons	10,000	10,000	0	10,000	30,000
Total	320,000	425,000	40,000	225,000	1,110,000
ODP-Weighted	350,000	450,000	140,000	228,000	1,200,000
Percent of World Production	29%	37%	12%	22%	100%

Note: Estimated on the basis of UNEP, Technology Review Panel Report, 1989, The Commission of the EC and CMA, 1987. Figures are rounded to nearest 5,000 or 10,000 tonnes.

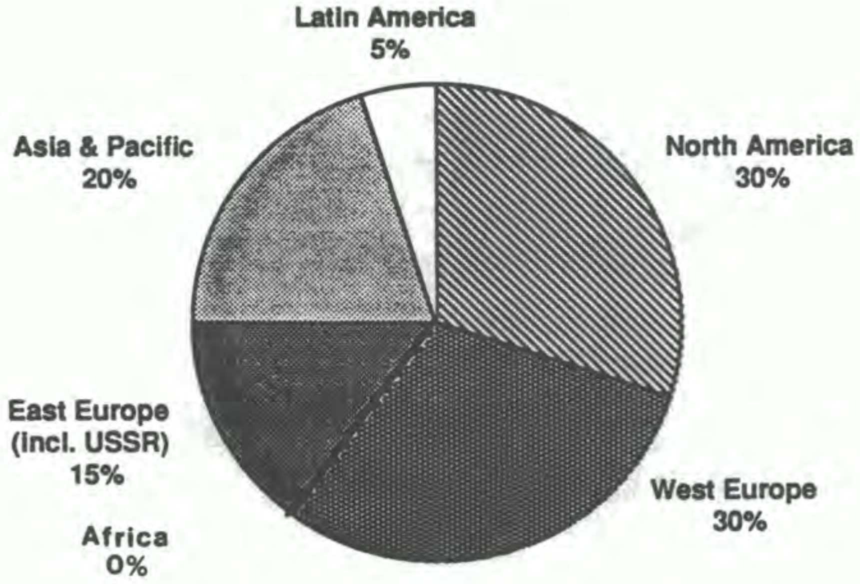

Figure 2-3. Indicative Regional Consumption Pattern for CFCs and halons (1986)

Based on the above and consumption estimates for Latin America and Asia/Pacific one can establish the following order of magnitude of the regional consumption of CFCs and halons (Figure 2-3).

The reason Figure 2-3 reports no consumption for Africa is that CFC imports and use of the CFCs as a production input are negligible in Africa.

Consumption per Capita

Data compiled by UNEP on the consumption of CFC-11 and CFC-12 in 17 industrialized countries and 6 developing countries, indicate a range of consumption per capita among countries (Table 2-5).

Table 2-5 is only an illustration; it should be recognized that the use of CFC-113 is not included in these figures and that consumption levels may have changed since 1984. The third column of Table 2-5 shows that there is a markedly higher consumption level in the industrialized countries. The fourth column of Table 2-5 illustrates the country's CFC consumption per billion dollars of total production value (Gross National Product) of the economy. The wide variation of ratios of CFC/GNP between industrialized and developing countries indicates a weak correlation between the country's economic level of development (measured in terms of GNP) and its total consumption of CFC-11 and CFC-12.

Primary Applications

The consumption of the controlled CFCs and halons can be divided among the following major areas of application shown in Figure 2-4.

Aerosols, refrigerants, and foam blowing are the three largest applications of the controlled compounds. Accounting for approximately equal proportions of use, these three applications together account for 70 percent of the ozone-depleting potential of total consumption. Solvents and fire extinguishing represent another 12 percent and 13 percent of consumption, respectively.

Within the area of refrigeration, mobile air conditioners represent slightly less than 50 percent of the CFC consumption. Industrial use, storage, retail, and transport account for more than one-third of the refrigerants, while domestic refrigeration and building chillers account for 5 percent and 6 percent of total refrigeration, respectively.

For the CFC blowing agents, about two-thirds is used in rigid foams and one-third in flexible foams. More than 85 percent of the CFC solvents are used for degreasing in, for example, the electronics industry, and less than 5 percent is used in dry cleaning.

In Table 2-6 the applications have been broken down by the individual compounds. CFC-11 and CFC-12 are the two compounds with most applications. CFC-113 is almost exclusively confined to solvents applications, CFC-115 to refrigeration, and halons to fire extinguishing.

Table 2-5. Consumption of CFC-11/CFC-12 in Selected Countries, 1984/85

Country	Consumption in 1,000 Tonnes	Use per: Capita (Kg)	Use per: Billion Dollar GNP (tonnes)
Australia	12.0	0.78	70.8
Austria	5.2	0.69	77.6
EC (10)	228.5	0.85	95.3
Japan	57.5	0.48	49.6
Kuwait	1.0	0.60	38.4
Norway	0.7	0.18	13.1
Sweden	3.6	0.43	36.1
USA	197.4	0.84	62.1
China	18.0	0.02	61.1
Egypt	2.9	0.06	96.2
Honduras	0.2	0.04	60.2
Malaysia	1.4	0.09	52.5
Mexico	5.2	0.07	33.0
Thailand	2.0	0.04	51.5

Source: Chlorofluorocarbons Production and Use Data,
ICF Incorporated, 1987.

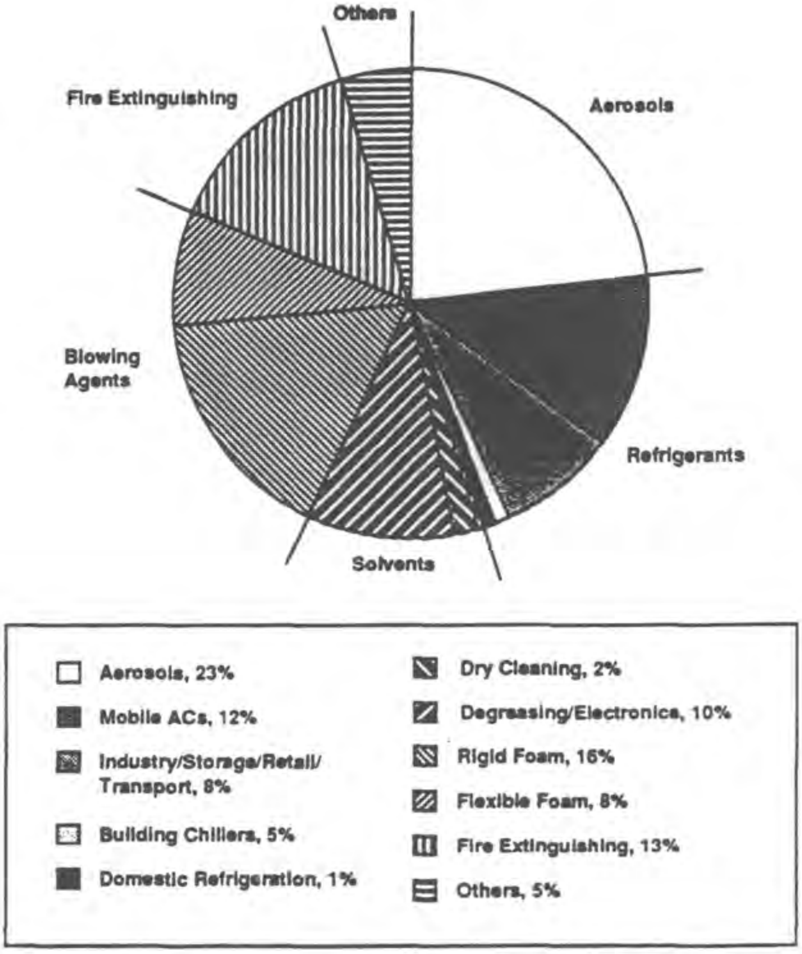

Figure 2-4. World Consumption of CFCs and halons by Major Application, 1986 (ODP-weighted). (Source: UNEP, Technology Review Panel, 1989.)

Table 2-6. World Consumption of CFCs and Halons by End Use and Compound in 1986 (Tonnes)

		Foam Blowing Agent				Fire			ODP	Percent
Compound	Aerosol	Flexible	Rigid	Refrigerant	Solvent	Extinguisher	Others	Total	Weighted	of ODP
CFC-11	122,700	60,000	153,400	33,800			25,100	411,000	411,000	33
CFC-12	162,300		50,500	228,600			31,900	487,000	487,000	40
CFC-113			3,500		182,000			182,000	146,000	12
CFC-114				3,600				15,000	12,000	1
CFC-115				15,000				15,000	6,000	-
Halon 1211						18,000		18,000	54,000	4
Halon 1301						11,000		11,000	110,000	9
Halon 2402						1,000		1,000	6,000	-
Total	285,000	60,000	207,000	281,000	182,000	30,000	57,000	1,140,000	1,232,000	100
ODP Weight	285,000	103,000	202,000	275,000	146,000	166,000	57,000		1,232,000	
Percent of Total	23%	8%	17%	22%	12%	13%	5%			100

Note: The total consumption of the individual compounds have been allocated among the major applications. In some cases the compounds may have other very minor applications.

Source: Figures are estimated on the basis of U.S. EPA, Regulatory Impact Analysis: Protection of Stratospheric Ozone Volume I, 1988, and UNEP Technology Review Panel, 1989.

The relative importance of the various CFC applications differ substantially among regions. In Table 2-7 the CFC consumption pattern is shown for Europe, North America, Asia/Pacific, and Latin America.

Table 2-7 shows that aerosols have the highest CFC application (40 percent) in Europe. In North America the quantity of CFC in aerosols is only 1 percent and the dominant application of CFCs is refrigerants (45 percent). In Asia and the Pacific solvents represent the largest application area for CFCs (35 percent). Refrigerants are the largest application area for CFCs in Latin America (50 percent).

Recent Trends in the Use of CFCs and Halons

The growth in total CFC and halon consumption since 1982 has been unevenly distributed among the major applications. Although many countries have restricted the use of CFCs in **aerosols**, the total volume of CFC-11 and CFC-12 used in aerosols has experienced a small growth after 1982, and still accounts for some 25 percent of total CFC and halon consumption. Western Europe is by far the largest consumer of CFCs as propellants in aerosols, and the European aerosol industries have indicated that major reductions in use will be implemented.

The use of CFCs as **blowing agent** for foams is another application that has had rapid growth, especially for rigid foams. As companies substitute non-CFC blowing agents in the production of flexible foam, use is expected to decline.

There has been a high growth in the use of CFCs as **solvents**, primarily in electronic and precision cleaning.

Use of **refrigerants** has also experienced growth. For all refrigerant applications, combined consumption is estimated to have increased by 15 percent from 1986 to 1989. The use of CFCs in **sterilization** has also increased in recent years.

The application of halons in **fire extinguishing agents** has increased dramatically over the last 10 years as manufacturing capacity has increased and the price of the compounds has dropped.

CFCs and Halons as Production Inputs

The cost of CFCs and halons as production inputs is generally a small part of the final price of consumer products. The higher the relative CFC/halon cost for a specific product, and the more costly the substitute, the more sensitive the product sales price will be to the cost of CFC or halon.

If, for example, the CFC-cost of a given product equals 1 percent of the market price at 1.3$/kg, the impact of a substitution cost of $5 per kg CFC is:

$$\text{Market price increase} = (\text{Substitution cost per kg}) / (\text{CFC-cost per kg}) * (\text{CFC-cost in percentage of market price}) = 5\ \$ / 1.3\ \$ * 1 \text{ percent} = \mathbf{3.8\ percent}.$$

Table 2-7. CFC Markets by Region, 1988 (percent)

	West Europe	North America	Asia and Pacific[a]	Latin America
Aerosols	40	1	15	20
Foams	25	20	20	20
Refrigerants	20	45	30	50
Solvents	10	15	35	8
Others	5	20	1	2
Total	100	100	100	100

[a] Includes Japan and Australia.

Source: UNEP, Technology Review Panel, 1989.

Table 2-8 shows an estimate of the CFC-cost as a percentage of the market price for a number of typical products using CFCs in the manufacturing process.

The relative CFC-costs indicated in Table 2-8 are from the Nordic study of Technical Trade aspects of CFC Regulation, 1988. It should be noted that these relative costs depend on the definition of the final consumer products. Thus for some of the intermediate products, like PU rigid foam, the CFC-cost is as high as 15 percent of the market price for certain of these intermediate products.

Atmospheric Release

The speed with which CFCs and halons are released to the atmosphere depends on the application. Emissions in many uses are prompt, while others are delayed by 10 to 15 years (for refrigeration) and 30 to 40 years or more (for halon fire extinguishing chemicals), except for emissions associated with testing and training.

Research on the emission profiles for CFCs and halons in the major applications have been compiled in the RIA study.[2] Table 2-9 presents an overview of the variation in emission fractions and periods by application.

The emission profiles in Table 2-9 are representative for the major applications. However, improved housekeeping practices during servicing and scrapping of products can substantially influence the emission profiles for refrigerants, solvents, halons, sterilants, etc.

On the basis of the cumulative production and consumption of CFC-11 and CFC-12 from 1930 to 1986, the CMA has estimated the total quantity of these two substances released by 1986 and the proportion that still remains in the stock of CFC-containing products (Table 2-10).

According to the CMA estimates shown in Table 2-10, some 14 million tons of CFC-11 and CFC-12 combined was released into the atmosphere by 1986. The total emission by 1986 equals 89 percent of the total cumulative production of the two CFCs.

Table 2-10 indicates that of the total volume of CFC-11 and CFC-12 used as blowing agent in rigid foam up to 1986, more than 40 percent is still contained in the foam while 60 percent is in the atmosphere.

Of the total volume of CFC-11/12 used as refrigerants up to 1986, some 20 percent has not yet been released. Finally, of the total volume of CFC-11/12 used in aerosols and flexible foam, less than 1 percent is not released.

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[2] US Environmental Protection Agency, Regulatory Impact Analysis: Protection of the Stratospheric Ozone, 1988.

Table 2-8. CFC-Costs for Selected Products

Product	Costs of CFC in Percent of Market Price for Final Product
Flexible foam	
Foam wash cloth	1%
Mattresses	2-3%
Rigid foam	
XPS insulation	2-3%
PU appliance insulation	<0.5%
PU building insulation	15%
Refrigerants	
Small refrigerators	<0.1%
Solvents	
Electronics	Negligible
Dry cleaning	1%

Table 2-9. Yearly CFC and Halon Fractions Released by Application in Percentage of Initial Consumption

Application	Released in Year of Initial Use: (percent)			Full Emission:	
	1	5	10	Year	Emission (percent)
Aerosol	100	-	-		
Flexible Foam	100	-	-		
Rigid Foam[a]	14	29	43	20	100
Fast Refrigeration[b]	19	100	-		
Medium Refrigeration	19	47	69	17	100
Slow Refrigeration	1	15	21	17	100
Solvent	85	85	85	1	85
Fire Extinguisher[c]	1	15	25	30	87

[a] Rigid Polyurethane Foam. Full emission in year 20 assumes a 20-year foam/building lifetime.

[b] Automotive Air Conditioners.

[c] US Halon 1211 Fire Extinguishing.

Source: U.S. EPA, 1988, op cit.

Table 2-10. Cumulative Combined CFC-11 and CFC-12 Production and Release, 1930-1986 (volumes in million tonnes)

	Production		Released		Unreleased	
	Volume	Percent	Volume	Percent	Volume	Percent
Refrigeration	3.8	100	3.0	79	0.8	21
Blowing Agent Rigid Foam	1.8	100	1.0	57	0.8	43
Aerosol and Flexible Foam	10.3	100	10.2	99	0.1	1
Total	15.9	100	14.3	89	1.7	11

Source: Grant Thornton, 1987.

2.4 MARKET TRENDS

The demand for products based on CFCs and halons as production inputs will depend on the pace of world economic growth, especially the economic growth in developing countries. The demand potential in these countries, with a total population of more than two billion, is tremendously high.

The degree to which compound use is correlated with GNP varies with the maturity of the products and technologies that use the compounds. For instance, a mature product market (such as refrigeration in developed countries) is expected to grow at rates comparable to population growth rates. The demand in relatively new markets (such as new solvents uses) is expected to grow more rapidly than GNP. In addition, new products not yet introduced would have created new demands for CFCs and halons.

In Table 2-11 an attempt has been made to characterize the magnitude of the growth factors for the major products with a CFC or halon application. Product demand growth rates are measured against GNP growth rates.

The extent to which expected growth in demand for products produced with CFCs or halons today will result in a parallel growth in CFCs or halons demand depends on:

-- Global regulations on CFCs and halons, in terms of the number of countries joining the Montreal Protocol and the chemical scope, stringency, and coverage of current and coming Protocol regulations.

-- Technological development of both CFC and halon technologies and substitution technologies.

-- Consumer preferences for products applying CFC and halon versus substitute products.

The U.S. EPA has in the 1988 RIA study established a comprehensive projection of global demand that would have occurred for the individual compounds and six regional groupings of countries **without** the Montreal Protocol or other substantial regulations. The projected demand growth for the major applications from 1986 to 2010 is shown in Table 2-12.

The highest annual growth rates in world demand are estimated for fire extinguishing and solvents with over 7 percent annual growth up to 1992 (Table 2-12). Refrigeration has a projected annual growth of around 5 percent. Aerosols and foams are projected to have a slightly lower growth rate. The relative distribution of growth between the individual applications is maintained for the period 1992 to 2000, but after 2000 the overall projected growth level is lower (2 percent and 4 percent per year).

The growth projections by region are presented in Table 2-13.

Table 2-11. Magnitude of Demand Growth Factors for Major Application Areas and Markets

Products	Industrialized Countries	Non-Industrialized Countries High/Middle Income	 Low Income
Refrigeration	< GNP growth	≥ GNP growth	< GNP growth
Foams	≤ GNP growth	≥ GNP growth	< GNP growth
Aerosols	≤ GNP growth	= GNP growth	< GNP growth
Solvents	≥ GNP growth	≥ GNP growth	< GNP growth
Fire Extinguisher	> GNP growth	> GNP growth	≥ GNP growth

Note: Because they possess advanced technologies, very large Low Income Countries (e.g., India and China) are exceptional cases and are most likely to follow the growth pattern of High/Middle Income Countries.

Table 2-12. Projected Demand Growth by Application Without the Montreal Protocol (1986-2010)

	Annual Rates (percent)		
	1986-1992	1992-2000	2000-2010
Aerosol	4.90	2.91	2.50
Flexible Foam	4.34	2.71	2.50
Rigid Foam	4.69	2.83	2.50
Refrigeration	5.08	3.00	2.50
Solvent	7.03	4.09	2.50
Fire Extinguishing	7.25	2.00	3.02
Miscellaneous	4.89	2.91	2.50

Source: U.S. EPA, Regulatory Impact Analysis: Protection of the Stratospheric Ozone, 1988.

Table 2-13. Projected Annual Demand Growth by Region Without the Montreal Protocol Regulation (1986-2000) (percent)

	1986-1992			1992-2000		
	CFC-113	Other CFCs	Halon 1211	CFC-113	Other CFCs	Halon 1211
United States	5.6	3.8	8.7	3.8	2.5	3.9
U.S.S.R. and East Europe	9.8	6.6	11.9	3.8	2.5	3.6
Other Developed	5.6	3.8	9.2	3.8	2.5	4.6
China and India	22.5	15.0	20.7	15.0	0.0	12.2
Developing I[a)]	11.3	7.5	13.0	7.5	5.0	7.5
Developing II[b)]	2.3	1.5	6.9	1.5	1.0	3.2
World Total	7.0	4.9	9.8	4.1	2.8	4.8

[a)] Algeria, Argentina, Liberia, Malaysia, Mexico, Panama, South Korea, Taiwan, Tunisia, and Turkey.

[b)] Other developing countries.

Source: U.S. EPA, Regulatory Impact Analysis: Protection of the Stratospheric Ozone, 1988.

As can be seen in Table 2-13, China, India and the 10 group I developing countries were projected to experience a dramatically fast growth in CFC and halon demand. Annual growth rates range from 7.5 percent to 22.5 percent in the period up to 1992 and from 5 percent to 15 percent in the period 1992-2000. These growth rates, however, are applied to extremely low current per capita consumption figures (see also Table 2-5). The bulk of developing countries (group II) have very low growth projections, all in the range of 1 percent to 2 percent for CFCs and 3 percent to 7 percent for halons.

CHAPTER 3

ECONOMIC ASSESSMENT ISSUES

3.1 INTRODUCTION

Depletion of the stratospheric ozone layer is an unintended consequence of the release of CFCs and halons. Halting these releases while providing substitute products and services will impose economic costs but will realize economic and environmental benefits by protecting the ozone layer. Economic analysis establishes a framework to evaluate the environmental effects of CFC and halon emissions in support of rational decision processes of individuals, firms, and nations.

Article 9(1)(c) of the Protocol provides that Parties shall share information on costs and benefits of control strategies. In the case of protection of the stratospheric ozone layer, the techniques of traditional benefit-cost analysis cannot be applied in a mechanical fashion. The problem is international and intergenerational in scope, and our understanding of the scientific basis for policy action is evolving rapidly.

Benefit-cost analysis for protection of the stratospheric ozone layer must take into account that economists cannot place a quantitative value on some of the external diseconomies. In particular, the technical and economic processes determining the costs and pace of diffusion of substitutes for ozone-depleting substances are dynamic in nature. This implies that policy design must reach beyond calculation of the costs of replacement of CFCs and halons at any particular moment in time; truly cost-effective policies for stratospheric ozone protection must provide incentives for rapid development of cheaper and better substitutes for ozone depleting processes, and for the adoption of those substitutes worldwide.

The structure of our Economic Panel Report is dictated by these considerations. It relies on the findings of the Technology Review Panel and of the Environmental Effects Panel. These Reports provide a summary of the best information now available on the effects of potential ozone depletion and the technical alternatives and substitutes that will be available in the near future.

Section 3.2 of this chapter outlines the elements of a benefit-cost analysis of alternative policies based on current data. Detailed numerical calculations are not presented, because it is recognized that each country will need to make their own calculation. Also, regional differences and gaps in data preclude application of a single benefit-cost calculation to all countries. Examples of the calculations that have been carried out by some of the Parties to the Protocol are presented to illustrate some of the approaches that are used in policy formation.

Section 3.3 of the chapter discusses in detail the special dynamic features of the problem. Finally, Section 3.4 lays out several of the most important policy issues facing the Parties as they proceed with revision of the Montreal Protocol. This chapter thus provides an overview of the issues that are developed in the remainder of the Economic Panel Report.

3.2 THE BENEFIT-COST FRAMEWORK

3.2.1 Quantification of Benefits and Costs

The benefit-cost approach can be applied to centrally planned, market, or mixed economies. Comparison of the effects of stratospheric ozone depletion to estimates of cost provides a common standard of measurement that can be used to weigh potentially conflicting outcomes of proposed policies. Careful comparison of the costs and benefits of alternative policies allows decision makers to link their actions to national goals, minimizing the unintended consequences.

It should be noted at the outset that benefit-cost analysis does not answer questions concerning the distribution of costs and benefits. Transfers of wealth could result from CFC and halon controls. These significant equity issues may be important within an individual nation's political context, but this report does not make recommendations concerning the resolution of such internal distributional questions. Some distributional issues have to do with equity across generations, a question that is both national and trans-national in character. Other matters of distribution involve equitable treatment of the differing circumstances of nations; these issues will be discussed in part in Chapter 6 in the context of technology transfer.

The harms that would follow from continued CFC and halon release and consequent stratospheric ozone depletion have been delineated by the Environmental Effects Panel (see Chapter 5). On the basis of the scientific literature summarized by that panel, these damages include:

1. Adverse effects on human health from increased ultraviolet (UV) radiation reaching the earth's surface. These health effects include increases in the incidence of skin cancer, cataracts, and suppression of the human immune system.

2. Reductions in yields, including those of major food crops.

3. Disruption of the aquatic food chain, with potentially large consequences for fisheries and the global marine ecosystem.

4. Increased global warming, and associated climate change. These changes in turn would cause sea level rise, alterations in seasonal weather patterns, and changes in the global distribution of land suitable for cultivating various crops.

5. Increases in tropospheric (surface level) ozone, with consequent impacts on agricultural productivity and human health.

6. Deterioration of polymer products due to their increased exposure to ultraviolet radiation.

There are no known benefits to depletion of ozone in the stratosphere. Mitigation of the anticipated environmental effects (e.g., health care) and long-term adaptations (e.g., seed strains tolerant of higher ultraviolet levels and warmer climates) are possible but the human effort and capital used to provide mitigation would not be available for economic growth. For this reason, potentially profitable mitigation of the effects of ozone depletion are not counted as benefits for purposes of benefit-cost analysis.

Prevention of stratospheric ozone depletion, through international regulatory agreement (such as the Montreal Protocol) and consequent country-by-country implementation, produces national and global benefits to the extent that the damages listed above are avoided. Alternative policy paths will lead to different estimates of both costs and benefits, depending on the timing and effectiveness of those measures in preventing stratospheric ozone depletion. These paths can be described in terms of levels of stringency in cutting back CFC and halon use, time schedules for limiting the use of these chemicals, and varying levels of participation by the countries of the world. The scope and coverage of the list of chemicals designated as "controlled substances" under the Protocol will also affect the consequences of alternative policies.

The cost of any policy program will depend on how rapidly CFC and halon use is reduced and the levels of reduction achieved. Assessment of the cost for a particular policy will depend on:

1. Cost of substitutes and alternatives including recycling of controlled substances.

2. Changes in consumer utility associated with reductions in the consumption of CFC- and halon-using products.

3. Timing of the phasedown of CFCs and of the introduction of substitutes. This will be determined by the implementation schedules chosen in regulating producers and users of CFCs, and by the incentives provided for development and adoption of the substitutes.

4. One-time transitional costs as productive factors (labour, capital, resources) are reallocated in response to the CFC phasedown.

Two points should be noted in conjunction with this list of costs. First, the "social cost" of CFC and halon regulation properly includes only losses in net consumers' satisfaction resulting from cutbacks in consumption of CFC- and halon-using products, together with the net resource cost incurred in replacing some of the uses of those products. Neither of these social costs is measured by increases in the price of CFCs and halons after regulation. To the extent that CFCs are produced by and consumed within a given country, the increased prices paid for the products may represent a transfer of wealth from one group to another, and therefore are not a net cost to the domestic economy. A country that is a net importer or net exporter of CFCs, however, may experience losses or gains if the price rises. Secondly, some of the loss to consumers will take the form of a change in the diversity of the products from which they can choose over the long run. This type of change is difficult to quantify, because it is associated with products that disappear from the market or never come into existence.

Different Parties may have different priorities in setting goals for public health, agricultural and industrial development, and environmental protection. Accordingly, one nation's framework for benefit-cost analysis should not simply be carried over to another country without modification. In particular, the situation of developing countries requires specialized treatment within the framework of the benefit-cost analysis.

3.2.2 Regional Differences

The diverse biological systems of different regions create differences in their vulnerability to ozone depletion. Not all countries cultivate the same food crops, so the impact of increased UV radiation on yields will not be uniform. Nations vary in their dependence on fisheries for food, and although world markets will reflect grain and fish scarcity to some degree, the effects of reduced yields on farmers', fishers', and consumers' incomes and wealth will be felt locally.

Health effects can also be expected to vary, both with latitude (which influences how much the UV flux changes with ozone depletion) and population composition (light-skinned individuals are more susceptible to UV-caused skin cancers). Increases in cataracts that could be corrected in countries with relatively high incomes could cause proportionally more distress and hardship in countries with low incomes and where medical treatment is less readily available to the cataract victims.

The climatic effects of CFC emissions are not expected to be geographically uniform. Models of the atmosphere predict that global climate changes due to changes in the composition of the atmosphere will vary with latitude (Houghton and Woodwell, 1989). CFCs contribute to global climate change and to expected increases in the average temperature of the earth. Because of differences in local climate and geography, some countries would suffer more from CFC-induced climate change than others. For example, countries with extensive coastal lowlands are more vulnerable to sea level rise than mountainous or inland regions. Increases in the frequency or severity of cyclonic storms would fall most heavily on areas now subject to hurricanes and typhoons. Drought and desertification in specific areas will result from the still-unknown changes in precipitation patterns.

In addition to regional differences in impacts, countries will also have different approaches to the valuation of benefits. With regard to health effects, alternative valuations could be based on the direct medical costs of treating the diseases associated with increased UV radiation, the loss of income and productivity due to morbidity and mortality caused by the UV, or on measurements of the population's "willingness to pay" to avoid the environmental risks of increased UV. Although similar valuation methodologies may be used by different countries, regional differences in prices, incomes, and other economic variables are likely to lead to differences in the benefit-cost calculations, even in the absence of uncertainty about effects or about substitution possibilities and costs.

Costs are also likely to differ across regions. The costs of development of substitute technologies, which will be undertaken mainly by nations that currently use CFCs at high levels, need not be borne by countries that follow the high CFC-using countries in adopting the new methods. Some output from research and development will take the form of public goods, such as scientific knowledge published in technical journals, that will thereby be available worldwide at no extra cost. Technology transfer through private channels, as in the case of enterprise-to-enterprise agreements or cooperative ventures, will also take place in the normal course of economic development. (See Chapter 6 for a more detailed discussion.)

Transfer of technologies that use CFC substitutes should be similar in process to the transfer of CFC-using technologies; while there may be differences in components, such as compressors or sealants, the technologies themselves will be qualitatively similar whether they use CFCs or substitute fluids. Safe production and use of CFC substitutes, however, may require chemical manufacturing and applications facilities capable of handling more demanding materials and operating under more complex procedures than existing CFC plants.

The different levels of economic development were recognized in the Montreal Protocol in Article 5, "Special Situation of Developing Countries," and elsewhere. The Protocol provided for a 10-year delay in adoption of the phasedown schedule by low-CFC using Parties, and called for special efforts to make non-CFC-using technologies available to developing countries. Divergence in levels of wealth and per capita income naturally influence the choice and application of evaluation methodologies in appraising the risk of stratospheric ozone depletion (Rayner, 1989; Rayner and Cantor, 1987).

3.2.3 Economic Uncertainties

Replacement of CFCs and halons entails substantial technological uncertainty. All studies to date of the costs of alternatives have been derived from the existing technological base or from technologies already under development, yet historical experience shows that technical change is demand driven (Schmookler, 1966; Rosenberg, 1976). The urgency of the need to reduce drastically CFC and halon use is certain to speed up the development of high-productivity substitute technologies. Because the specifics and details of such advances are presently unforeseen, they cannot be included in current cost calculations. This means that the cost estimates overestimate the actual costs of substitution that will prevail as investments in the new technology are made. The emergence of new, lower-cost alternatives to CFCs since the signing of the Montreal Protocol supports this optimistic expectation. The technical community now projects that half of the existing volume of CFC use can be eliminated at no net cost. (See Chapter 4, below.)

There are uncertainties associated with the effects data as well. The CFCs have very long half-lives in the atmosphere (75-110 years or more) (Dull, Seidel, and Wells, 1988), so estimation of their cumulative effect under different policy scenarios depends on (1) forecasts of the future emissions of CFCs extending beyond the horizon of ordinary economic forecasting, (2) similar long-term forecasts of the emissions of the other trace gases (methane, carbon dioxide, and oxides of nitrogen) that interact with the CFCs in determining the ultimate equilibrium of the ozone layer; and (3) reliability of the computer models that are used to produce the long-term forecasts. Since these computer models involve hundreds of equations governing the chemical and physical reactions that determine the equilibrium ozone concentrations, uncertainties in the structure and parameters of the models produce uncertainties in the forecasts as well.

In some areas (such as the cancer incidence caused by increased UV radiation) the effects of projected changes in the ozone column are relatively well known. In others, such as the potential effects of increased UV on crop yields and on the aquatic food chain, there is a much greater degree of scientific uncertainty. Although appraisals such as that conducted by the NASA Ozone Trends Panel (Watson, 1988) have attempted to clarify the state of knowledge in atmospheric science, uncertainties remain in that area as well. Those uncertainties are magnified by the additional biological, engineering, and social factors needed to develop national-scale estimates.

Further uncertainties arise in the course of translating the cost and effects information into usable economic form. A particular source of difficulty is the long time horizon needed to estimate the impacts of CFC emissions. The effects of present-day CFC emissions are spread over many future generations. The time lag between exposure to UV radiation and its adverse health effects further lengthens the time spans that must be considered in the analysis. Such very long periods of time are likely to be ones of large-scale economic change, if the history of the last two centuries is any indication. Yet the magnitude and distribution of these changes -- which will affect both the nature of the societies coping with ozone depletion and the resources they can bring to bear -- are impossible to project with confidence.

Social and ethical factors must also be taken into consideration in assessing such long-term effects since the future generations are not represented in any contemporary decision-making arena. Present-day policy-makers face the challenge of protecting the interests of a constituency with no political voice. Future generations would not want an inhospitable environment. Undoubtedly, different countries will approach this difficult problem of practical political philosophy from different perspectives.

Even if a country arrives at a consensus on one particular approach to the intergenerational problem, that of discounting costs and benefits, severe problems remain in making that approach operational. Different markets exhibit different interest rates, reflective of different risk-return tradeoffs in alternative investment activities. Typically, large segments of a nation's total investment are embodied in assets whose rates of return are difficult or impossible to measure accurately -- such as the housing stock and human capital (acquired skills and education). The tax treatment of different forms of capital also makes it problematic to infer the suitable discount rates from market data, because of the difference between before-tax and after-tax returns

(Lind, 1982). Even if these practical difficulties can be resolved, discounting carried out across generations still involves making implicit judgments about the preferences and behaviour of the future inhabitants of the globe.

Finally, as described below in Chapter 5, actual ozone depletion greatly exceeds predictions of current atmospheric models. It is difficult to formulate properly the economics of social discounting, intergenerational equity, non-marginal options, and non-market approaches to such problems with high or irreversible risk. Even with extended sensitivity analyses, benefit-cost conclusions remain sensitive to the assumptions for key parameters and therefore can provide only tentative policy guidance.

Despite these economic and technical uncertainties, it is essential to have a working understanding among Parties to the Protocol that the investments necessary to decrease or eliminate CFCs and halons are jointly in the world's interest. It is likely that high CFC users would find it economically rational to provide incentives in the form of finance, information, and cooperative projects to assist developing nations in adopting CFC-free technology. As discussed in Chapter 6, Technology Transfer, there are means available to Parties to translate the elimination of CFCs and halons into feasible arrangements that make the common global interest one that is also economically attractive to all.

3.2.4 Review of National Studies

Several countries have already conducted extensive economic studies as part of their risk management programs. There is much to be learned from examination of these studies. Examples of results reached in typical country studies are presented.

The benefit-cost comparison contained in the U.S. Environmental Protection Agency's study "Regulatory Impact Analysis: Protection of Stratospheric Ozone" (1988) is overwhelmingly supportive of an international phasedown in the use of CFCs and halons. The U.S. EPA's calculations apply to the United States alone, but in order to estimate benefits, assumptions had to be made regarding the level of world participation in the control effort. The calculations took into account the costs of replacing capital equipment. The U.S. EPA conducted an extensive sensitivity analysis to see how the results depended on parameters such as the discount rate, the valuation of health benefits, or the magnitude of the UV dose-response relationship. Under a wide range of alternative assumptions, including all values of the parameters plausible from the U.S. point of view, the benefits of international ozone protection far outweigh the costs. A representative example of the cost-benefit comparison shown in the U.S. EPA's Regulatory Impact Analysis is shown in Table 3-1.

As large as the margins of benefit over cost are (as shown in this table), they do not reflect all of the health and environmental benefits to the United States of stratospheric ozone protection. The table covers only the costs and benefits accrued through 2075; in all scenarios the additional benefits over the period 2075-2165 exceed the costs of control for the same period. Furthermore, the benefits shown in Table 3-1 do not include protection of the human immune system and avoidance of the pain and suffering of skin cancers. The environmental benefits do not include those of saving coastal wetlands and avoiding beach

Table 3-1. Comparison of Costs and Benefits Through 2075 by Scenario, United States Only (billions of 1985 dollars)[a]

Scenario	Health and Environmental Benefits	Costs	Net Benefits (Minus Costs)	Net Incremental Benefits (Minus Costs)[b]
No Controls	-	-	-	-
CFC Freeze	3,314	7	3,307	3,307
CFC 20% Cut	3,396	12	3,384	77
CFC 50% Cut	3,488	13	3,475	91
CFC 80% Cut	3,553	22	3,531	56

[a] See RIA for assumptions and definitions of scenarios. Estimates assume a 2 percent discount rate and $3 million per unit mortality risk reduction. All dollar values in the Table reflect the difference between the No Controls scenario and the specified alternative scenario. Valuation of health and environmental benefits applies only to people born before 2075; costs are estimated through 2075.

[b] Changes in net incremental benefits represent movement to the indicated scenario from the scenario listed above it.

Source: U.S. EPA, "Regulatory Impact Analysis: Protection of Stratospheric Ozone, Vol. I: Regulatory Impact Analysis Document" (1988). Segments of Exhibit 10-9.

erosion, nor the avoided UV impacts on recreational fishing, the overall marine ecosystem, or forests. The calculations underlying Table 3-1 assumed an energy efficiency penalty for substitution away from the controlled substances; instead, as described elsewhere in this Report, the substitutes may actually be more energy efficient than CFCs in some applications. Table 3-1 also does not include certain transition costs, such as temporary layoffs while new capital equipment is installed, or the administrative costs of enforcing compliance with CFC and halon control regulations. These are much smaller than the estimated benefits, however.

The Nordic study, "Reduction of CFC Consumption: A Technical-Economic Assessment of the Options for Reducing CFC-consumption in Denmark, Finland, Norway and Sweden" (1988), is focused on the current or foreseeable availability of CFC reduction possibilities, and on the cost of those reduction opportunities. A detailed breakdown by sector and use is provided, together with estimates of the reductions in consumption that would be possible at different levels of cost. (Note that a similar type of analysis was carried out for the United States in "Volume III: Addenda to the Regulatory Impact Analysis Document," 1988.) The Nordic study does not venture to quantify the benefits of ozone protection. It does conclude, however, that considerable reductions in CFC use are possible for the four Nordic countries that sponsored the study -- Denmark, Finland, Norway, and Sweden -- even without the use of any new technology. The estimates are shown in Table 3-2.

The Netherlands study, "Costs of CFC-Phase Out in the Netherlands" (1988), also does not attempt to quantify the benefits of preventing depletion of the ozone layer. For a small country such as the Netherlands, hardly any benefit could be obtained by unilateral action if the other countries of the world did not also act to reduce ozone-depleting emissions.

The Netherlands study also contrasts the costs of a "gradual" phase-out (in which CFC-using equipment is replaced by non-CFC-using methods according to normal marketing and depreciation schedules) with the cost of an "accelerated" phase-out, in which all CFC and halon uses are eliminated by the year 2000. This comparison supports the conclusion that the timing and definition of the phase-out schedule will have important cost implications to be considered in revising the Montreal Protocol.

Calculations recently carried out by the Netherlands Ministerie van Economische Zaken for the case corresponding to current EC policy (85 percent reduction in 1995, total phase-out by 1998) yield the estimates presented in Table 3-3.

It should be noted that the Dutch estimate appears to be high in comparison with the U.S. estimate, given the difference in scale of the two economies. The Environmental Agency of the Federal Republic of Germany is completing a similar national study, which concludes that a 90-95 percent reduction can be achieved by the mid 1990s at reasonable costs.

Table 3-2. Levels of CFC Consumption as a Percentage of 1986 Consumption That Are Technically Feasible by the Indicated Date, Four Nordic Countries (percent)

	Existing Technology	Existing and New Technology
In About 1991	50-90	65-95
In About 1996	15-25	5-20
In the Longer Term (in about 2016)	5-30	0-15

Note: Percentages in the table are expressed in terms of 1986 consumption; 15 percent of 1986 consumption corresponds to an 85 percent CFC phasedown.

Source: "Reduction of CFC-Consumption: Technical-Economic Assessment of the Options for Reducing CFC-Consumption in Denmark, Finland, Norway and Sweden, Main Report," COWIconsult (1988).

Table 3-3. Costs of an 85 Percent CFC Reduction in 1995, and Total Phase-Out in 1998, in the Netherlands (Millions of Guilders: 1 US$ = 2 Guilders)

Year	Investment	Capital Cost	Operational Cost	Total
1995	319.0	63.8	13.1	76.9
1998	282.7	153.4	15.8	169.2
2000	180.7	196.6	16.1	212.8
2010	231.2	289.9	13.8	303.7

3.3 ISSUES IN DYNAMIC ANALYSIS

The country studies all take a static perspective, which is appropriate to the situation of gradual phasedowns in CFC use in the developed economies and gradual increases in CFC use in some developing nations. In light of new scientific information, the alternative of complete elimination of CFCs and halons must now be examined. Part of such an examination involves considering the impact of technology change on costs of substitution, and analyzing the effects of international transfers of technology on the possibility and costs of reaching a CFC-free world.

A dynamic analysis indicates that opportunities for speeding the transition to a CFC-free economy are available to the Parties. Taking advantage of these opportunities will hasten the day when CFCs and halons are no longer released to deplete the ozone layer. Technological change involves both unforeseen advances and the accumulation of experience. The magnitude and importance of unforeseen advances can be appreciated by examining historical examples and precedents for rapid change. Gains in productivity and reductions in cost associated with learning by doing have been measured in a variety of industries (David, 1970 and 1985; Sahal, 1981; House and da Silveira e Silva, 1983; Gordon, 1989), and the same kinds of reductions in cost may be expected to accompany the general adoption of non-ozone-depleting technologies worldwide.

The number of substitutes for ozone-depleting substances and their economic attractiveness have increased over time. End-user firms and trade associations have announced (and in some cases, implemented) phasedowns of CFC use that go beyond present regulatory requirements, and exceed past estimates of their capabilities for substitution. For example, only a year and a half after the U.S. EPA's Regulatory Impact Analysis made detailed estimates of substitution possibilities in rigid extruded polystyrene foam sheet (the type of foam used in food packaging) the foam food packaging industry in the United States achieved virtually a total phaseout of CFCs in its manufacturing processes (White, 1989).

It is likely that the costs of CFC substitutes will decline in the future. In the evolution of technology, the options that survive are those that lower costs while maintaining quality or effectiveness. As learning by doing and realization of economies of scale occur, costs will tend to fall. Because the search for CFC substitutes has only recently begun in earnest, it is reasonable to anticipate that substitutes developed in the future will be less expensive than those currently available.

This fact has two important implications. First, the cost estimates developed in the static analyses and summarized in Section 3.2.4 are upper bounds on the costs actually to be incurred in implementing the policies under review. To the extent that it does not reflect learning by doing, realization of scale economies, and unanticipated technical advances, static analysis can overstate the costs of substitution. Second, time should be allowed for substitutes to emerge, so that low-cost alternatives will in fact be available in commercial markets. Careful attention needs to be paid to the timing of the phasedown schedule, so that the overriding objective of protecting the ozone layer is accomplished without incurring unnecessary transition costs.

As experience with implementation of the Montreal Protocol has developed, governments and industrial firms have begun to discover and remove hidden obstacles to CFC and halon substitution. The U.S. Department of Defense, for example, had previously specified the use of CFCs in production of electronic components for military hardware. Upon review, the Defense Department revised its specifications to make them performance-based, rather than requiring that specific solvents be used (U.S. Department of Defense, 1988).

In the history of technology, choices are frequently made on the basis of slim differences between alternatives. Over time, the advantage of the selected technology over the discarded alternatives grows, not because of the intrinsic superiority of the selected technology but because of economies of scale and experience in production and use (Arthur, 1984, 1989). Discovery of the adverse environmental consequences of using CFCs and halons may cause re-examination of known alternative technologies. Had they been understood at the time, the environmental costs of CFC use might have tipped the choice against the fully halogenated compounds for some uses and limited the use of others, such as halons, to applications high in value. With the re-examination now underway, it is possible that some of the once-discarded technologies will prove attractive. Some of these are likely, in turn, to prove as inexpensive and convenient as CFCs, after they have received further R&D funding and production experience has fostered learning by doing. For example, electronic equipment whose protection from fire is now dependent on halon systems can be changed to permit protection with water. Surgical instruments now sterilized with CFCs can be replaced by instruments made of heat-resistant plastics that can be heat (steam) sterilized.

In the dynamic process of technical progress, the political atmosphere, domestic regulatory climate, and degree of international cooperation strongly influence the pace of change. The search for alternative technologies will proceed with different intensities, depending on whether a decisive political commitment to phase out CFCs has been made or not. The scope of the list of controlled substances is also relevant. Uncertainty about which other substances might be included in the Protocol in the not very distant future adds another dimension of risk to the development of substitutes.

Before regulatory policies have been decided, it is rational for some CFC producers and end users (particularly in developed countries) to be prepared for implementation of any of the policies being seriously considered. In such a situation, producers and users can be expected to devote part of their efforts and attention to political action, to try to obtain a regulatory outcome favourable to their narrow interest. After the decision has been made, these firms are freed from uncertainty and can then concentrate their R&D and management resources in the policy-sanctioned direction. While an individual firm's interests may be set back, policy certainty will speed up the process of developing and diffusing the substitute technologies.

The certainty with which firms know the direction of policy increases with the degree of international consensus and participation in the regulatory effort. International cooperation enhances the commitments of individual governments to encouraging CFC substitution and increases the market opportunities for firms that are successful in that effort. Many of the leading edge end users produce products that are important in international trade, so their interests are directly involved in avoiding trade barriers that could result from less than complete participation in the Montreal Protocol and its revisions.

Governments can also play a direct role in the transition to non-ozone-depleting methods. Funding of R&D on substitutes is justifiable both because of the new scientific knowledge created and because the substitutes will help control an environmental externality. Governments are themselves large consumers of products containing or made with CFCs and halons, so they can take the initiative in developing markets for substitute products and processes. And while governments cannot create technological alternatives by fiat, careful design of regulatory policies to implement the Montreal Protocol can support and enhance incentives for replacement of CFC and halon uses.

3.4 AGENDA OF ECONOMIC ISSUES

The Parties to the Montreal Protocol face economic issues both on the global and on the national scale. As discussed previously, the present state of knowledge does not support a quantitative worldwide analysis. Consequently it is not possible to prepare a traditional benefit-cost analysis for the international community, nor to determine an optimal schedule for regulation of the CFCs. In the absence of a quantitative solution, however, the logic of economic analysis implies that Parties should address a series of questions in revising the Protocol:

1. **Coverage.** Advancing scientific understanding of ozone chemistry in the atmosphere is changing our appreciation of the ozone-depleting potential of halogenated compounds. The list of substances to be controlled under the Protocol should accordingly be examined by the Parties, particularly methyl chloroform and carbon tetrachloride.

2. **Stringency and timing.** The pace and level of reduction in emissions of controlled substances will substantially determine the costs of compliance with the Protocol. It is important for Parties to evaluate the dynamic aspects of the transition to CFC-free technologies, so that the capital and operational costs of phasing out CFCs can be balanced against the benefits of protecting the ozone layer for the world.

3. **Participation.** A preponderance of today's production of CFCs and halons occurs within the economies of the Parties to the Protocol. There is a potential for substantial use and production in nations that have not agreed to the Protocol, however. Protection of the ozone layer can only be assured if all nations can harmonize their economic interests in the benefits of CFC technology and their economic and environmental interests in the ozone layer. Chapter 6 below on the subject of technology transfer addresses this matter.

The technical and economic uncertainties described in this Report imply that nations may differ in their judgments on these three issues. Economic analysis cannot supply authoritative answers today on the optimal global path toward a CFC-free world economy. Economic logic does demonstrate, nonetheless, the central importance of these issues on the agenda to be taken up by the Parties in revising the Protocol.

3.5 CONCLUSIONS

It is clear from this survey that a considerable body of experience has been accumulated in the economic evaluation of measures to protect the stratospheric ozone layer. While important differences in the approaches taken by the Parties to the Protocol will persist, a common basis of scientific knowledge exists that can form the basis for economically rational decision-making.

It is important to stress that economic analysis points to the existence of significant opportunities for economically sound choices, arising from the dynamic character of the innovation process and market shifts brought about by the elimination of CFCs. While the very dynamism of the technological changes makes it difficult to estimate the magnitude of these opportunities, the constantly increasing range of substitution possibilities points to the direction of the likely trend.

Although the direction is clear, the pace and timing of policies to achieve reductions in CFC emission will have significant economic impact. Rapid phase-out of CFCs and halons will increase transitional costs such as the losses associated with discarding or modifying equipment built to produce or use CFCs. While it should be possible in some cases to avoid these costs, the prudent management of the transition will not be automatic. National policies and international action, via the Protocol and other means, can reduce the costs of transition and mitigate the unavoidable burdens of change.

Finally, advances in the methods used to assess alternative policies will be an added benefit of the reviews called for under the Protocol, particularly where new methods enable Parties to learn from the emerging experience of controlling CFC and halon emissions to protect the ozone layer. Economic analysis can play an important part in this process, provided its underlying concepts, its data requirements, and its strengths and weaknesses are carefully assessed in the context of the problems to which it is applied.

REFERENCES

Arthur, W. Brian. "Competing Technologies, Increasing Returns, and Lock-In by Historical Events." **Economic Journal** (March 1989): 116-131.

Arthur, W. Brian. "Competing Technologies and Economic Prediction." **Options**, International Institute for Applied Systems Analysis, Laxenburg, Austria (April 1984): 10-13.

David, Paul A. "CLIO and the Economics of QWERTY." **American Economic Review** (May 1985): 332-337.

David, Paul A. "Learning By Doing and Tariff Protection: A Reconsideration of the Case of the Ante-Bellum United States Cotton Textile Industry." **Journal of Economic History** (September 1970): 521-601.

Dull, David, Stephen Seidel and John Wells. "Moving Forward: Key Implications of the Montreal Protocol." United States Environmental Protection Agency, Office of Air and Radiation. Washington D.C.: 1988.

Gordon, Robert J. "The Postwar Evolution of Computer Prices." In **Technology and Capital Formation**, edited by D. Jorgenson and R. Landau. M.I.T. Press, 1989. (Forthcoming).

Houghton, Richard A. and George M. Woodwell. "Global Climatic Change." **Scientific American** 260 (April 1989): 36-44.

House, R.W. and W. da Silveira e Silva. "On Transferring Microelectronics Technology Internationally: Brazil's Case." Systems Approach to Appropriate Technology Transfer, Proceedings of the IFAC Symposium, Vienna, Austria, March 21-23, 1983. Edited by P. Fleissner. New York: Pergammon Press, 1983.

Lind, R.C. "A Primer of the Major Issues Relating to the Discount Rate for Evaluating National Energy Options." In **Discounting for Time and Risk in Energy Policy**, edited by R.C. Lind. Washington D.C.: Resources for the Future, Inc., 1982.

Ministerie van Economische Zaken. "Costs of CFC-phase out in the Netherlands." The Netherlands: 1988.

Nordic Council of Ministers and Federation of Nordic Industries. "Reduction of CFC-Consumption: A Technical-Economic Assessment of the Options for Reducing CFC-Consumption in Denmark, Finland, Norway and Sweden, Main Report." COWIconsult. Denmark: 1988.

Rayner, Steve. "Risk in Cultural Perspective." Oak Ridge National Laboratory, unpublished, January 1989.

Rayner, Steve, and Robin Cantor. "How Fair is Safe Enough? The Cultural Approach to Societal Technology Choice." **Risk Analysis** 7 (1987): 3-9.

Rosenberg, Nathan. **Perspectives on Technology**. Cambridge: Cambridge University Press, 1976.

Sahal, Devendra. **Patterns of Technological Innovation**. Massachusetts: Addison-Wesley Publishing Company, Inc. 1981.

Schmookler, Jacob. **Invention and Economic Growth**. Cambridge: Harvard University Press, 1966.

United States Department of Defense, Office of Public Affairs. "Department of Defense Seeks Alternatives for Ozone Depleting Chemical." Press Release No. 541-88. Washington D.C.: November 2, 1988.

United States Environmental Protection Agency. "Regulatory Impact Analysis: Protection of Stratospheric Ozone." Washington D.C.: U.S. Environmental Protection Agency: 1988.

Watson, R. T. et al (NASA). "Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report." National Aeronautics and Space Administration (NASA-RP- 1208), June 1988.

White, George. "Canning the Ozone Wreckers." **Los Angeles Times** (March 3, 1989): part IV, pp. 1, 12.

CHAPTER 4

THE COSTS OF TECHNICAL SUBSTITUTION

4.1 INTRODUCTION

This chapter provides an overview of the economic costs of substitutes and alternatives for the substances presently controlled by the Montreal Protocol. The analysis is primarily based on the findings of the UNEP Technical Panel Report and the five Technical Options Reports. The work of the Technical Panel was conducted and concluded in the same period of time as the work of the Economic Assessment Panel.

The present CFC- and halon-producing and -using industries have intensified their research into and development of new and alternative chemicals, production processes, and end user products in order to diminish or eliminate the future use of CFCs and halons. This search for alternatives has been energetic. Companies and governments all over the world continuously announce the "discovery" of new options for reducing the ozone-depletion effects of production and products.

The actual cost of reducing or eliminating use of CFCs and halons will in most cases reflect both technical substitution of the CFC by another chemical, process, or product, and reduction or elimination of use of CFCs without substitution. Because both changes in levels of use and substitution of new uses are involved, estimating the cost of eliminating or reducing CFC use requires detailed analysis of the users of CFCs and halons. Such an analysis lies beyond the scope of this chapter.

The Technical Panel has estimated the technical feasibility of different substitution options for the major areas of CFC and halon uses:

- refrigeration, air conditioning and heat pumps;
- rigid and flexible foams;
- electronics, degreasing, and dry cleaning;
- aerosols, sterilants, and miscellaneous uses of CFCs; and
- Halon fire extinguishing agents.

For each application area, the present CFC and halon use in the CFC- and halon-producing and -using industries has been determined.

The Technical Panel has identified not only the existing technical substitution possibilities, but also the substitution options that are presently being tested for commercialization within the next 1-5 years. The technical substitution options are divided into different categories:

-- chemical substitutes;
-- process substitutes;
-- product substitutes; and
-- recycling/reclaiming programmes.

For each substitution alternative or "technical option" the Technical Panel has determined or evaluated:

-- the year when the technical option will be available for commercial use;
-- the part of the CFC and halon use that can be eliminated; and
-- the efficiency of the technical option in reducing ozone depletion, greenhouse effects and energy use.

Based on this information, the Technical Panel has evaluated the technical feasibility of reducing CFC and halon use in accordance with the requirements of the Montreal Protocol (a 50 percent reduction in CFC use by 1998 and a freezing of halon consumption and production by 1992 compared with the 1986 level consumption). The Technical Panel has further investigated the possibilities, within each application area, of a complete phase-out of the controlled substances and of reductions in methyl chloroform and carbon tetrachloride emissions.

This chapter does not provide a calculation of the economic cost of different reduction policies to the world or to different regions of the world. At present it is only possible to give a summary of the state of art in the technical field and to discuss the economic considerations that individual countries must evaluate.

For the sake of illustration the Economic Assessment Panel has made a simple example calculation of the costs of substituting the use of CFCs in a sector of particular global interest, namely the refrigeration sector. These calculations are based on the findings of the Technical Panel and the earlier results of the U.S. EPA and Nordic studies. In addition, an example from the solvents sector is briefly outlined.

A detailed discussion of the methodology that has been applied in the earlier mentioned Nordic Study and the U.S. EPA Regulatory Impact Assessment Study for calculating the economic costs of the different controls is given in Appendix III.

4.2 TECHNICAL SUBSTITUTION OPTIONS

The executive summaries of the Technical Options Reports are in Appendix IV. The Technical Panel has provided estimates of some of the costs of various technical options for substituting CFC and halon within the different application categories.

4.2.1 Summary of Earliest Substitution Dates and Phase-Down Schedule

Table 4-1 summarizes the earliest possible substitution dates and the technically feasible phase-down schedule for each application area as determined by the Technical Panel. However, the Technical Panel has emphasized that since technological development is progressing rapidly, it may be possible to accelerate these substitution dates and this phase-down schedule in some CFC and halon sectors when new technical options are known and reported by the time of the next technical review.

From the table it can be seen that the process of substituting CFC in most applications can start immediately. Technically well-developed substitution options are already available today for a multitude of different uses (e.g., water-based cleaning systems in surface treatment, alternative propellants); they could be employed immediately to reduce large quantities of CFCs in use. For certain problematic uses, however, a prolonged period of development and market introduction is required. Based on the current knowledge, it is possible to phase down the use of controlled CFCs by the year 1998 within all application areas except refrigeration. In refrigeration a complete phase-out is feasible even with the long lifetimes of refrigeration equipment if aggressive containment, recycling, and retrofit programs are started.

4.2.2 Soft CFCs and Other Ozone-Depleting Substances

The HCFCs (soft CFCs) are feasible technical options for a rapid reduction of dependency on the fully halogenated CFCs. However, these chemicals continue to exert an ozone depletion potential (ODP), albeit very small compared with those of CFC-11 and CFC-12. While HCFCs are substituted for fully halogenated CFCs on a pound-for-pound basis, they can clearly be considered to meet part of each Party's obligation for CFC substitution, reducing ozone depletion rapidly and substantially. However, if the global growth in the use of these chemicals expands, ozone depletion could continue, although at a slower pace.

Some Parties view the HCFCs, which are presently not regulated by the Montreal Protocol, as "bridging" chemicals that could be used in the intermediate period until ozone-safe chemicals have been developed. Of course, this would mean a transition period before reaching the final ozone safe solution. Other Parties view the adoption of HCFCs as a more "permanent" solution because the ozone depletion and greenhouse effects of these chemicals are small compared with the effect of other chlorinated substances emitted to the atmosphere.

4.2.3 Status of Recovery and Recycling Programmes

Recovery and recycling programmes for CFCs and halons offer an important potential for reducing emissions in the near term. Two candidates for recycling are CFC-113, used as a cleaning solvent, and CFC-12, used in mobile 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 cannot occur immediately due to the lack of infrastructure, economic incentives, etc. Assistance from the developed countries to the developing countries in this area will be required.

Table 4-1. 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	1989-1993
Polypropylene	1989-1993
Solvents	
Electronic	1995-1997
Metal cleaning	1993-1996
Dry cleaning	1995-1995
Miscellaneous Uses	
Aerosols, non-medical	1990-1995
Aerosols, medical	1995-2000
Sterilization	1990-1995

* Some refrigeration use may be able to be reduced sooner if retrofitted to accept HFC and HCFC blends now under development.

Source: UNEP Technical Panel.

Recycling of CFCs is an immediate opportunity, and the infrastructure developed will prove useful in facilitating the reclaiming and recycling of HCFCs or other ozone-safe chemicals in the future. Recycling of CFC will also be important for providing usable CFCs to existing equipment, in order to avoid expensive scrapping in certain application areas.

4.2.4 Status of Destruction Technologies

At present there are only a few small plants for the destruction of compounds containing chlorine, bromine, and fluorine. However, no significant technical impediments are anticipated. What is not known is under what reaction conditions the destruction can be most effectively achieved. Research projects are now underway in several countries to answer these questions. As soon as there is a sufficient economic incentive or a regulatory demand, such facilities are expected to appear.

4.3 ESTIMATION OF ECONOMIC COSTS OF SUBSTITUTION

There is worldwide agreement that the benefits of reducing the use of CFCs and halons outweigh the possible costs of substitution of CFC and halons. The existing documentation for this is presented in Chapter 5. Therefore national governments, industries, corporations, and consumers face the challenge of identifying the most cost-effective strategy for substitution or elimination of the use of CFCs and halons.

The Technical Options Reports identified many alternatives and substitutes to CFCs and halons that require initial capital investment or management attention but ultimately are less expensive to operate or offer improvements in product quality. These low-cost or no-cost alternatives therefore have little or no "net" cost. Together these low-cost/no-cost substitutes and alternatives can reduce CFC use by over 50 percent if companies have access to capital investment (Table 4-2).

The national capital investment to employ new technologies depends on the extent of the change and on whether the country has factories that are currently manufacturing CFC-dependent components or whether they buy components from foreign suppliers. For example, some refrigerator factories manufacture the refrigerator case, evaporator, condenser, controls, and accessories locally but import compressors. In these cases the retooling to change to a new refrigerant is much less since compressor capital investment will be made in other countries.

The identified technical options vary in terms of the following factors:

-- commercial availability,
-- extent of performance verification,
-- efficiency in terms of substituting CFC and halons,
-- capital and operational costs or savings,
-- energy savings or penalties,
-- safety characteristics including potential hazards from flammability and toxicity, and
-- ease of adoption.

Table 4-2. Typical Examples of Low-Cost/No-Cost Substitutes and Alternatives

CFC/Halon Use Sector	Technical Option	Investment
Aerosols	Hydrocarbons	Explosion-proof filling station
Aerosols	Spray, pump, etc.	Product reformulation, assembly equipment, pump components
Aerosols	Simple bottles	Bottles, daubers
Air Conditioning	HCFC-22	Compressors, evaporators, condensers, controls, etc.
Auto Air Conditioning	Recycle	Recycle equipment, filters
Flexible Foam	Water, new polyals, etc.	Storage, metering, ventilation, chemicals, etc.
Flexible Foam	Cotton, etc.	Minor
Foam Insulation	Water, HCFC-22, HCFC-142b	Pumps, pipes, mixing heads, chemicals, etc.
Foam Insulation	Fibreglass, non-CFC foam, etc.	Expand production at existing facilities or build new plants
Foam Packaging	HCFC-22	Gaskets, seals, tanks
Halon	No discharge tests	Door fans, computers
Halon	No training	Training materials, simulators, etc.
Halon Portable Extinguishers	Dry chemical, water, etc.	Tanks, charging stations, etc.
Refrigeration	HCFC-22	Component manufacturing equipment, etc.

Table 4-2. Typical Examples of Low-Cost/No-Cost Substitutes and Alternatives (Continued)

CFC/Halon Use Sector	Technical Option	Investment
Refrigerators	Reduce fee, CFC-500, blends	Re-balance, match motor to compressor
Solvents	Contain and recycle	Leak detection, hoists, covers, gaskets, etc.
Solvents	CFC-113 blends	Minimal (gaskets and seals)
Solvents	Alcohol	Cleaning machine, fire protection, gaskets, etc.
Solvents	Low-solid flux	Minimal
Sterilization	Separate heat-sensitive devices and steam	Minimal if steam sterilizers already owned

The rapid development of new technical options means that the cost effectiveness of final CFC and halon substitution is improving over time. New technical options have different cost, performance, safety, and environmental properties, and the cost estimates of the individual technical options are being revised regularly by industry and others. The actual substitution costs in the different application areas depend on many technical and local parameters such as interest rates, energy prices, etc., which of course means that substitution costs will differ between countries.

It should be recognized that the costs of CFC and halon normally only constitute a minor part of total production cost and product prices, with the exception of some foam products. (A list of CFC cost shares in product prices are given in Chapter 2.) This means that even a relatively large increase in the cost of CFC/halon (or its substitutes) will have only a small influence on the price of the final end-user product. As a consequence, major changes in the demand for and prices of end-user products should not be expected when CFCs and halons are substituted. Exceptions include substitution of non-foam insulation for CFC-blown foam or alternative dispensing of CFC aerosols. In these cases demand for the CFC and halon products may be expected to decrease.

Attention should be paid to the uncertainties with respect to successful research and development of new technical options. Many existing options may provide cost-effective replacements for CFCs and halons. However, other options may be worth waiting for.

For instance, elimination of CFCs in the refrigerator sector seems at first to be expensive, but it turns out that the Protocol has encouraged manufacturers to look for and research a total revision of the design of the refrigerators. This may actually result in the development of a new and energy-saving refrigeration technology.

Governments, Industries, and Companies Face Difficult Choices

In determining the most cost-effective substitution strategy a number of economic and technical tradeoffs should be evaluated. These include the following:

-- The fast adoption of existing and emerging technologies versus the strategy of waiting for certain future alternatives that offer greater economies or improved environmental protection.

-- The choice of a few generally applicable substances/technologies versus the choice of many different alternatives for each specific application area.

Due to the very rapid development of new technical options it may be very important for individual governments to determine the sensible choice and timing of technical options or families of options in collaboration with the nations' industries. Many governments will want to identify and implement a social cost-effective transition programme that simultaneously considers energy efficiency.

Individual industries will seek to change their use of CFCs and halons in order to minimize their cost of transition or to optimize their cumulative expected future earnings from existing CFC markets and new CFC-free markets. A rapid substitution risks the possibility of rendering existing capital equipment obsolete, possibly before it has been depreciated. For many companies, production costs may be lessened if the timing of the substitution of CFCs and halons is phased with the technical and economic lifecycles of the existing facilities. At the same time, new investments should not be made with obsolete CFC and halon technologies, even if the prices of these obsolete technologies are low and profitable in the short run. In addition, some industries may not have sufficient access to financing to purchase the technology.

New technologies may have different economies of scale compared with the old CFC and halon technology or compared with other new alternatives. Some industries will face production complications such as co-production of several chemicals or end-user products or may face problems of materials compatibility.

The choice made by an industry may be significant for individual companies making short-term decisions on technical options. A coordinated choice of the future technology within an industry (e.g., the refrigeration sector) can improve product performance, energy efficiency, cost, and durability.

In some cases, the implementation of technical options generates reductions in operating costs that outweigh the direct investment cost of the option. One reason that cost savings and performance improvements are possible as CFC use is phased down is that the cost of CFC has been negligible in most application areas and, therefore, alternatives to CFC in production have not been considered until now. The worldwide concern for the ozone layer and the profit opportunities of developing and using the new alternatives has resulted in rapid technical progress. Engineers are now considering not only a direct substitution of the chemicals in question but are also investigating technical options for a fundamental redesign of the production processes in both the chemical industry and the CFC- and halon-using industry.

Nordic and U.S. EPA Economic Analysis

The most comprehensive studies of the costs of substitution are the Nordic study and the Regulatory Impact Assessment of the United States Environmental Protection Agency (U.S. EPA), where specific and detailed evaluations have been conducted for each industrial subsector, and the Japanese and the Dutch studies, which mainly focus on total sector costs. All of these studies evaluate the technical feasibility of fulfilling the Montreal Protocol requirements. The economic consequences of a total phase-out have only been reported in the U.S. EPA and Dutch studies.

The studies all consider two types of scenarios:

- a no-growth scenario where demand for end-user products, and, consequently, CFC for this application, remains constant in the future at the 1986 level; and

- a growth scenario, which projects demand if no regulatory measures are taken.

The studies of the Nordic countries and the U.S. EPA both calculate the total social costs, i.e., the real resource costs to society. Taxes are treated as transfer payments with offsetting revenue and expenses.

Both the Nordic and the American studies present a survey of the technical options available, their availability in time, their ability to penetrate the CFC markets, and the time needed for this penetration. The studies also estimate the average economic costs of substituting one kg of CFC within each application area. The detailed cost estimates of these reports are not reproduced here partly because they overestimate the cost of reductions due to the latest technical progress. Readers are asked to refer to the original studies for these cost analyses.

The Nordic, U.S. EPA, Dutch and Japanese studies all conclude that technical options are available. The studies calculate that the marginal costs of substitutes increase as the requirements for reducing the use of CFCs are tightened when technology is assumed to be fixed. This assumption is valid for the short term, but emerging and unpredicted new technologies (identified after the completion of these studies) have already lowered cost estimates significantly.

All the studies note that for some applications, reduction in the use of CFC can be achieved up to a point at no net social costs. In other words, economic savings can be generated from substituting CFCs and halons.

The cost estimates are conducted for "technically feasible" CFC-use reductions at the time of the respective studies. The studies evaluate technical options that are expected to be commercially available with the present and foreseeable future technologies.

When evaluating the economics of a total phase-out important questions may be raised:

- how to use the HCFCs,

- how to fulfil the demand for CFC from recycling and halon bank management, and

- how to develop an optimal plan for vintaging existing production and use equipment.

The U.S. EPA is presently preparing studies of capital vintaging, which are expected to generate new low-cost plans for technical substitution.

From the reported studies, a number of economic lessons can be learned with regard to the importance of optimal choice and timing of technical options. These are illustrated by a few examples below.

Economic Lesson: Some Technical Options Can Be Selected Now, But Other Choices Must Wait in Order to Protect the Ozone Layer at Least Cost

If industry promptly accepted every technically feasible option for reducing the use of CFCs and halons, the costs of transition would be higher than if the optimal economic choices were made. Therefore, evaluation of different substitution strategies can save money and/or better protect the ozone layer with limited funds.

Consider, for example, alternative strategies for the refrigeration sector. Within the refrigeration sector, mobile air conditioning and food processing (including retail, cold storage, and refrigerated transport) are the most important applications. Together they constitute approximately 90 percent of the total 1986 consumption of CFC within the refrigeration sector.

Domestic refrigeration only accounts for 5 percent of the 1986 consumption of CFC within refrigeration but the demand for CFC in this area is expected to grow markedly in the future, particularly for domestic refrigerators in developing countries.

With this high growth rate in mind, consider the technical options discussed in the Nordic and U.S. EPA economic analyses.

Annualized substitution costs were estimated for each control option within all applications. The costs are interpreted as additional social costs of implementing a given control option and are expressed in terms of dollars per kilogram of CFC use avoided. The methodology for estimating these costs has been described in Appendix III.

It should be noted that these social costs are expressed as the net costs per kg of CFC substitution. Any operational savings and/or penalties have been calculated and balanced against the capital cost requirements.

The technically feasible reductions in the use of CFCs in the future years were estimated using a combination of the control options. Aggregation of the individual control possibilities was based on the assumption that available least costly controls will be undertaken first. Furthermore, an assessment has been made regarding the interaction of the different control options. Some control measures will complement each other while others are mutually exclusive.

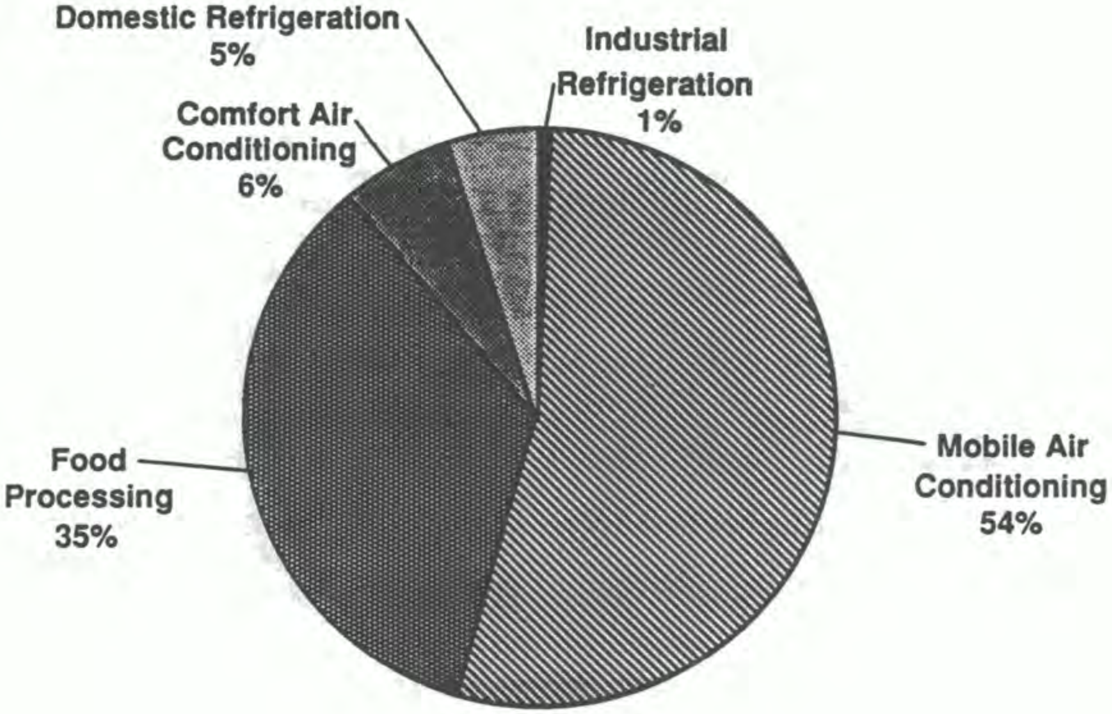


Figure 4-1. CFC World Consumption between Sub-Groups within Refrigeration. Relative Share in 1986.

Table 4-3. Technical Options Analyzed in the U.S. EPA and Nordic Studies

Mobile Air Conditioning	-- Recovery at service -- DME (pending resolution of toxicity concern if operated at very high temperatures) -- HFC-134a
Food Processing and Handling	-- Leak test -- Recovery at service and disposal -- Ammonia -- CFC-502, HCFC-22, HFC-134a
Comfort Air Conditioning	-- Leak test -- Recovery at service and disposal -- HCFC-123, HCFC-22, HFC-134a -- Market Mix
Domestic Refrigeration	-- Recovery at service and disposal -- CFC-502, HCFC-22, HFC-134a
Industrial Refrigeration	-- Hydrocarbons -- Ammonia -- CFC-502, HCFC-22, HFC-134a

Source: Nordic Study and U.S. EPA Study. Many new alternatives have been developed since completion of this work.

For independent control measures, the least expensive measure was assumed to achieve its full reduction potential. In addition, more costly measures will not always provide the same level of reduction that would occur if they were used alone, because the cheaper control measures have already reduced the total use within the application. For example, a carbon absorber on a solvent machine has less opportunity to recover CFC if the machine itself has been modified to reduce emissions.

Figure 4-2 illustrates the structure of the marginal costs of substituting CFC and the resulting feasible CFC use reduction for two typical application areas within refrigeration: Domestic refrigeration and mobile air conditioning. The maximum reduction in CFC use is indicated by year. The figure illustrates that for domestic refrigeration there is an important tradeoff between reducing the use of CFC immediately at rather high economic costs and postponing the phase out until cheaper control options are available. For mobile air conditioning, economic gains can be achieved by implementing new technologies, such as recovery at service/quality engineering, immediately.

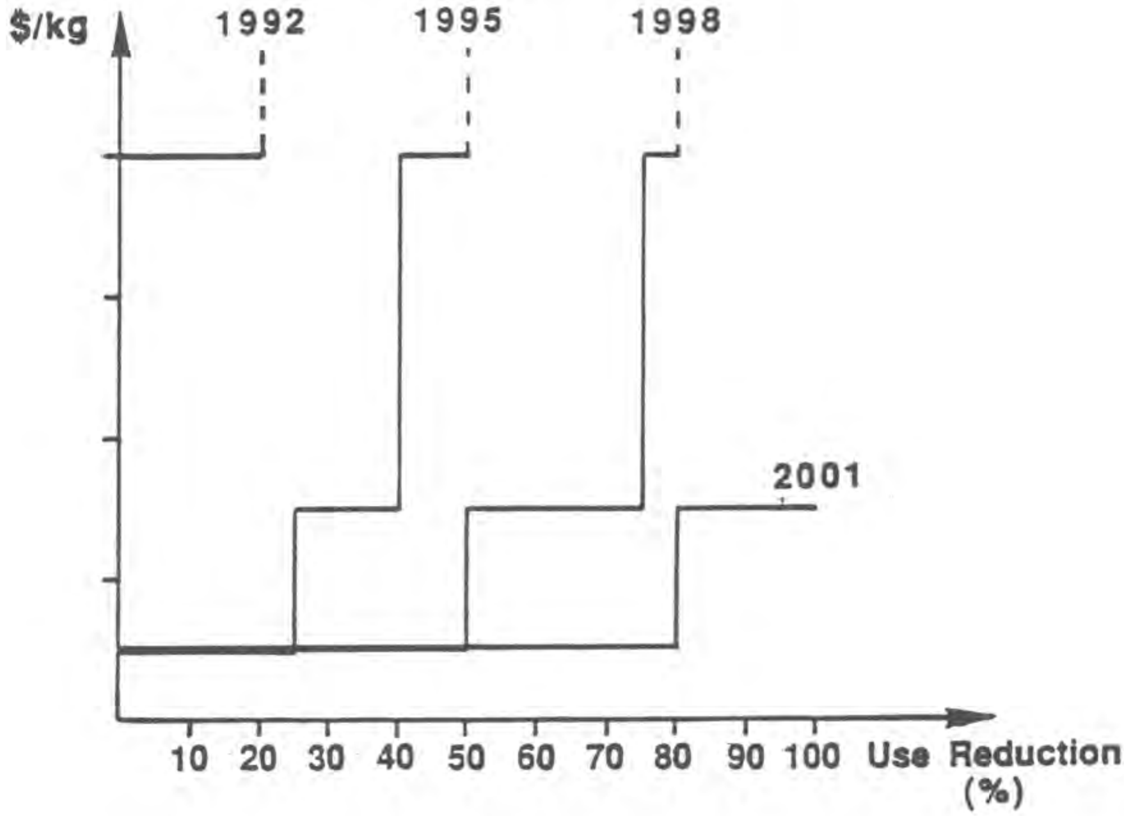
In the case of domestic refrigerators the timing of the reduction programmes is very important, because the most promising, energy-efficient technical options are not yet commercially available. The only technical options that can be put into force before 1992 are recovery at service and disposal, reduced fee, and reduced emissions at manufacturing level. The social cost of recovery at service and disposal was estimated by U.S. EPA in 1988 to be 0-40$/kg and a maximum of 20 percent use reduction can be expected by 1992. More recent estimates by refrigerator manufacturers indicate that significantly reduced refrigerant fee reduced CFC used in foam, and that reduced emissions at the manufacturing level can be achieved at low costs.

Both studies have indicated that options for using chemical substitutes such as CFC-502 and HCFC-22 are available now and that HFC-134a will be available by 1995. The social cost of these alternatives has been estimated to be in the range of 0-15$/kg CFC substituted. As the transition to CFC-free refrigerants proceeds, the market share of new and less expensive refrigerants is expected to increase and the average cost of substituting CFC to decrease.

In the case of domestic refrigeration, Figure 4-3 illustrates the importance, in terms of total economic costs, of choosing the most suitable new technologies. For the same amount of money a greater CFC reduction can be achieved if sufficient time is allowed to develop more cost-effective technical options. The tradeoff is that an early reduction of 20 percent can be made immediately, while a cost-effective 80-100 percent reduction is possible if more time is allowed. The average cost of substitution could be between four and five times higher per kg of CFC if too large an early reduction programme is chosen.

The expected marginal costs of substitution within the mobile air conditioning sector are illustrated in Figure 4-2. In this sector it has been estimated by U.S. EPA that it is possible in the short run to achieve a 30 percent reduction

I. Domestic Refrigeration



II. Mobile Air Conditioning

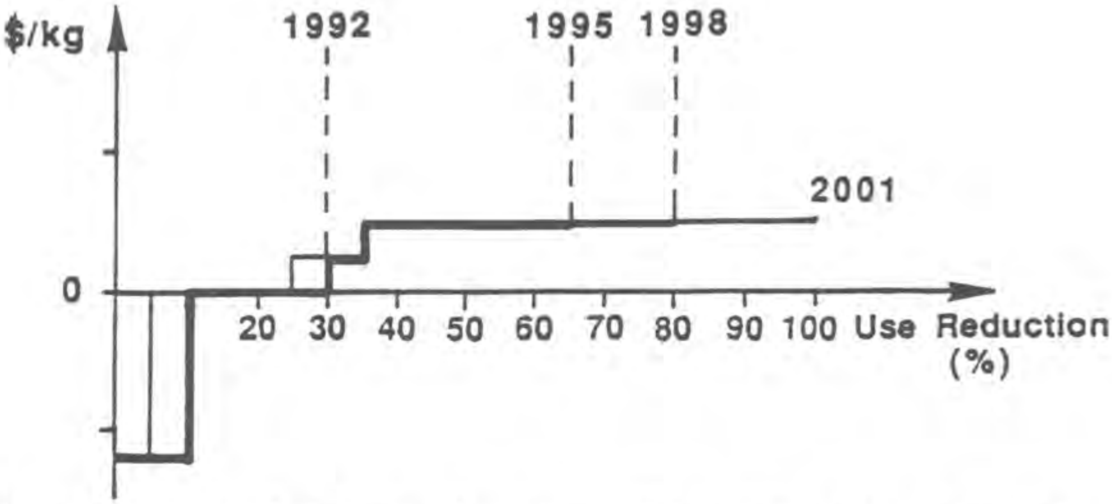


Figure 4-2. Expected Marginal Substitution Costs ($/kg CFC) within Domestic Refrigeration and Mobile Air Conditioning for 1992, 1995, 1998, and 2001 (Example)

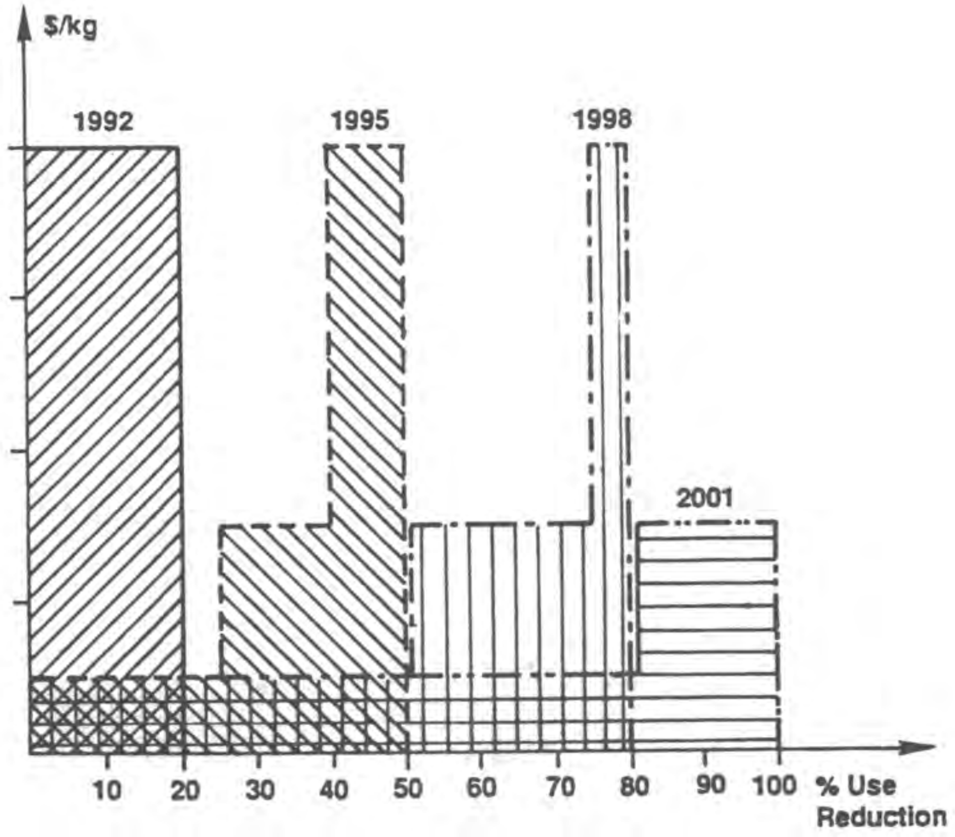


Figure 4-3. Estimated Cost-Effectiveness of Different Substitution Strategies within Domestic Refrigeration

in CFC use at little, if any, net cost. In particular, considerable economic gains can be achieved, if the control option "Recovery at Service/Quality Engineering" is introduced.

It can be seen that in the near future the average cost of substituting one kg of CFC in domestic refrigeration is likely to be at least a factor of 2 higher than in the mobile air conditioning sector. This point is even more important considering that total CFC use in the mobile air conditioning sector is more than ten times larger than within domestic refrigeration.

Economic Lesson: The Energy Savings From the Proper Choice of Refrigerants Are Worth Waiting For

Technological progress within the domestic refrigeration sector is presently very rapid. Several of the world's largest chemical-producing industries are announcing the discovery of new refrigerants or refrigerant blends.

The commercial and environmental potential for these new refrigerants are not known precisely, but their technical properties are very promising. The potential for energy savings is large and reasonably certain. These refrigerants could have very important consequences for the cost of changing to CFC-free technologies in the refrigeration sector. On the one hand, the energy savings will offset the energy penalty, which must be expected if the presently available substitutes are chosen. Moreover these expected energy savings may also offset the cost penalty of substituting CFC as a blowing agent in the insulation of refrigerators. There is a potential for discovering a totally new refrigeration technology, which is both CFC-free and cheaper for the consumer than the present technology.

A variety of options exist for replacing CFC-12 as a refrigerant and CFC-11 as a blowing agent in insulation. As mentioned, HFC-134a has been proposed as an alternative chemical by a number of companies. Recently the chemical industry has announced ternary blends such as HCFC-22/HFC-152a/HCFC-124 as possible replacement chemicals. Additionally, in the U.S. and Europe twelve blends of non-azeotropic mixtures (NARMs) that utilize two evaporators and counterflow heat-exchangers are now under investigation.

The possible energy efficiency of these technical options has been estimated by the U.S. EPA using an assumed 3 percent penalty for HFC-134a, a 3 percent gain for the ternary mentioned above, and a 20 percent gain for the NARMs. At this time it is not precisely known what the actual energy penalties or bonuses of the various refrigerants will be. Table 4-4 presents the result of the preliminary calculations of the economic implications of these differences in energy efficiency using examples of typical electricity costs in a number of countries.

Although energy costs are only a part of the net cost of a change in technology, this preliminary calculation clearly illustrates that the potential economic advantages of energy-efficient NARMs are significant compared with the other alternatives under consideration. The cumulative discounted savings in electricity costs measures how much society should be willing to pay for research, development, and installation of this technology. Moreover, there are other environmental, economic, and developmental advantages of using less electricity.

The U.S. EPA is presently also conducting research for improving the thermal conductivity of insulation foams not containing CFCs. A changeover to the presently available alternatives will imply an energy penalty because of the increase in thermal conductivity. This energy penalty can be offset by thickening the walls of the refrigerator or by discovering new insulation methods. U.S. EPA has recently estimated the differences in energy cost for potential insulation techniques, including HCFC-123 with unchanged wall thickness and HCFC-123 with thicker walls to compensate for the increased thermal conductivity. Further, the options of using HCFC-141b and superinsulation such as vacuum panels with fine particles or autogels and HCFCs with shards have been analyzed.

Based on recent estimates from U.S. EPA, Table 4-5 illustrates the possible energy cost consequences of using these technical options. Note that this calculation is for energy cost, not the total cost differences between the individual technologies. Nevertheless, this example demonstrates that a refrigerator's operating costs constitute an essential part of the total cost of refrigeration, and can vary significantly depending on the choice of insulation and the local cost of electricity.

The expected engineering cost of the different chemicals will be on the same order of magnitude. For example, the cost of the technology to shift to HFC-134a will be about the same as the cost of using a ternary chemical blend, but the potential electricity savings in the U.S. associated with using a ternary blend is US$ 800 million/year.

The economic lesson is that better substitutes will be very important not only for ozone protection but also for consumer costs of refrigeration and for governments in their attempt to reduce energy consumption and the emission of CO2 from electricity production.

Clearly, premature selection of the wrong technical option could be quite costly to government, industry, and consumers, particularly if the fast market penetration of "poor" technical options resulted in industrial standards and other barriers that would be difficult to change later.

Economic Lesson: Options Should Be Rejected if Other Options Can Yield Larger CFC Reductions at Lower Cost

Another example of how the sequence of decision making in industry and governments is important for the substitution costs can be provided by considering the question of capturing CFC-113 vapour from the air around solvent machines in the electronics industry.

Table 4-4. Preliminary Estimates of Average Annual Energy Cost (in Billions of US$ - 1987) in Domestic Refrigeration Using New Refrigerants

Residential Refrigerators

Substitute	Energy Costs (billions of 1987 U.S. dollars) Cumulative Undiscounted Costs (1990-2075)	 Cumulative Discounted Costs (1990-2075) R = 3 Percent	 Average Annual Costs (1990-2075)
Japan			
HFC-134a	$8.38	$2.11	$0.10
Ternary	($8.38)	($2.11)	($0.10)
NARM[a]	($56.03)	($14.06)	($0.66)
US			
HFC-134a	$35.17	$8.82	$0.41
Ternary	($35.17)	($8.82)	($0.41)
NARM[a]	($234.63)	($58.86)	($2.76)
China			
HFC-134a	$13.12	$2.72	$0.15
Ternary	($13.12)	($2.72)	($0.15)
NARM[a]	($87.45)	($18.16)	($1.03)
France			
HFC-134a	$4.89	$1.23	$0.06
Ternary	($4.89)	($1.23)	($0.06)
NARM[a]	($32.97)	($8.27)	($0.39)

[a] Source: U.S. EPA.

Table 4-4. Preliminary Estimates of Average Annual Energy Cost (in Billions of US$ - 1987) in Domestic Refrigeration Using New Refrigerants (Continued)

Partial List of the Basic Data

	Japan	U.S.	China	France
Price of electricity (cents/kWh)	17.1[g]	6.91[a]	3.60[b]	11.9[g]
Stock of refrigerators in 1989	36,527,554[c]	120,347,691[e]	22,808,000[d]	18,030,712[c]
Net per unit energy consumption (kWh/yr)	350[c]	1,100[e]	270[b]	600[f]
Net energy consumption (bbtu/yr)	43,647	451,954	21,024	36,934
Growth rate for stock additions	1%[a]	1%[a]	4%[a]	1%[a]
Improvement in energy efficiency	0%	0%	0%	0%

[a] Source: U.S. EPA.

[b] Source: U.S. EPA.

[c] Obtained by first dividing the country's population by the average household size and then multiplying the result by the market penetration percentage for refrigerators. Estimates of market penetration and household size were provided by the French and Japanese embassies.

[d] A first estimate is made by summing up all the production figures from 1977 to 1989.

[e] Source: U.S. EPA.

[f] Assume same data as the U.S.

g) Source: 1987 EIA.

Table 4-5. Preliminary Estimates of Annual Energy Costs (in Billion 1987 US Dollars) in Domestic Refrigeration Using Different Insulation Materials

Insulating Foams for Refrigerators

	Energy Costs (billions of 1987 U.S. dollars)		
Substitute	Cumulative Undiscounted Costs (1990-2075)	Cumulative Discounted (1990-2075) R = 3 percent	Average Annual Costs (1990-2075)
Japan			
HCFC-123 (same thickness)	$13.95	$3.50	$0.16
HCFC-123 (thicker walls)	$0.00	$0.00	$0.00
HCFC-141b (same thickness)	$13.95	$3.50	$0.16
HCFC-141b (thicker walls)	$0.00	$0.00	$0.00
Superinsulation	($63.03)	($15.82)	($0.74)
HCFC-123 (shards)	($1.40)	($0.35)	($0.02)
US			
HCFC-123 (same thickness)	$58.63	$14.71	$0.69
HCFC-123 (thicker walls)	$0.00	$0.00	$0.00
HCFC-141b (same thickness)	$58.63	$14.71	$0.69
HCFC-141b (thicker walls)	$0.00	$0.00	$0.00
Superinsulation	($263.99)	($66.22)	($3.11)
HCFC-123 (shards)	($5.89)	($1.47)	($0.07)
China			
HCFC-123 (same thickness)	$21.88	$4.54	$0.26
HCFC-123 (thicker walls)	$0.00	$0.00	$0.00
HCFC-141b (same thickness)	$21.88	$4.54	$0.26
HCFC-141b (thicker walls)	$0.00	$0.00	$0.00
Superinsulation	($98.38)	($20.43)	($1.16)
HCFC-123 (shards)	($2.19)	($0.45)	($0.03)
France			
HCFC-123 (same thickness)	$8.23	$2.06	$0.10
HCFC-123 (thicker walls)	$0.00	$0.00	$0.00
HCFC-141b (same thickness)	$8.23	$2.06	$0.10
HCFC-141b (thicker walls)	$0.00	$0.00	$0.00
Superinsulation	($37.09)	($9.31)	($0.44)
HCFC-123 (shards)	($0.77)	($0.20)	($0.01)

Source: U.S. EPA.

Table 4-5. Preliminary Estimates of Annual Energy Costs (in Billion 1987 US Dollars) in Domestic Refrigeration Using Different Insulation Materials (Continued)

Assumptions for Analysis of Residential Refrigeration for UNEP Report:

Substitutes	Replacement Factor	Radiative Forcing Potentials (°C/ppbv)	Change in Energy Consumption
Re: Insulating Foam			
HCFC-123 (same door)	1.15	0.043	5.0
HCFC-123 (thickened door)	1.27	0.043	0.0
HCFC-141b (same door)	0.85	0.037	5.0
HCFC-141b (thickened door)	0.94	0.037	0.0
HCFC-123 (shards)	1.00	0.043	-0.5
Superinsulation	1.00	0.000	-22.5[d)]
Re: Refrigerant			
HFC-134a	1.00	0.047	3.0
Ternary blend	1.00	a)	-3.0
NARM[b)]	1.00	c)	-20.0

[a)] To be provided by ICF from HCFC estimates.

[b)] Assumes a NARM with an ODP of 0.01 and a 6 year lifetime.

[c)] To be provided by ICF from HCFC estimates.

[d)] 7/8" to 1" aerosol without changing cabinet size. Aerosol only one of many alternatives, others would have different characteristics.

When technology is changing rapidly it is desirable to consider the complete path to phase out CFC use even though short-term technical options exist and are economically feasible for reducing present CFC-113 use. A number of substitutes already exist, but CFC-113 can be eliminated by the so-called no-clean solutions, such as low-solid flux and controlled atmosphere soldering or cleaning solutions using aqueous, terpene, alcohol, or the new chemical substitutes.

The costs of recovery and recycling using an adsorber system include the adsorber itself, system piping, and room enclosure to prevent dilution of CFC-113 vapours in the general plant. The room enclosure allows for complete capture and recycling of CFC through a carbon bed of all solvent emissions. With such an enclosure, the system operates at 85 percent efficiency.

Companies have reported that it is possible to recover the full cost of containment and recycling within 2 years while they select and implement the new and longer-term technology. However, it is not possible to recover the costs of the carbon absorbers if CFC use is reduced and if the new technology will negate the usefulness of the carbon adsorber. Therefore, the designers of carbon adsorbers are now considering the potential for later conversion to adsorbing other solvents, because the adsorber itself must be reprogrammed for the new solvent characteristics.

These examples all illustrate that there are economic tradeoffs to be analyzed before governments and industry select reduction policies. These include:

1. Achieving a maximum reduction in CFC and halon use as fast as possible.

2. Finding the reduction policy that minimizes the total costs of substitution over time.

3. Finding the least-cost reduction policy that just fulfils the requirements of the Protocol.

4. Balancing other environmental concerns and taking full advantage of the necessity to change technology by improving product performance, durability, energy efficiency, etc.

Sensible technologically and economically qualified choices of technical options are necessary in order to achieve an affordable protection of the ozone layer. The recent technological evidence documents that the potential for minimizing the total costs of substitution of CFCs/halons is large, but also that governments and industries must consider the options carefully in order to avoid unnecessary transition costs.

4.4 ECONOMIC INCENTIVES TO FURTHER TECHNICAL SUBSTITUTION AND RECOVERY

The favourable prices and performance properties of CFC and halons are, as a rule, important obstacles to the introduction of technical substitutes on the market. By levying a fee on CFC and halons, it would be possible to adjust the tradeoffs in favour of the necessary substitution and to provide incentives for curtailing the overall use of CFC/halons and for directing the remaining amounts of CFC/halons into the best use sectors.

The basic idea behind the provision of economic incentives as a steering tool is primarily to make polluting uses of the environment a cost factor in investment decisions. A price could be placed on environmental goods and uses, thereby creating economic incentives for a more careful and economical use of environmental media. In comparison to the use of other instruments, such as bans, the levying of fees is a steering tool that has the advantage of providing affected enterprises with great flexibility. This latitude accorded to enterprises leads to a gain in economic efficiency and thus to a reduction of control costs. The use of fees as a steering tool results in the implementation of abatement measures which, in given cases, are cheaper than the respective fee, this means, the higher the fee, the greater the interest in implementing alternative technical options.

Any fee scheme would have to include specifications as to who would be obliged to pay the fee, the assessment basis, and the rate levied. For practical reasons, the fee should be levied on the producers of CFCs and halons in order to keep the number of parties liable to pay fees within a manageable limit. The amount of the fee to be levied per measuring unit (rate) will determine the economic pressure with which alternative options penetrate the market. Thus, the higher the rate levied and the greater the recovery of CFCs and halons, the greater the number of substitutions.

The yield from the fee, which would fall with decreasing CFC/halon production volume, could be used to transfer technology to developing countries and for the subsidization of measures aimed at the recovery of CFC/halon quantities which are already on the market (in products).

CHAPTER 5

ECONOMIC/ENVIRONMENTAL BENEFITS OF REDUCED CFC/HALON USE

5.1 INTRODUCTION

This chapter discusses the benefits of reducing the use of chlorofluorocarbons (CFCs) and halons. Benefits are considered in two parts. First, the reduction in ozone depletion that results from reduced use of CFCs has various physical effects, including impacts on human health and the environment, that may or may not be quantifiable. The enumeration of these physical effects (e.g., lives saved, illness avoided, fish and crop harvests not lost) provides an important measure of the benefits of reduced CFC use. In some cases, however, these physical effects can be anticipated and identified, but the available data do not permit explicit quantification. The ability to provide such quantification is discussed in light of the current state of scientific knowledge on the human health and environmental impacts. Second, the benefits that result from reduced use of CFCs can theoretically be evaluated in economic terms (e.g., value of human lives not lost, value of crops not lost, etc.). Possible approaches for providing an economic evaluation of benefits are discussed, along with empirical and theoretical problems that are encountered when actually attempting to provide an explicit valuation of the human health and environmental benefits.

The knowledge on which the conclusions on human health and environmental impacts are based is summarized in the following sections of this chapter. In many instances, the scientific basis for these concerns is limited and/or poorly understood, which can pose serious problems for quantifying global impacts. Nevertheless, while quantification and subsequent valuation of the quantified benefits may be difficult, the available evidence does suggest very strongly that the benefits of CFC reductions can be enormous.

5.2 SUMMARY OF AVOIDED EFFECTS

5.2.1 Overview of Effects

The primary human health effects from increased CFC levels in the stratosphere arise as a consequence of the decreased stratospheric ozone levels and consequent increases in the amount of UV-B radiation reaching the earth's surface. UV-B radiation has been implicated in numerous types of damage, ranging from cosmetic damage (such as premature "ageing" of the skin) to life-threatening illnesses (such as malignant skin cancers). In addition, UV-B has been implicated in the suppression of the immune system, which may lead to reduced resistance to a wide range of diseases. In most cases, the evidence of an effect is relatively clear, but the underlying studies do not provide sufficient quantification to allow estimates of the number or severity of cases that may arise. Studies suggest a relationship between UV-B and increased illness for the following diseases: Skin cancer, particularly non-melanoma cancers, melanoma cancers, and other skin disorders; cataracts; suppression of the immune system, which may affect the herpes viruses, leishmaniasis, malaria, bacterial and fungal infections, tuberculosis and leprosy; and respiratory problems from increases in tropospheric ozone. The environmental impacts that could result due to stratospheric ozone depletion include the following: radiation impacts on tropospheric ozone, agricultural crops and other plant species, aquatic species, and man-made materials; and global warming impacts from CFCs, resulting in many different types of effects, including among other impacts more severe droughts, storms, temperature extremes, and sea level rise, among others.

5.2.2 Skin Cancer

Increased UV-B levels are expected to cause increases in cancer-related skin disorders, including melanoma skin cancers, non-melanoma skin cancers, and precancerous lesions. The effect that has been most studied is non-melanoma skin cancer, primarily among Caucasians. Additional data, which are less clear, have been developed for cutaneous malignant melanoma (CMM). CMM is a form of skin cancer that, although less prevalent than melanoma skin cancer, results in a higher proportion of fatal cases. Finally, epidemiological data suggest that increased lifetime exposure to UV-B results in an increased incidence of precancerous conditions, including actinic keratoses.

Non-Melanoma Skin Cancer

There are two types of non-melanoma skin carcinoma (NMSC): squamous cell carcinoma (SCC) and basal cell carcinoma (BCC). Basal cell carcinomas are more frequent, typically representing 80 percent of the reported cases. Where good medical care is available, the overall mortality is less than 1 percent, with most of the mortality due to SCC.

The amount of data collected on these carcinomas is highly variable. In many cases, the tumours are treated (removed) in physicians' offices, with no reporting to a cancer registry necessary. In cases where the tumours are reported to cancer registries, many registries record only SCC, and others report both BCC and SCC under the designation of non-melanoma skin cancer.

The increased incidence of UV-induced skin cancers is generally developed as a combination of the radiation amplification factor and the biological amplification factor (see Effect Group Report, or EGR). For example, the Dutch State Institute for Public Health and Environmental Hygiene estimates that a 1 percent reduction in stratospheric ozone will lead to an increase of skin cancer incidence of 1 to 5 percent (Jansen, 1989).

Squamous Cell Carcinomas. Squamous cell carcinomas have been shown to have a convincing and clear-cut relationship to UV-B radiation: (1) SCC occurs primarily on the exposed parts of the skin, face, neck and hands, and (2) in comparable populations, the incidence of SCC is highest in areas with the most sunlight. The risk of developing SCC is strongly related to the cumulative dose received throughout life. Experiments on mice have provided a dose-response relationship that can be expressed as a power function of the dose of UV-B regularly received; this relationship has been traced back in human epidemiological data.

Overall, the available studies indicate that a 1 percent decline in ozone concentrations will lead to a 4.6 percent increase in SCC. Because SCC is a long-term reaction of the skin to chronic irradiation, however, the full effects may not be realized for several decades.

There remain several problems before these estimates can be extrapolated to world populations. First, the incidence of SCC among non-whites is much less than among whites (by at least a factor of 10). As a result, the dose-response relationships have not been estimated as well. Second, many of the studies have been done in regions recently settled, such as the U.S. or Australia, where there is a reasonably random distribution of many skin colours for a given latitude (allowing for some inferences to be drawn for the given latitude band). However, there are many variations in skin colour throughout the world at many different latitudes for which dose-response relationships could vary from currently available estimates. Third, the decrease in stratospheric ozone is not anticipated to have a uniform latitudinal distribution. Thus, accurate estimation of the increased incidence will require the use of two- or three-dimensional models of CFC concentrations and stratospheric ozone depletion.

Basal Cell Carcinoma. The relationship between UV-B and incidence of basal cell carcinoma is less clear. For example, BCC also is more prevalent on more highly exposed skin, but the relationship is not as clear as for SCC. Also, BCC occurs more frequently in areas with more sun, but the latitudinal gradient for BCC is not as strong as that for SCC. Moreover, mice exposed to UV lamps do not develop BCC, so that an action spectrum has not been developed.

Because of the clinical and epidemiological similarities between BCC and SCC, however, it has been assumed that BCC is a consequence of solar UV-B radiation. By further assuming that BCC and SCC have the same action spectra, the overall amplification can be estimated to be 2.7.

It should be noted that, although BCC is a far more common form of NMSC, the response estimates are far less certain than for SCC. For areas where only combined data on BCC and SCC are available, the most appropriate estimate of the increased incidence in NMSC appears to be about 3.

Cutaneous Malignant Melanoma

There are four major types of cutaneous malignant melanoma (CMM); for only one, Lentigo maligna melanoma (LLM), is there a clear relationship between incidence and cumulative exposure to the sun. The overall evidence supporting a relationship between CMM and solar radiation include (1) higher incidence among people lacking protective pigmentation, (2) a correlation in some well-designed epidemiological studies between CMM incidence and decreasing latitude (i.e., increasing sunlight and UV-B levels), (3) an association in case-control studies between solar exposure and risk factors for CMM (including freckling and nevus formation), and (4) higher incidence of CMM among immigrants to sunny climates than among natives. Several facts, however, have caused some controversy about the dose-response relationship between radiation and non-LLM cancers: (1) individuals who spend much of their time outdoors do not have an increased risk of developing non-LLM cancers; (2) no clear relationship exists between site-specific incidence and solar exposure on the skin; (3) several epidemiological studies have failed to find a latitudinal gradient (and, therefore, a relationship with the dose of solar radiation) for CMM; and (4) no animal model exists.

Based on a review of the overall data, however, the U.S. Environmental Protection Agency (U.S. EPA, 1987) determined that the experimental data and literature supports a role for sunlight in all CMM, not just LLM, with the active spectrum most likely in the UV-B range. The overall dose response suggested by the study indicated that each 10 percent reduction in stratospheric ozone would correspond to a 3-5 percent increase in CMM, and a 2-10 percent increase in CMM mortality.[3]

There are several difficulties in extrapolating this dose-response relationship to the global community. First, the action spectrum has not been adequately delineated, so the increase in active radiation per decrease in stratospheric ozone can only be estimated. Recently, two researchers have developed promising animal models (one in fish and one in marsupials), but quantitative results have not yet been obtained and published. Second, the dose-response relationship is quite uncertain, with a range of 60 percent between the low and the high estimate. Thus, the estimated incidence will be highly uncertain. Third, the incidence of CMM appears to be race-dependent, which means that regional incidence rates would be needed.

5.2.3 Other Skin Disorders

A 1988 study used data from a 1971 to 1974 survey of more than 20,000 United States citizens to determine the relationship between exposure to the sun and the incidence of skin disorders (Engle et al., 1988). Exposure to the sun was estimated through a questionnaire covering occupational and recreational activities that would lead to exposure. The study found significant increases in the prevalence of actinic skin damage among whites exposed to higher levels of sunlight, as well as strong correlations between levels of actinic skin damage and the incidence of a wide range of oral and skin disorders. Except for localized hypermelanism and localized hypomelanism, the study found that blacks have both a low incidence and a statistically insignificant correlation between sunlight exposure and skin damage.[4]

The most significant finding was the correlation between the incidence of basal cell carcinoma (BCC) and actinic skin damage. Among Caucasian males aged 65 to 74, 11.3 percent of those with severe actinic skin damage were found to have BCC, as compared with 1.0 percent of those with undamaged skin. In addition, there was a significant correlation between the incidence of actinic skin damage among white males and sunlight exposure. White males with high sunlight exposure (determined through studies of occupational and recreational activities that would lead to exposure) had 1.6 times as many cases (36.7 percent vs. 23.3 percent) of actinic skin damage as white males with low exposure. The most significant form of actinic skin damage, actinic keratosis, was 2.6 times as likely for white males with high sun exposure as for white males with low sun exposure (14.4 percent vs. 5.6 percent). For white females, there was an eight-

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[3] Research by the Dutch State Institute for Public Health and Environmental Hygiene estimate a 0.8-1.5 percent increase in fatal melanoma skin cancer for each 1 percent reduction in stratospheric ozone levels (Jansen, 1989).

[4] In fact, black women with high sun exposure had a significantly lower incidence of actin skin damage than black women with low sun exposure (0.6 percent vs. 3.5 percent).

fold increase in BCC between women with no actinic skin damage and women with severe skin damage, but the difference was not statistically significant.

The study also found a significant relationship between exposure to the sun and a variety of dermatological disorders. Sunlight exposure was positively correlated with localized hypomelanism, localized hypermelanism, seborrhoeic keratoses, senile lentigines, freckles, acne rosacea, spider nevi, varicose veins, venus star, dry skin, wrinkled skin, pterygia, arcus senilis, and a variety of minor oral lesions.

The study does not, however, provide adequate data to determine a dose-response relationship between sunlight exposure and skin disorders, because no quantitative measure of sunlight exposure was made. The study suggests that blacks may have lower levels of impacts as a result of increasing UV-B irradiation. The effect of increased sunlight on other races was not examined in the study, possibly because of an inadequate sample size. Thus, the global increase in skin disorders with increasing UV-B irradiation cannot be estimated.

5.2.4 Cataracts and Other Eye Disorders

Current evidence suggests that exposure to UV radiation may contribute to a wide variety of eye disorders. Although the most significant disorder is cataract, other disorders include photokeratitis (snow blindness), and retinal and corneal disorders (such as retinal degradation, arcus senilis, and pterygia). In the U.S. and other developed nations, corrective surgery can prevent most cataracts from causing blindness. Still, cataract remains the third leading cause of legal blindness in the U.S. In developing nations, where such operations may be less available, cataracts result in a much higher incidence of blindness. The World Health Organization estimates that cataracts were responsible for 17 million cases of avoidable blindness in 1985.

A variety of epidemiological and animal studies have suggested that the formation of cataracts is etiologically related to exposure to solar radiation, with the most active portion of the spectrum in the UV-B range. Based on earlier epidemiological data on occupationally exposed individuals, it has been estimated that a 1 percent decrease in stratospheric ozone could result in an increase of 0.3-0.6 percent in the incidence of cataracts.

Extrapolating the dose-response relationships to estimate global impacts is difficult for several reasons. For example, the incidence of cataracts increases with increasing age, and the life expectancy in developing nations is expected to grow. Whereas only half of the world's elderly resided in developing nations in 1985, two-thirds are expected to reside in developing nations by 2000. Thus, the extrapolation will need to consider changes in the age distribution of both developed and newly developing nations. Also, other causes, such as nutritional deficiency, have been implicated in the formation of cataracts. In principle, the extrapolation should consider the baseline incidence of cataracts in various regions, and try to consider changes in the incidence of malnutrition.

5.2.5 Suppression of the Immune System

Ultraviolet radiation has profound effects on the immune system, particularly that of the skin. A growing body of evidence shows that UV radiation reduces the ability of the cell-mediated arm of the immune system to respond adequately to foreign substances.[5] There are a large number of diseases that might be affected by UV-induced immunosuppression, including all diseases that have a stage involving the skin and to which cell-mediated immunity is important. Examples include (1) measles and other viral diseases (including chicken pox and herpes), (2) parasitic diseases induced through the skin (including leishmaniasis and malaria), (3) bacterial diseases (potentially including tuberculosis and leprosy), and (4) fungal infections, such as candidiasis.

To date, the only disease for which human studies have found a link between UV-B irradiation and illness is herpes simplex, where exposure to UV radiation has been shown to lead to reactivation of the virus. The reactivation has been shown to occur both from single doses equivalent to a mild sunburn (3 MED) and from multiple sub-erythemal doses (10 exposures equivalent to 5 or 6 MED).[6] Although the mechanism leading to reactivation in humans is unknown, studies in mice indicate that UV irradiation of a herpes infection leads to the development of T_s cells, which decrease the activity of the T cells that would normally react to the herpes-infected cells (Aurelian et al., 1988).

Studies in mice, however, have implicated UV radiation in reduced immune response to a wide variety of infections, including those caused by protozoa, parasites, and bacteria. If true for humans, these studies suggest that increased UV irradiation could have extensive world health impacts. For example, leishmaniasis is a protozoan infection estimated by the World Health Organization to lead to 400,000 new cases a year as a "gross underestimate" (UNDP, 1980). Based on a series of studies using mice, the hypothesis has been developed that exposure to sunlight could result in a suppressed immune system and predispose individuals to more severe disease. Preliminary models using mice have also found that UV irradiation at low doses can impair the ability of the host to control malarial infections, although additional work will be needed to determine whether UV affects the immune response to malaria in humans. Animal studies have also shown that animals given moderate doses of UV radiation may be immunosuppressed, and have difficulty clearing infections of yeasts and bacteria commonly found on the skin, when the diseases are administered through an intravenous dose.

A major implication of the studies is that if pathogens are administered after exposure to the sun, the body's immune response may be diminished, and the effect may be <u>increased</u> tolerance to the pathogen. Thus, if an individual is immunized through UV-exposed skin, the potential exists for the treatment to render the individual more susceptible, rather than less susceptible, to the disease. Because the effective control of many infections (e.g., measles) depends on

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[5] The immune system has two principal forms of defense. One is achieved via a soluble molecule termed an antibody, the second is mediated via the activity of lymphocytes. Traditionally, immune responses in which lymphocytes play a role are termed "cell-mediated." A summary of the effects of UV radiation on the immune system is provided in Chapter 3 of the Effects Group Report (EGR).

[6] The MED, or minimal erythema dose, is defined as the minimum amount of energy required to produce clearly a defined sunburn on the sun-exposed area of the skin (Parrish et al., 1983).

effective vaccination, the implications of UV exposure for disease control in both developed and developing nations are staggering.

Unfortunately, the studies have not provided dose-response relationships for a single illness for any racial group, much less disease-specific dose-response relationships for the wide range of potentially relevant diseases. In virtually all cases, the effects have been determined through animal models, generally using mice. No human epidemiological data have so far been developed to support or refute the results of the animal models. In addition, the costs associated with increased morbidity are unclear. In nations with extensive health care systems, the costs can be estimated in terms of the costs of medical care and lost productivity. Where health care is not as widely available, the cost to the society may be larger in real terms, but non-quantifiable.

5.2.6 Increase in Tropospheric Ozone

Studies have identified a relationship between UV-B increases and the formation of tropospheric ozone (smog). As stratospheric ozone is destroyed, UV-B radiation penetrates further into the atmosphere, accelerating the creation of ground-based or tropospheric ozone. A study by Liu and Trainer (1988) reported that a 20 percent loss of stratospheric ozone in rural mid-latitude regions induced a 10 percent increase in tropospheric ozone. Generally, increases in UV-B radiation were found to result in higher levels of ground-based ozone.

Current measures used to control air pollution levels fail to take into account the effects of increased UV-B radiation on smog formation. Research conducted in the U.S. by Gery and Burton (1989) concludes that additional emission controls will be needed to compensate for the effects of stratospheric ozone loss in order to maintain present tropospheric ozone standards (EGR, Chapter 6). They conclude that increases in tropospheric ozone can be avoided by reducing volatile organic compounds (VOC) emissions by between 0.3 and 0.8 percent for each 1 percent decrease in stratospheric ozone. Further restrictions on VOC emissions would be an additional cost of stratospheric ozone depletion.

Public concern surrounding the growth in tropospheric ozone concentrations generally centres on the potential harm to people's health. A recent study by the U.S. EPA (1986) lists a number of human health effects from increased ground-based ozone. They include:

- changes in pulmonary function (respiratory capacity);
- increased likelihood of asthma attacks;
- decreased resistance to disease; and
- extrapulmonary changes such as aberrations in red blood cell structure, enzyme activity, and liver metabolism.

While these human health effects clearly occur in response to increases in tropospheric ozone, the actual extent to which people are affected is difficult to quantify.

The adverse effects from tropospheric ozone, however, go beyond threats to human health. A risk assessment by the U.S. EPA (1987) identified several additional harmful consequences of tropospheric ozone. This report indicated that increased amounts of low-level ozone may also adversely affect agricultural yields, forests, other plant species, ecosystems, and materials. Much of this study specifically examined the level of foliar injury due to increased exposure to ground-based ozone. The observed impacts varied according to the type of plant, as well as length of exposure and the concentration of ozone present.

Additionally, results from the European Open Top Chamber Program also clearly indicate that, for example, an assumed 10 percent increase in ground-level ozone concentrations will produce some increase in crop loss in many areas of Europe, and show effects on natural vegetation. Thus, outcomes of research in Europe and the U.S. confirm the damaging effects of increased tropospheric ozone.

Several factors complicate understanding of this phenomenon. Studies analyzing these impacts were conducted predominantly in the U.S. and Europe over a limited period of time. Additionally, the production of tropospheric ozone involves several factors in addition to UV radiation, all of which can vary by geographic region and over time. Thus, the actual amount of low-level ozone produced for a given rise in UV-B radiation may be different in other countries, and increase or decrease as conditions change with time.

The available evidence also implies that damage to human health from increased tropospheric ozone levels increases significantly as the amount of time people are subjected to "unhealthy" levels increases. This may affect developing countries more severely than most developed nations due to rapid growth in population and urbanization in these countries since as the growth of these cities continues, an increasing number of people will suffer from the effects of low-level ozone.

Impacts on agricultural productivity may also affect certain regions more severely than others. For example, as the populations of developing countries continue to grow, the pressure on current sources of food will also rise. Declines in the level of food production may affect these countries to a greater extent than developed nations, such as the U.S., which produce a surplus of agricultural products. Different cultivation techniques, such as lower usage of fertilizers and pesticides, may also alter susceptibility of crops to damage from ozone.

5.2.7 Effects of UV-B on Plants

Several studies have suggested that many commercially important crops may be sensitive to the levels of UV-B radiation. The studies have found effects on both the yield of the crops and in the chemical composition of the plant leaves, although the extent of UV-B sensitivity is highly dependent both on species and on the specific cultivar examined. The crops that have been studied include soybeans, cucumber, gymnosperms (conifers), sunflowers, wheat, flowering plants, cabbage, lettuce, rape, potato, squash, rice, peanut, and corn. So far, about 300 species and varieties have been investigated for sensitivity to UV-B radiations, of which about two-thirds have been shown to be sensitive.[7]

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[7] Based on personal communication with Dr. Alan H. Teramura.

One long-term study of soybeans suggested the variation in responses that is possible. The study design reviewed 23 soybean cultivars in greenhouse studies, followed by a study of 6 cultivars in field studies. Finally, two commercially important cultivars ("Essex" and "Williams") were followed over a 5-year period. For 3 of the 5 years, at a simulated 25 percent reduction in ozone, UV-exposed "Williams" cultivars were found to have a 10-22 percent higher yield, whereas "Essex" cultivars were found to have a 20-25 percent decline in yield. No consistently significant relationship could be found in either "Essex" or "Williams" at a UV level simulating a 16 percent decrease in ozone (Teramura and Sullivan, 1988).

Other studies have implicated increased UV-B irradiation with an increase in UV-absorbing compounds in the upper epidermal layers of leaves. These compounds are primarily phenylpopanoids, such as cinnamoyl esters, flavones, flavanols, and anthocyanin compounds. Increased concentrations of these compounds have been found in rye and radish seedlings exposed to increased UV-B levels. Exposed cucumbers have been found to experience a change in the surface lipids, with the alkane and alcohols of the main wax compounds being shifted to shorter-length homologues.

Some plants have also shown an effect of UV-B irradiation and flowering. Although there are no supporting data, there has been speculation that UV-B could affect the timing of flower induction. If plants flowered earlier or later than the appearance of their natural insect pollinators, this could have far-reaching consequences on natural ecosystems.

Except for soybeans, none of the studies has provided field-based dose-response relationships, and the study on soybeans showed a large difference in response across cultivars. Many of the studies have been conducted in growth chambers, under conditions of unrealistically low light that have been found to increase the sensitivity of plants to UV-B radiation. Other studies have been conducted in greenhouses, where the control group received no UV-B radiation. Because this is not realistic for most crops, the significance of the response may be questioned. Still other studies have shown that plants are less sensitive to UV-B radiation under drought or mineral deficiency, suggesting that the greatest impacts on yield may be in societies with abundant fertilizer and water supplies.

In addition, there have been no studies of natural ecosystems, including natural forests, meadows, savannas, tundra, or alpine areas. The UV-B effects on growth and reproductive cycles of lower plants, including mosses, fungi, and ferns, have not been studied. These natural plants are important because they provide a reservoir of genetic diversity for crop breeding programs, as well a providing an important source of new drugs, medicines, and natural products.

5.2.8 UV Impacts on Aquatic Life

Other recent studies indicate that increased UV radiation due to ozone depletion adversely affects marine life. The U.S. EPA (1987) reports that fish larvae and other organisms essential to the food web suffer decreased fecundity, growth, and survival rates from exposure to increased UV radiation. Researchers express concern that this damage may potentially upset the natural balance of the food chain.

A study by Hunter et al. (1982) analysed the effects of increased UV radiation on anchovy larvae and the resulting impact on anchovy populations. In a laboratory experiment, Hunter et al. estimated the dose-response relationship between increases in UV radiation levels and the loss of anchovy larvae. The results indicated that 8 percent of the annual larval population would be killed by a 20 percent increase in UV-B radiation. Factors found to affect the dose-response rate include: the abundance and distribution of larvae, the degree of vertical mixing (number of larvae found and various depths), and the amount of UV radiation penetrating the seawater. Other studies prepared in the U.S. provide evidence that similar deleterious effects occur for several other types of marine life (Worrest, 1983).

The potential impact of increased UV-B radiation on the ocean's microscopic plant and animal life is also a source of concern. Planktonic organisms, for example, serve not only as a primary food source for many species of marine life, but also as a major sink for carbon dioxide. Studies of several types of plankton indicate that UV-B radiation affects the motility, orientation, growth and development of these organisms (EGR, Chapter 5). The studies found that increased radiation led to lower rates of growth and reduced populations.

Research clearly indicates the deleterious effects of UV-B radiation on marine life. However, several factors make it difficult to quantify the overall impact of the damage from potential increases in UV-B radiation. For example, the results of the study by Hunter et al. on anchovy loss are based on laboratory rather than ocean conditions. Also, differences in the damage to larvae will occur as seawater clarity and the vertical mixing of the fish vary. Thus, the actual loss of anchovy larvae will likely vary from estimates made in the study.

An important limitation of the research on plankton is that the studies often used artificial sources of UV-B radiation. These sources frequently produce radiation that is quantitatively and qualitatively different from natural radiation.

A final consideration in extending these observed impacts to all aquatic organisms is that very little is known about the dose-response effect of UV-B radiation for other species. Differences in preferred habitat and physical characteristics may make certain aquatic life more or less susceptible to the damaging effects of UV-B radiation.

5.2.9 Materials Damage

Several studies have found polymeric materials to be sensitive to UV radiation. Researchers discovered that the molecular structure of polymers can be broken down by exposure to radiation. Thus, decreases in stratospheric ozone that result in higher levels of UV radiation may affect the usable life of exposed polymers. Polymers most likely to be affected are those used in outdoor applications. Andrady (EGR) also notes that the level of damage is potentially greater for polymers used in locations near the equator. A common technique used to counteract the effects of UV radiation is to add a light stabilizer to the polymer. The stabilizer absorbs light in the UV range of the spectrum, thus reducing the damage to the polymer itself.

Much of the research to date has focused on the impact of increased UV on a very limited number of polymers. While some information exists about the UV-B dose-response effect on PVC, relatively little data exists on the dose-response effects for other polymers. These data limitations make it difficult to evaluate the impact of increased UV radiation when materials other than PVC are used. In addition, very little evidence is available on the impact on polymers that receive intermittent exposure to UV radiation.

Polymers play a critical role in the economic development of many countries. These plastics are often used in construction materials because they are strong, lightweight, and relatively inexpensive. The potential for damage may be greatest in many developing countries located in the tropics since material degradation is believed to occur more quickly in these regions. However, determining impacts on a global basis will be difficult due to the following factors: (1) variations in polymer usage across regions, (2) differences in the types of polymers needed for the specific environments and usages in different regions, and (3) possible impacts of increased light stabilizer on materials properties, including strength, flexibility, brittleness, and longevity.

5.2.10 Global Climate Change Impacts

In addition to destroying stratospheric ozone, CFCs contribute to global climate change. There are a wide variety of adverse impacts associated with climate change. For example, as the earth warms, a rise in the sea level is expected to occur as the world's glaciers, ice sheets, and polar ice caps gradually melt. Studies indicate that an increase in the level of the world's oceans would lead to flooding, coastal erosion, stronger storm surges, and the destruction of wetland areas. Additionally, there is an increased likelihood of extreme weather events, such as droughts, hurricanes, monsoons, etc. A rapid rate of climate change could also seriously stress existing ecosystems as plants and animals would be unable to adapt quickly enough to climate-induced changes. It is also possible that major destabilization of the atmosphere could occur as a result of biogeochemical and geophysical feedback processes that are currently poorly understood.

The current state of knowledge on the type and magnitude of impacts associated with global climate change is too limited to allow for quantification of the impacts. While some studies have analyzed some of these impacts, such as some of the impacts due to a rise in sea level, the atmospheric processes are too complex and too varied to provide much detail. Additionally, quantifying the extent to which stratospheric ozone depletion contributes to global warming is difficult because (1) it is not certain how much CFCs will contribute to global climate change and (2) there is much uncertainty over the type and magnitude of effects to expect for a given amount of global climate change. These impacts, however, could have catastrophic implications in many regions. For example, in some low-lying regions (such as Bangladesh) the impacts of sea level rise could be severe for several reasons, including high population concentrations, flooding and salination of agricultural areas near the coast (e.g., rice paddies, which supply an important food source for many developing countries), and increased storm intensity, which may cause more severe damage to crops.

5.3 VALUATION OF BENEFITS

As discussed in the preceding section, the available scientific evidence indicates that stratospheric ozone depletion will affect human health and the environment through several pathways. However, there is sufficient scientific uncertainty concerning the magnitude of the dose-response relationships and about which human, animal, and plant populations will be affected such that quantification of the impacts cannot be done reliably. Without such quantification, it is also not possible to place an economic value on the impacts. Moreover, as will be discussed in the following sections, there are many problems associated with valuing global human health and environmental impacts. Ideally, the most appropriate concept would be to measure consumers' surplus, yet no data or estimation functions exist to measure it on a global basis. The methodologies suggested here should be viewed simply as possible approaches for evaluating a complex global problem; other approaches may be more appropriate.

5.3.1 Valuation of Human Health Effects

Estimation of the value of human health effects has three major parts: value of quantifiable illnesses, value of quantifiable deaths, and value of nonquantifiable illnesses. In the United States (U.S. EPA, 1988) analysis of the value of health effects resulting from reductions in ozone depletion has started from the available dose-response data. As discussed above, the available studies provide relationships for basal cell carcinoma, squamous cell carcinoma, malignant melanoma, fatal malignant melanoma, and cataracts. Estimates of the number of fatalities from non-melanoma cancers has been inferred as a percentage of the total number of cases. These data have been developed primarily for Caucasians in the U.S. (mid-latitudes) and may not be applicable to other races in other areas of the world. No quantitative models yet exist for estimating changes to the immune system or increased incidence of actinic keratosis or other skin disorders. Key issues to consider are discussed below.

First, the value of quantifiable cases of illness can be estimated. If medical care is generally available, and if the incidence of increased disease is not so great as to cause severe socioeconomic disruption, then the value of increased illness can be obtained by estimating the cost of medical care and the value of lost work-days of production. If medical care is not available, however, or if the level of disease is such as to strain the productive capacity of the society, then the effects of increased illness may be simultaneously more disruptive and costly, and less easily valued. Moreover, measuring only the medical costs probably significantly undervalues this benefit since the total benefit is the reduction in risk, which is enjoyed by many more people than just those unfortunate enough to develop the illness.

Second, the value of cases of fatal diseases can be estimated in several ways. In the United States, a substantial body of literature based on risk-wage relationships in a market-based labour market has been used to estimate the dollar value placed on voluntarily assumed low-level risks. Some of the literature, however, suggests that the "value of life" is, economically, a "superior good." That is, the proportion of income spent on medical care to extend expected lifetimes increases more than proportionately with income. Because of differences in overall wage rates and employment opportunities in other regions of the world, the values developed in U.S.-based studies may not be appropriate for other countries, yet using lower (or higher) values proposes that where one lives changes the value to be used in analyzing the economic merits of reducing CFC production and emissions.

Third, the value of illnesses that cannot be quantified cannot be measured. However, these illness may have the most significant impact, in terms of numbers of cases of disease and potential for severe socioeconomic distortions. One effect that has not been studied is the increase in respiratory illness caused by increased tropospheric ozone. Many of the world's largest and fastest growing cities are in developing regions with significant levels of ozone precursors in the atmosphere; these cities may experience substantial effects, including potential "killer smogs."

Another significant, but as yet unquantified effect, is the apparent ability of UV radiation to reduce the ability of the immune system to respond adequately to antigens. UV-B can apparently affect the host's ability to respond to infectious diseases that enter through the skin, including viral, bacterial, fungal, and protozoan infections. Because these diseases are more prevalent in less developed nations of the world with less medical care, the impact of UV-induced immunosuppression is likely to fall most heavily on the societies that are least able to treat the illness.

The potential impact of UV-B induced immunosuppression on human disease is, at this point, still a matter of hypothesis; there are no experimental data that have specifically documented the precise nature of UV-radiation-induced immunosuppression. Based on research to date, however, a number of hypotheses seem reasonable: (1) all populations, black and white, may be at risk; (2) individuals who are already immunosuppressed, such as transplant patients, could be at greater risk than the rest of the population due to additive effects; and (3) in developing countries, particularly those exposed to higher UV-B levels near the equator, parasitic infections of the skin could be exacerbated.

It should be emphasized that the analyses to date assume marginal increases in the number of cases of disease, with effective medical treatment readily available. In the event of extensive increases in the mortality and morbidity of populations, the net impacts on society could be much larger than those measured through the costs of treatment. If worker productivity in agricultural-based economies declines substantially, for example, "ripple" effects such as crop failures could extend the impacts well beyond the original population of diseased individuals. Also, the analyses to date have assumed that medical treatment is generally available, so that the effects are constrained in time and severity. If treatment is not available, than the proportion of fatal cases would exceed the estimates based on the available studies.

5.3.2 Decline in Aquatic Life Populations

As a measure of the economic consequences to the U.S. of these effects on marine life, the U.S. EPA (1988) estimated the potential economic loss to commercial fisherman if a decline comparable to the loss observed for anchovies in laboratory studies occurred in the populations of various commercial fish. The U.S. EPA looked at the size and market value of fish harvests between 1981 and

1985, and estimated potential future economic losses due to decreases in the level of stratospheric ozone.

This approach does not resolve many of the difficulties in valuing aquatic losses. For one thing, it does not take into consideration impacts on freshwater species, or non-commercial species. Also, future harvest levels and market values will vary due to factors other than UV radiation, making it difficult to extrapolate to other years. Also, it should be noted that 30 percent of the world's protein is currently derived from fish. Potential losses to these resources may significantly affect the economies of individual countries (e.g., loss of a major food source or source of export income).

Adverse impacts on aquatic productivity may affect some regions more than others. In many developing countries fish and other aquatic animals serve as a vital source of protein and other nutrients. Overall, more than 30 percent of the world's animal protein for human consumption comes from the oceans. In addition, development efforts in many countries often focus on enhancing their ability to harvest sea life for domestic consumption and export. The impact of significant declines in the populations of certain types of aquatic life, or other disruptions in the aquatic food chain, could be very severe for those countries that depend on these animals for food and income since other alternatives may not be available.

5.3.3 Tropospheric Ozone Impacts

Attempts to place a value on the effects of increases in tropospheric ozone have only been made with regard to agricultural impacts in the U.S. For example, Rowe and Adams (1987) estimated that a 15 percent decrease in stratospheric ozone levels would lead to $1 billion annual decrease in the economic surplus produced by the U.S. This study estimated the value of lost production in terms of the loss of "economic surplus" -- the difference between the total market value of the crop and the total cost of production. The focus was only on wheat, rye, rice, corn, oats, barley, sorghum, and soybeans; potential impacts on other crops, including fruits and vegetables, forests, and other non-commercial species, were not included.

This approach has several limits since in regions with higher production costs or artificially suppressed prices, this approach may distort the actual value of the crop loss. Also, it does not consider possible price changes over time or the possibility that market prices do not adequately reflect the value of the losses. For example, a loss of agricultural productivity in some regions could have catastrophic consequences on human populations dependent on their production for survival. This approach also does not value ecosystem impacts, such as species diversity or forest or non-commercial species, that have no market price on which to value the losses.

Insufficient data on dose-response effects and the difficulty in establishing a meaningful dollar value on changes in human health have limited the assessment of the economic consequences of increased tropospheric ozone on human health. However, as noted earlier, these effects may be greatest in areas already experiencing substantial tropospheric ozone problems or likely to do so in future years.

5.3.4 UV Impact on Plants

Attempts to place a value on the effects of increased ultraviolet radiation have been made only for crops in the United States. Rowe and Adams (1987) developed estimates of the annual change in economic surplus for soybean production in the U.S. as a result of ozone depletion. Additional research by the U.S. EPA (1988) has estimated changes in economic surplus based on the market value of the crop by assuming that all agricultural crops have the same dose-response relationship as soybeans.

5.3.5 Materials Impacts

One method for measuring the potential economic impact of polymer degradation would be to examine the cost of protecting exposed plastics from increased UV-B radiation. Horst (1986) estimated the cost of adding the light stabilizer titanium dioxide to certain PVC products used in the building industry. He then developed an approach for evaluating the costs associated with the production of new PVC with the necessary levels of light stabilizer needed to maintain the characteristics of the polymer. This approach combined with the work of Andrady (1986), who estimated the amount of stabilizer necessary as a function of ozone depletion to maintain the characteristics of the polymer, provides a way of assessing the cost to society of polymer degradation. Using this approach, the Regulatory Impact Analysis (1988) prepared by EPA found that the potential cost to the building industry in the U.S. from polymer damage could be over $5 billion dollars (1988).

5.3.6 Global Climate Change Impacts

As discussed earlier, there are a wide variety of adverse impacts associated with climate change. Among these are sea level rise, which would lead to flooding, coastal erosion, stronger storm surges, and the destruction of wetland areas; an increased likelihood of extreme weather events, such as droughts, hurricanes, monsoons, etc.; inability of existing ecosystems to adapt quickly enough to climate-induced changes; and major destabilization of the atmosphere as a result of biogeochemical and geophysical feedback processes that are currently poorly understood.

The current state of knowledge, however, on the type and magnitude of impacts associated with global climate change is too limited to allow for quantification of the impacts. While some studies have analyzed some of these impacts, such as some of the impacts due to a rise in sea level, the atmospheric processes are too complex and too varied to provide much detail. As an example of one possible approach for valuing the effects, the impacts of sea level rise in the United States were valued using an analysis by Gibbs (1984) that evaluated the effects of a 0.75- to 2.2-meter rise in sea level by 2075 on two coastal communities -- Charleston, South Carolina, and Galveston, Texas. Gibbs analyzed impacts for two types of community responses -- damages if actions anticipating the rise in sea level were undertaken and damages if no anticipatory actions were undertaken. These cost ranges were then used to determine potential impacts at all major U.S. coastal ports.

Clearly, this is a crude estimating technique and real damages could be much higher or lower than indicated by these estimates. Many sea level damage issues, such as flooding of coastal wetlands, beach erosion, increases in salinity in aquifers, among other factors, are not included here. For many areas of the world, however, these effects will be much more significant than the economic damage to port areas. This example illustrates the difficulty of valuing the effects of global climate change.

5.3.7 One Example For Valuing Effects

The preceding discussion illustrates the problems associated with global quantification and valuation of the effects of reduced use of CFCs. As one example of how such an exercise could be conducted if dose-response relationships and valuation procedures were better understood globally, a summary of an analysis on the U.S. is presented below.

Table 5-1 shows the estimated benefits to the U.S. economy of implementing the Montreal Protocol (a 50 percent reduction in CFC use), relative to a scenario with no controls on CFC use. The estimate assumes varying rates of participation among signatories and nonsignatories of the Protocol, based on participation assumptions that appeared reasonable in the Summer of 1988. The most significant effects result from the decrease in human illness and deaths due to skin cancer, which account for more than 95 percent of the total benefits. Nevertheless, the other damages avoided, despite only focusing on U.S. food crops (other ecosystem effects were not directly valued) and despite limits placed in the model used for the analysis that restrict the total damage estimates, account for benefits with a present value of more than $60 billion. In most cases, the range of the benefits estimates are as much as 100 percent higher than indicated in Table 5-1, based on the uncertainty in the dose-response relationships alone. [In 1987, before the Ozone Trends Panel, before the proposed revisions of the Protocol, and before the development of less expensive technologies, the U.S. EPA estimated that costs to comply with the Montreal Protocol were estimated to be $21-$40 billion (1985 U.S. dollars) while the benefits were $3,517 billion.]

Table 5-2 shows estimates of the benefits and costs of controlling CFCs in Japan as developed by a consultant to the Ministry of International Trade and Technology. Differences between the U.S. and Japanese estimates are attributable to several factors: (1) the U.S. estimates of the value of avoided risk to lost human life are 10 times higher than the Japanese assumption of $300,000; (2) the Japanese estimates assume HFC-134a is used in refrigerators with a high energy penalty, whereas the U.S. estimates do not; (3) the Japanese estimates for reductions smaller than a phase-out are scaled as a percentage of phase-out costs, while the U.S. estimates are modeled around cost curves; and (4) the estimates include very different end-points for effects and costs.

It should be noted that neither the U.S. nor the Japanese analysis considers the amount of actual depletion that has already occurred, but both are based on pre-Montreal projections of ozone depletion.

Table 5-1. Quantification of Effects on U.S. Economy from Global Implementation of Montreal Protocol (Based on Effects on Population Born Before 2075)[a]

Effect	Measure	Quantity Assuming No Depletion	Additional Quantity Assuming No Controls	Additional Quantity Assuming Protocol	Quantity Avoided (Relative to No. Controls[a]	Value of Benefit (billions of 1985 U.S. dollars)
Nonmelanoma Cancer	Million Cases	160.1	178.0	5.1	172.9[c]	73
Nonmelanoma Deaths	Thousand Deaths	Not Available	3,528.1	80.6	3,448.1	3,216[d]
Melanoma Cancer	Thousand Cases	4,230.0	839.3	45.9	847.4	1
Melanoma Deaths	Thousand Deaths	1,200.0	211.3	10.8	200.5[e]	224[d]
Cataract	Million Cases	182.2	20.1	0.9	19.1	3
Fish Harvest	Decrease	-	>25.0%	0.0	>25.0%	7
UV-Induced Crop Decline	Decrease	-	>7.5%	0.6%	>6.9%	27
Tropospheric Ozone-Induced Crop Decline	Decrease	-	Variable[f]	Variable	Variable	15
Polymer Damage	Avoided Stabilizer	-	>25.0%	7.6%	>17.4%	4
Sea Level Rise	Cm. of rise avoided	-	99.6	87.0	12.6	5-12[g]

[a] Although the effects will be incurred by people of all generations, the highest effects are incurred by people born later in the period.

[b] Recent evidence suggests that ozone levels have already declined by about 3 percent from the levels preceding the development of CFCs. The number of additional cases (relative to zero ozone depletion) if ozone levels were stabilized at the current depletion level (3 percent) has also been estimated: Cases of nonmelanoma skin cancer, 11.2 million; deaths from nonmelanoma skin cancer, 179,000; cases of melanoma skin cancer, 98,000; deaths from melanoma skin cancer, 23,000; cases of cataracts, 19.7 million.

[c] The increased incidence of non-fatal cancers in the Netherlands is estimated to be about 750 to 7,500 cases per year, assuming no restrictions on CFCs and considering only the effects of CFC-11 and CFC-12 (Jansen, 1989).

[d] Value of human mortality reductions estimated as $2 million per unit mortality reduction, in 1985 dollars.

[e] The increased mortality in the Netherlands is estimated to be about 16-60 cases/yr., assuming no CFC restrictions and considering only the effects of CFC-11 and -12 (Jansen, 1989).

[f] Crop impacts vary depending on specific crop and local levels of tropospheric ozone increase avoided.

[g] Value of sea level rise depends on extent to which the rise is anticipated and mitigatory measures are taken.

Table 5-2. Comparison of Costs and Benefits Through 2075 by Scenario, Japan Only (billions of 1985 dollars)

Scenario	Health Benefit by Skin Cancer	Energy Cost	Net Incremental Net Benefits Net Incremental	Benefits (Minus Cost)
No Controls	--	--	--	--
CFC Freeze	62	4	58	58
CFC 20% Cut	63	12	51	-7
CFC 50% Cut	66	30	36	-15
CFC 80% Cut	68	48	20	-16

Source: "A Study of the Economic Impact Analysis on Regulation for CFC/Halon", Masuhiro Sato; Environmental Science Research Institute, Inc.

NOTES:

1. Health benefits are estimated only considering the skin cancer deaths without medical treatments for skin cancer illness. In Japan benefits considering medical treatments can be negligible since the ratio of deaths to patients in the case of skin cancers is 0.8 and costs of deaths are more expensive than the medical treatment fee. The cost for each death is evaluated using a method which is adopted in the automobile insurance industry for casualties. Using this method, the average cost for each death becomes about $300,000.

2. The health benefits projected for skin cancer alone are estimated assuming no ozone depletion has occurred at the current time. The Ozone Trends panel has demonstrated 1.5-3 percent depletion. With a higher ozone depletion rate, the skin cancer estimated by models would be much higher than used in this analysis. In Japan, however, the number of skin cancers decreased as compared with 10 years ago.

3. HFC-134a is assumed to have an 8 percent energy loss as the refrigerator's working fluid, and HCFC-123 to lose 7 percent as the insulating blowing agent for refrigerators. HFC-134a is assumed as the new mobile source air conditioning fluid.

4. Costs are estimated considering only the decline of the energy efficiency caused by substitutes. They do not include other costs, such as the replacement costs of equipment of CFCs-users, the risk of harmfulness of substitutes, etc. The additional energy use for HCFC-123 could be eliminated if the walls of the refrigerator were thickened.

Table 5-2. Comparison of Costs and Benefits Through 2075 by Scenario, Japan Only (billions of 1985 dollars) (Continued)

5. The estimation is done by using the substitutions as follows: HFC-134a is used for cooling equipment; HCFC-123 is used for foams as an insulator; and HFC-134a is used for automotive air conditioning. Use of ternaries like HCFC-22/HFC-152a/HCFC-124 is not assumed in Japan because of the possible toxicity of HCFC-124 and because of the inclusion of a flammable component in a nonflammable mixture. Such uses elsewhere might save 3 percent energy.

6. The average size of refrigerators in Japan is projected to increase; 514.8 kwh is used as the estimated electricity use. The average number of refrigerators assumed per household is 1.2. In the future the number of refrigerators may increase in Japan.

7. The price of electricity assumed is 23 yen ($0.16) per kwh.

8. A. Increase in gas consumption when HFC-134a is substituted in automotive AC: (1) Mileage per litre: 10 km\litre; (2) Total mileage/year = 20,000 km/year; (3) Season for air conditioning (May-September): 5/12; (4) Total gas consumption per year = total mileage per year/mileage per litre = 2,000 litre/year; (5) Energy loss coefficient for substitution of HFC-134a = 0.33 percent; (6) Total increase in gas consumption per automobile = total gas consumption during air conditioning season X energy loss coefficient = 2.75 litre/year per automobile; (7) gas price in Japan from 1976-1988 was 89.9-146.6 yen/litre.

   B. Total number of automobiles with air conditioning in 1985 = 32,000,000.

   C. Total cost for substitution with HFC-134a = total increase in gas consumption/automobile X total number of automobiles X price of gasoline = 7.9-12.9 billion yen/year = 56.5-92.1 million $/year.

9. The method of cost estimation was to assume a 100 percent reduction starting in 1985 and to scale smaller reductions to that level (e.g., a 20 percent reduction annually costs 20 percent of a 100 percent reduction).

5.4 ISSUES AFFECTING GLOBAL BENEFIT ANALYSES

This section reviews some of the key issues affecting the quantification and monetization of benefits as a result of global reductions in the use of CFCs. The first section discusses some of the scientific uncertainties and is followed by a discussion of the problems encountered when attempting to value the impacts in monetary terms. The last section discusses some of the basic problems encountered when attempting to quantify and monetize the benefits of reduced CFC use when these benefits are enjoyed by all people in the world and by future generations.

5.4.1 Scientific Uncertainties

As presented above, there is a limited amount of information on which to quantify the benefits of reduced use of CFCs. There are several types of difficulties encountered. First, the dose-response relationships on which the impacts are based are not fully understood. They have been determined from a limited number of scientific analyses, which has made it difficult to resolve uncertainties concerning the magnitude of the dose-response relationships and the action spectra on which the potential impacts are based. Also, because much of the evidence is based on laboratory or limited epidemiologic studies, the full-scale applicability to a real world setting cannot easily be quantified. Second, uncertainty over the exposure pathways makes it difficult to ascertain how widespread the impacts might be. For example, while certain agricultural crops appear to be adversely affected by increases in UV-B, other crops (in many cases, even different cultivars of the same crop) do not appear to be damaged. These uncertainties make it difficult to identify which species are likely to be most affected by stratospheric ozone depletion. Third, the geographic distribution of the human health and environmental impacts is difficult to gauge due to global variations in the extent of UV-B increases and warming impacts and the possibility that the dose-response mechanisms may vary significantly from one region of the world to another as a result of processes that are poorly understood at the moment. Due to these various uncertainties, our ability to quantify all potential human health and environmental impacts is limited. For example:

- Exposure to UV-B radiation has been implicated by laboratory and epidemiologic studies in the U.S. to cause non-melanoma and melanoma cancers, but the appropriate action spectrum is not known and the applicability to non-Caucasian populations and populations outside of the latitudinal location of the U.S. is unknown.

- Studies have linked UV-B radiation to suppression of the immune response system in animals and possibly humans. This impact has been studied only for the herpes simplex virus and leishmaniasis in animals; the impact on other diseases and on humans has not been studied.

- Studies of the impact of UV-B radiation on plants suffer from difficulties in experimental design, the limited number of species and cultivars tested, and the complex interactions between plants and their environments, preventing firm conclusions from being made for the purpose of quantifying risks.

- The impact of UV-B radiation on aquatic organisms requires additional research to better understand the ability of these organisms to mitigate adverse effects and any possible implications of changes in community composition as more susceptible organisms decrease in numbers.

- The linkage between UV-B radiation and tropospheric ozone formation is based on only one study, necessitating additional research before any conclusions can be drawn.

- Generally, inadequate information exists to quantify the risks related to global warming. Although many of the potential effects have been identified, such as changes in hydrology, warmer temperatures, and increases in storm intensity, the lack of information about the regional nature of climate change makes quantification of these effects difficult.

5.4.2 Uncertainties in Economic Valuation

In addition to the difficulties of estimating the magnitude of the benefits of reduced use of CFCs, providing an economic valuation of the global effects can also be difficult. As mentioned earlier, the ideal approach would be to measure consumers' surplus, yet no data or estimation functions exist to measure it on a global basis. Other approaches may help to understand the potential magnitude of the benefits, yet it may be impossible to resolve all uncertainties. The extent of the uncertainties may depend on the benefit in question.

Human Health Impacts

The magnitude of the value of human health impacts will depend on the methodology used to determine costs to society. One approach to determine these costs is to base the value on the costs of medical treatment on the assumption that the costs associated with medical treatment represent one measure of society's willingness to pay to avoid the human health impact. There are several drawbacks with this approach, however:

-- Even where people can afford the cost of medical treatment, many would place a greater value on the knowledge that such medical treatment could be avoided.

-- It assumes that all human health impacts are amenable to medical treatment. This may not be the case, as with the case of increased susceptibility to diseases that do not respond to medical treatment.

- -- While medical treatment may be possible, not all people afflicted may choose to receive or have access to medical treatment. For example, the value of avoiding non-melanoma may be fairly low if diagnosed early and treated. In the case of people who do not have access to adequate medical treatment, however (as in many regions of the world), the costs could be much larger.

- -- The costs of medical treatment differ from one region of the world to another as a result of different treatment techniques, cost of equipment used, cost of professional medical care, etc.

For human health impacts that are not amenable to medical treatment and/or ultimately result in loss of life, the problem of valuation is compounded. Valuation of these impacts often depends on the value one assigns to human life and pain and suffering. There are no reliable methods for determining such costs on a global basis. For example, in the U.S. two possible methods for assigning value to human lives lost are basing value on (1) the amount of wages lost as a result of death, and (2) the size of awards from the judicial system when liability for loss of life is attributed to one of the litigants. Both of these approaches, however, are very controversial within the U.S. and would be even more so in other regions. For example, basing the value of human life on lost wages implies that people that earn less are inherently valued less than others: such an approach is not suitable for a global valuation since many people may believe that the value should be higher or lower than indicated by this measure. These decisions are clearly value judgments that ought to be left to each society to determine. Additionally, this approach only values the outcome -- a person's death -- and not the additional risk to which each person may be exposed. Many people would value a reduction in risk to which they are exposed, yet this approach ignores the value of any reduction in risk. Among all people exposed to the greater risk the value of reducing risk could be far greater than indicated here.

Environmental Impacts on Plant and Animal Systems

The ease of valuing the impacts on plant and animal systems may depend on the commercial value of the species. For example, losses in the productivity of agricultural crops or commercial aquatic species could be valued using world market prices for the affected foods. For other impacts, however, such as wetland loss or changes in the diversity of the ecosystem, an appropriate valuation methodology would be much more difficult since markets rarely place a monetary value on such assets. Moreover, it is not clear that world market prices fully reflect the value of various commodities. In many regions of the world agricultural crops are produced and consumed without any ties to the world markets, drawing into question the true value of such commodities (the value may be higher or lower than indicated by market prices). It must also be noted that world market prices reflect the marginal value of the commodity; if large shifts in the availability of commodities occur as a result of CFC use, marginal prices are no longer an appropriate price for valuing the changes. Also, world market prices may be more indicative of "ability to pay" than "willingness to pay." Many people might be willing to pay an amount in excess of world market prices to avoid crop losses that are critical to their health and well-being, but are unable to do so because they have insufficient monies or insufficient avenues to express their desires in the world market economy. Additionally, many countries do not choose to allow the free rise and fall of prices in response to supply and demand -- it is not clear how these benefits should be valued.

5.4.3 Other Issues Associated With Global Economic Impacts

Intertemporal Valuation

In assigning a monetary worth to specific impacts avoided as a result of reduced use of CFCs, one is implicitly attempting to value the benefits of these reductions vis-a-vis the costs of achieving the reductions. One of the problems encountered with valuing many of the avoided impacts discussed in this chapter is that these impacts, in the absence of action to reduce CFC use, would be incurred over the lifetimes of people alive today as well as during the lifetimes of generations yet to come. To contend with the problem of impacts over time, one common approach is to discount future impacts using a predetermined discount rate. This discounting approach implicitly values the impacts on future generations less since the value to society today of avoiding those future impacts tends to be negligible once the discounting is done.

Since discounting often minimizes the value of impacts on future generations, it has been argued that standard social discounting procedures are inappropriate for intergenerational valuations. One concern is that it does not recognize the willingness and/or ability of future generations to assign a much higher value to avoiding the impacts because there is no method for properly registering the concern of future generations. Another argument is that social discounting does not adequately incorporate the desire of current generations to bequeath a better world to their children and successive generations. In this sense, there is value in avoiding impacts, thereby preserving options for future generations to decide how best to meet global needs.

Evaluating Large Outcomes With Small Probabilities

The nature of stratospheric ozone depletion is such that the benefits of reducing the use of CFCs are enjoyed in the longer term; that is, many of the effects of ozone depletion would not be realized to their fullest extent for many years or decades to come, and therefore, the value of avoiding these impacts is often greatly discounted (as discussed above for intertemporal valuations). Additionally, there is some evidence that people often have a difficult time evaluating events that have a small probability of occurring (or events in which the probabilities are poorly understood), yet entail very large potential costs if the event were to occur. In these instances, the tendency is often to discount completely the likelihood of the event occurring, or to value it disproportionately since the impact is so catastrophic.

For example, in the case of stratospheric ozone depletion, it is possible that the amount of depletion that occurs may be much greater than indicated by the current state of scientific knowledge, and/or that the human health and environmental impacts may be much greater than currently estimated. Although the probability of these events occurring may be very small, the costs associated with such outcomes may be very large for the world community. Since it is often very difficult to value correctly the expected value posed by such an event, one resolution may be to avoid any attempts to quantify the overall costs, choosing only to highlight the potential outcomes for any decision-making body.

This problem of correctly evaluating events with perceived low probability but catastrophic implications is particularly acute with the impacts of reduced CFC use since the effect mechanisms are often poorly understood. For example, there are a number of potential synergistic effects associated with stratospheric ozone depletion that fall into this category, including possible interactions between (1) increased UV radiation and higher temperatures, (2) suppression of the human immune response system and increased levels of oxidants in the atmosphere, and (3) biogeochemical feedbacks, such as changes in ocean circulation, chemistry, or biology and release of methane hydrates, and increased UV radiation and global warming. The quantification of these impacts is not possible at this time, but the potentially catastrophic implications require that they be seriously considered.

5.5 CONCLUSIONS

As discussed in this chapter, reducing the use of CFCs could have enormous impacts on human health and the environment. In many instances, the current state of scientific knowledge makes it very difficult to quantify the magnitude of many of these impacts. Nevertheless, the scientific evidence is mounting that the impacts could be very large indeed, in terms of cancers avoided, human lives saved, and ecosystem effects on plants and animals, among others. In attempting to value these impacts, there are many issues associated with proper valuation procedures from one region of the world to another and between people alive today and generations to come. These issues make it inherently difficult, if not impossible, to assign a monetary worth to the impacts avoided as a result of reduced CFC use. Regardless of the specific problems encountered when attempting to quantify and monetize the benefits of reduced CFC use, however, it is clear that the overall magnitude of the benefits is very large. As a result, while additional work could be done to quantify the benefits further, this effort would not change the basic conclusion that the monetary value of the benefits will undoubtedly be orders of magnitude greater than the costs of CFC reductions.

REFERENCES

Andrady, Anthony, **Analysis of Technical Issues Related to the Effect of UV-B on Polymers**, Research Triangle Institute, Research Triangle Park, North Carolina, March 1986.

Ashford, Nicholas A. and Robert F. Stone, "Cost-Benefit Analysis in Decision-Making: Theoretical Considerations and Applications to Protection of Stratospheric Ozone (DRAFT)," April 1988.

Chung, H-T, Lee, D.C., Im, S.Y, and Daynes, R.A., "UVR-Exposed Animals Exhibit and Enhanced Susceptibility to Bacterial and Fungal Infections," **Journal of Investigative Dermatology**, Vol. 90, No. 4, April, 1988, p. 552.

Denkins, Y., Fidler, I.J., and Kripke, M.L., "Exposure of mice to UV-B Radiation Suppresses Delayed Hypersensitivity to **Candida albicans**," **Photobiology and Photochemistry** (in press).

Engel, A., Johnson, M.L., and Haynes, S., "Health Effects of Sunlight Exposure in the United States: Results from the First National Health and Nutrition Examination Survey, 1971-1974," **Archives of Dermatology**, Volume 4, January 1988, p. 72-79.

Giannini, S.H., and DeFabo, E.C., "Abrogation of Skin Lesions in Cutaneous Leishmaniasis by Ultraviolet B Irradiation" in **Leishmaniasis: The First Centenary (1885-1985) New Strategies for Control**, Heart, D.T. (ed.), NATO ASI Series A: Life Sciences, London, Plenum Pub. Cos., 1987.

Gibbs, M. "Economic Analysis of Sea Level Rise: Methods and Results." In: Barth, M.C. and J.G. Titus (eds.), **Greenhouse Effect and Sea Level Rise: A Challenge for this Generation**, New York, Van Nostrand Reinhold, 1984.

Horst, R., K. Brown, R. Black, and M. Kianka, **The Economic Impact of Increased UV-B Radiation on Polymer Materials: A Case Study of Rigid PVC**, Mathtech, Inc., Princeton, New Jersey, June 1986.

Hunter, J.R., Kaupp, S.E., Taylor, J.H. (1982). "Assessment of effects of radiation on marine fish larvae." In: Calkins, J. (ed.) **The Role of Solar Ultraviolet Radiation in Marine Ecosystems**, pp 459-497, Plenum, New York.

Jansen, Huib, Vrije Universiteit, Instituut voor Milieuvraagstukken, Institute for Environment, letter to John Hoffman, U.S. EPA, 24 April 1989.

Lacis, A. et. al., "Greenhouse Effect of Trace Gases," **Geophysical Research Letters**, 8:1035-1038, 1981.

Moore, Michael J. and W. Kip Viscusi, "Doubling the Estimated Value of Life: Results Using New Occupational Fatality Data," **Journal of Policy and Management**, Volume 7, Number 3, 476-490 (Spring 1988).

Perna, J.J., Mannix, M.L., Rooney, J.E., Notkins, A.L., and Straus, S.E., "Reactivation of Latent Herpes Simplex Virus Infections by Ultraviolet Light: A Human Model," **Journal of the American Academy of Dermatology**, 1987, 17:473-8.

Rowe, R.D. and Adams, R. M., **Analysis of Economic Impacts of Lower Crop Yields Due to Stratospheric Ozone Depletion**, draft report for the U.S. EPA, Washington, D.C., August 1987.

Rowe, R.D., T.N. Neithercut, and W.D. Schulze (1987), **Economic Assessment of the Impacts of Cataracts**, Draft Report, prepared for U.S. Environmental Protection Agency, January 30, 1987.

Scotto, Fears, and Fraumeni, 1981, "Incidence of Nonmelanoma Skin Cancer in the United States," U.S. Department of Health and Human Services, (NIH) 82-2433, Bethesda, Maryland, pp. 2, 7, and 13.

Taylor, D.W., and Eagles, D.A., "Assessing the Effects of Ultraviolet Radiation on Malarial Immunity," submitted to Sobotka and Company under EPA contract no. 68-01-7288, subcontract no. 132.914 (no date).

Teramura, A.H. and N.S. Murali, "Intraspecific Differences in Growth and Yield of Soybean Exposed to Ultraviolet-B Radiation Under Greenhouse and Field Conditions," in **Env. Exp. Bot.**, in press, 1986.

U.S. Environmental Protection Agency, **Assessing the Risks of Trace Gases that Can Modify the Stratosphere**, Washington, D.C., 1987.

U.S. Environmental Protection Agency, Office of Air and Radiation, **Regulatory Impact Analysis: Protection of Stratospheric Ozone**, August 1, 1988.

Valerie, K., Delers, A., Bruck, C., Thiriart, C., Rosenberg, H., Debouck C., and Rosenberg, M., "Activation of human immunodeficiency virus type 1 by DNA damage in human cells," **Nature**, vol. 333, May 5, 1988, p. 78-81.

Whitten, G.Z. and M. Gery (1986). "Effects of Increased UV Radiation on Urban Ozone," Presented at EPA Workshop on Global Atmospheric Change and EPA Planning. Edited by Jeffries, H. EPA Report 600/9-8 6016, July 1986.

CHAPTER 6

TECHNOLOGY TRANSFER

6.1 INTRODUCTION

An affordable phase-down of ozone-depleting substances will be achieved only if non-CFC technologies are available and adopted worldwide. Forty-nine nations have signed (and 40 have ratified) the Montreal Protocol and thereby have agreed to the Protocol's goal of protecting the ozone layer through a 50 percent cut in CFC production and consumption and a freeze on halon production. Some nations have announced a commitment to a complete phase-out of CFC and halon use. Diffusion of non-CFC technologies depends to a significant degree upon a transfer of technology from those Parties already on a course to eliminate CFCs to those nations whose economic development would have experienced increased CFC consumption had the ozone problem not been recognized.

The underlying principle that informs our approach to the technology transfer issue is that the benefits of controlling ozone-depleting substances are greatly enhanced by worldwide participation. The environmental problem that must be solved is global in scope, and meeting the challenge effectively requires international cooperation. At the same time, the Parties to the Protocol recognize the special situation of the developing countries. Full participation in the phase-down of CFCs and halons should be accomplished without compromising the developing countries' prospects for economic growth. Technology for the transition to a CFC-free world will be created largely in the richer countries that until now have been the main producers and consumers of CFCs. Many of the substitute technologies will be no more expensive, and some are likely to be lower in cost, than existing CFC and halon technologies. Some of the replacement methods will be more expensive. In either case, the initial or transition costs of moving from CFCs to substitutes may be an obstacle to adoption of CFC-free methods by developing countries. For these reasons, a variety of international technology transfer mechanisms need to be examined and tested, including technical training, trade incentives, joint ventures, and multilateral or bilateral assistance measures.

The commercial transfer of CFC-free technologies can be encouraged, while chemical companies in the industrialized countries follow the lead of the CFC producers of the European Community, Australia, and Japan in abstaining from exporting CFC production technologies to any State not party to the Montreal Protocol.

There is a potential conflict between the global aims of the Protocol and manufacturers' desire to recover their development costs via licensing fees and royalties on CFC substitutes. In order for innovation in chemical substitutes, substitute processes, and CFC-free technologies to proceed, it will be necessary for manufacturers to anticipate recovery of the cost of successful research and development. Yet seeking a rapid payback of these development costs could drive up the cost of adopting CFC-free technologies, a factor that would tend to slow adoption of the new methods by developing nations. As we discuss below, multilateral and bilateral economic assistance can play an important role in facilitating diffusion of CFC-free technology.

It should be pointed out that there is still substantial uncertainty concerning the scientific dimensions of the ozone layer problem. This suggests that sustaining a ready capacity to innovate in the face of changing circumstances will be necessary. Retention of part of the profit from new technology is one of the most important stimuli for research and development. A high return on patents is one of the strongest incentives for research. Successful technology transfer will be built on arranging for financing of the new methods in developing countries, promoting exchanges of information already in the public domain, and encouraging cooperative ventures in a variety of forms suited to local conditions.

Three basic economic issues are of concern in evaluating the prospects for CFC-replacing technology transfer: cost, trade implications, and availability of aid. All three will need to be addressed in multilateral and bilateral channels to facilitate the transition. The negotiation of agreements to create an effective and equitable set of institutional commitments to reduce or phase out CFCs and halons is an indispensable adjunct to the review of the Protocol now underway. While outlining the content of potential agreements is beyond the scope of this Report, the importance of technology transfer is already recognized in Articles 5, 9, and 10 of the Montreal Protocol. It is also appropriate, in the process of reviewing the Protocol, to examine the kinds of institutional arrangements needed to make such transfers beneficial to nations not yet party to the Protocol.

6.2 COST

The relative cost of CFC-using versus CFC-free technologies will matter particularly to policy-makers in the developing and newly industrializing countries. The leaders of developing economies may consciously spurn environmental protection policies if those policies make economic development objectives more difficult to achieve (Tyson, 1989). The existing Protocol puts low CFC-using nations on a different footing than high-use nations; implicit in that distinction is the need to facilitate transfer of CFC-free technologies to the developing regions as part of the global ozone-protection strategy of the Protocol.

Other sections of this Report summarize the results of detailed cost comparisons between CFC-using and non-CFC technologies conducted by the UNEP Technology Assessment Panel. Some of those findings are directly relevant to the technology transfer issue. Recent experience strongly suggests that substantial reductions in CFC use can be achieved at no cost or at very low cost. Some electronics manufacturers have announced plans to phase out most of their CFC use voluntarily; others have declared that reductions of more than 50 percent in CFC emissions are possible through housekeeping methods--containment, recapture, and recycling--alone (see Chapter 4).

Aerosol sprays that use CFCs as propellants currently represent about 23 percent of total world CFC consumption weighted by ozone-depleting potential (see Chapter 2). Yet the experience of the United States, Canada, and the Nordic countries, which have banned CFCs in most aerosol applications, and of Japan, Australia, and other European countries that have adopted aerosol phase-out plans, shows that alternative propellants can be substituted in a great many aerosol applications with decreases in costs. These examples are important because they show that for some major applications no cost disadvantage is incurred by choice of a technology that will not harm the ozone layer. The Chairs of the subcommittees of the Technology Assessment Panel have tentatively reported that the provisions of the Montreal Protocol (50 percent CFC reduction; halon freeze) can be achieved with costs less than or equal to current costs (UNEP, 1989).

In the cases where a cost differential is present, it is likely that most of the burden of the changeover to non-ozone-depleting technologies will be borne by the countries that until now have been large users of CFCs. The costs of substitution are principally those of research and development (R&D), as well as transitional expenses associated with the switch from CFC-using to non-CFC-using methods.

The high-use countries have declared that they will follow a path of CFC phase-down; over 80 percent of world production of CFCs occurs in nations that are already party to the Protocol. As a result, manufacturers in these nations have in effect been committed to making the associated R&D and transitional expenditures. Countries that have not yet or only recently have begun to make investments in CFCs need only observe the outcome of the research and development efforts of the high-CFC-use countries; they do not need to make these initial investments of scarce resources themselves. (R&D expenditures include toxicity testing currently underway under the auspices of the multi-firm consortium.) The opportunity to observe this transition to non-CFC-using technology is thus of strategic importance to developing countries considering investing scarce domestic savings or foreign exchange in CFC-dependent facilities.

As experience with CFC substitutes and alternative technologies is accumulated, the cost of these substitutes is likely to decrease. This is an instance of the well-known phenomenon of "learning by doing" (see references given in Chapter 3). Again, the initial steps in the transition to non-CFC technologies taken by the high-use countries will work to the benefit of all. A successful record of production and application of non-CFC technologies will contribute to reductions in their cost. Learning by doing implies that current cost differentials estimated for the high-CFC-use countries are upper bounds for the cost differentials that ultimately will prevail.

Current patterns of CFC usage reflect development of "path dependent" technologies. This means that prevailing uses and the specific nature of the solutions of various engineering problems depend on the path taken historically in the development of CFC-using technology. CFCs often do not represent the only possible engineering solution of a problem. For example, other heat - exchange fluids are used in a variety of refrigeration applications. Some blends of fluids with different boiling points even possess thermodynamic efficiency advantages over the single-fluid systems using CFCs now in production (Kruse et al., 1980). It may be that CFC technologies predominate today for historical reasons distinct from any intrinsic economic or technical superiority. This phenomenon has been observed in a variety of instances in which the historical development of a particular technology has been examined in detail (McLaughlin, 1954; Gee, 1981; David, 1985; see also Arthur, 1984 and 1989).

To the extent that current CFC-using technologies are path dependent, much of their apparent cost advantage results from the fact that over a long period of time engineering optimization has been carried out on CFC-using equipment. The advantages of learning by doing have accrued to the CFC-using processes and methods. Once the switch is made to non-CFC using methods, the normal course of technological progress will result in cost reductions as well as performance improvements. Transitional costs will fall mostly on those developed countries that already have extensive investments in CFC technologies, where the benefits of past optimization to CFCs will be lost, rather than on developing countries that have not yet made investments in CFC-dependent technologies.

In some instances, the changeover to non-CFC technologies will actually increase productivity while lowering cost. Water-based methods of cleaning computer disk drives during the manufacturing process have led to some unanticipated possibilities for improvements in removing certain types of contaminants (Ko, 1989). The more efficient blends would allow construction of refrigeration systems that are more energy efficient than CFC-using systems (Kruse, 1980). The benefits of more energy efficient refrigerators would be particularly marked for any country that planned large increases in refrigerator use, especially if such uses had to be supported by expansion of the electrical power supply infrastructure.

These examples are not meant to imply that the withdrawal of the entire range of CFC-using products from the market can be achieved without cost; only that there will be some unanticipated benefits from the increased research stimulated by the CFC phase-out. If CFCs have not yet become embedded in a country's economy, a maximum of flexibility will exist to take advantage of unexpected or subsidiary technological advances.

It should be noted that all of these mitigations of the cost of adopting non-CFC technologies by developing countries can occur regardless of the level of international financial assistance that is available to ease the transition. The existence of low- or no-cost reduction opportunities, the shouldering of research and development costs by high-use countries, the benefits of learning by doing, and the unanticipated technical advantages of some CFC substitutes will become more and more tangible over time. They represent a specific instance of the general principle that for some new technologies, it is advantageous not to be the first to adopt them (Frankel, 1955).

6.3 TRADE

The emergence of CFC-free technologies will present significant trade opportunities to developing countries. The elimination of CFC-using products in the industrialized countries provides a market-entry opening for exporters elsewhere in the world. Countries and firms seeking to increase their market shares where CFC consumption is high today will be able to offer substitutes at a time when established patterns of consumer choice will be changing. While some products (including many foams) have weight and bulk to value ratios that make them unlikely candidates for trade expansion, other products, including refrigerators and air conditioners, should be subject to brisk competition as the old technology is phased out.

From a trade expansion standpoint, firms and nations seeking to enlarge their exports will face a competitive environment far different from that prevailing today. Because of the change in product technology, firms seeking to compete internationally in markets for CFC-free products can start from essentially the same point, if they have access to technology and expertise. New entrants in the CFC-free market will not be competing against a refrigeration industry in the industrialized countries with decades of optimization on CFC-based compressor and insulation designs behind it. Patterns of international trade today often reflect the advantages of large-scale production, cumulative experience, and leads in innovation (Krugman, 1986). Being at similar points on the learning curve will allow international factor cost differences to condition comparative advantage in CFC-replacing products, rather than existing scale economies, distribution networks, or past technological success.

At the same time, the decline of CFC-based technologies in the already-industrialized countries will surely influence the direction of technical progress in related applications. It is highly unlikely that manufacturers will invest in further improvement of CFC-based technologies, in view of the fact that huge segments of the world market for these products have a lifetime that will not extend beyond the year 2000. Advances in solvents, foam blowing, and refrigeration originating in today's high-CFC using countries can be expected to be based on CFC substitutes; manufacturers in developing countries will be able to benefit from the scientific and technical literature originating in the developed world to the extent that they, too, are moving away from CFC applications.

The benefits to industrializing nations from adopting CFC-free products and processes depend upon their having access to CFC-free technology. Spreading participation in the Montreal Protocol provides one incentive to share CFC-free technology: Parties to the Protocol will seek to forestall the growth of new CFC consumption among non-Party states. One means of doing this is to make available CFC-free technology through access to manufacturing information, training fellowships, and development assistance programs as discussed below.

It will also be necessary to avoid the "dumping" of obsolete CFC-using technologies onto developing countries. Projected phase-downs of CFCs already agreed to or announced will idle a considerable portion of existing CFC-producing capacity and may result in a surplus of equipment that uses CFCs. Government and industry in the industrialized countries need to cooperate to forestall sale of this excess equipment to developing countries. This responsibility has already been recognized by the CFC producers in the European Community, who have pledged not to export technology for controlled CFCs to any State not party to the Montreal Protocol (Conseil Européen des Fédérations de l'Industrie Chimique, 1988), and by the CFC producers of Australia (see Chapter 7.)

Technology transfer is necessary if damage to the ozone layer is to be limited. Yet it must be recognized that technology transfer may not always be in the interest of all stake holders (Hardin, 1969). Manufacturers of CFC-free technologies will compete with one another, particularly in global markets such as consumer appliances. Manufacturers in industrialized nations may seek to hinder the flow of technical know-how to competitors through exercise of proprietary control. An international instrument such as the Protocol is not by itself capable of counteracting such tendencies. National policies need to address the potential behaviour of those who might benefit from blocking technology transfer, while at the same time preserving the incentives of firms to develop and market substitutes for CFCs as rapidly as possible.

Finally, manufacturers in non-signatory countries who adopt the substitute technologies will not have to worry about potential barriers to export of their products to Protocol nations. The Montreal Protocol (Article 4, Section 3) specifies that within three years of the date of entry into force, the Parties to the Protocol will develop a list of "products containing controlled substances" and within one year after that, may ban import of such products from countries that have not joined the Protocol. The Montreal Protocol goes farther; in Article 4, Section 4, a procedure is set up whereby the Parties will examine the feasibility of banning imports from non-signatories of the very broad category of products "made with" CFCs.

The scientific consensus on the environmental harm caused by CFCs has solidified since the signing of the Montreal Protocol. It is only reasonable to expect that revisions of the Protocol will be in the direction of greater stringency. Clearly, the prospects for trade between signatory and nonsignatory countries in products made with CFCs will not be good in the long run.

6.4 AID

6.4.1 Opportunities and Options

Concern about the availability and level of international assistance funds is one of the issues to emerge from the "Saving the Ozone Layer" ministerial level meeting held in London during March 1989. Accordingly, the outlook for international financial transfers that might facilitate the technological transfers must be considered.

It should be noted that the problems associated with the transfer of non-CFC technologies will be less severe than those frequently encountered in technology transfer. While difficulties are present that can be addressed through international assistance mechanisms, the need for a coordinated worldwide approach to the protection of the ozone layer offers opportunities for facilitation of technology transfer that are not ordinarily available.

The first of these favourable conditions is that policy of governments (although not always of firms) in the developed countries is already skewed in favour of widespread diffusion. Promotion of non-CFC technologies by the governments of high-CFC-using countries should help to advance the spread of non-CFC technologies. The goal of environmental protection will to some extent counterbalance the factors originating within the industrial world that sometimes thwart technology transfer. Because the transfer will be taking place in the context of an international cooperative effort for environmental protection, some of the distrust that often acts as a barrier to technology transfer (Perlmutter and Sagafi-nejad, 1981) will be lowered.

Given that the industrially developed countries will bear the initial costs of research and development, technology transfer will be of the "horizontal" variety (involving transfer from one location to another) rather than of the "vertical" sort (transmission of information from basic research to development and production). The resource costs involved in horizontal technology transfer tend to be lower than in the case of vertical transfers (Mansfield, 1974).

Many of the difficulties of technology transfer stem from differences in resource bases, infrastructures, levels of general human capital, and availability of trained scientific personnel. Barriers arise because of cultural, institutional, and income differences between countries or regions. It is noteworthy, therefore, that there appears to be little difference in these respects between the CFC-using and CFC-free technologies. The very rapid reductions in CFC use forecast in developed economies reflect the fact that neither CFCs nor their substitutes are on the frontier of theoretical science, and both CFC-using and CFC-free technologies have similar requirements in terms of capital, skilled personnel, resources, and engineering. While initial costs may differ, the knowledge and training needed to implement either type of technology are similar, at least in the substitutions discussed thus far.

The changeover to non-CFC using methods in the developed countries actually will make it easier to transfer these innovations. The large chemical firms and major CFC end users of the developed countries will be making the switch to substitutes themselves. The substitute technologies will be the focus of their own engineering and managerial attention, so the lessons they have learned will be fresh as they provide inputs to new operations being set up in the developing countries. Inputs from firms based in the developed countries are likely to be important whether the transfer takes the form of direct investment, joint projects involving subsidiaries, cooperative enterprises, or technical assistance provided through the market or through government programs.

There remains the question of the availability of international assistance funds. Parties to the Protocol have a substantial interest in seeing that their reductions in CFC use are not undermined by rising CFC consumption elsewhere. Nations contemplating investments in CFC-using technology have an interest in obtaining technical and economic assistance to ease the transition to CFC-free methods. Structuring of the quantity and form of economic assistance can evidently be of strategic importance to reaching the global aims of the Protocol. Institutional arrangements to handle this global problem will work best if they take root in a partnership between developed and developing nations. There is a pragmatic value in avoiding controversial questions of North-South transfers or development assistance generally, emphasizing instead practical solutions to the challenge of phasing out CFCs and halons in a cost-effective and timely fashion. The policy questions raised by this issue are thus a matter of interest to all the current and potential signatories of the Montreal Protocol.

Some of the forms that international assistance might take include:

1. Action by multilateral lenders that are supportive of the goals of the Montreal Protocol. For example, CFC-substituting potential could be included among the criteria for project evaluation, or rapid transfer of

technology could be made a requirement for funding. Loans for CFC-using projects could be restricted, while lending to promote alternative technologies is expanded. The president of the World Bank has recently stated that the Bank "should be there to help" countries whose industries face costs to re-equip because of international efforts to protect the ozone layer (World Bank, 1989).

2. Special access of CFC-substitute products to the markets of Protocol signatories. These incentives would be the positive counterpart to trade restrictions on products containing or made with CFCs.

3. Facilitation of the licensing or transfer of patents for substitute technologies. This could take the form of direct subsidies (whereby assisting countries would purchase patents or other rights in the new products or processes and make those rights available to developing countries) or the offering of tax and/or regulatory relief to firms that transfer their CFC substitute technologies on a private basis.

4. Training of personnel. Countries that have made the investment in R&D and shifting to non-CFC technologies could provide demonstrations, symposiums, fellowships, or internships to technical personnel of developing and newly industrializing countries. These technical experts would then carry knowledge about the substitute technologies to their home countries and firms.

5. Linkage of CFC controls with external debt relief. Compliance with the Montreal Protocol (and its successors) could be a necessary or sufficient condition for favourable resolution of international debt issues.

6. Support of non-CFC infrastructure in conjunction with other assistance projects. Vaccination and other public health programs, for example, could be designed to use non-CFC medical refrigeration devices as part of their efforts, or to employ new technology that could avoid refrigeration altogether in delivery of medicines and vaccines.

7. Providing technical assistance to developing countries in carrying out technical/economic assessments of various CFC replacement technologies in the context of their particular industrial structures and development plans and priorities. This assistance could include providing an information clearing house and helping to fund consultancy studies on how the developing

countries can make the best choice of replacement technologies.

8. Direct subsidies for CFC-free projects (e.g., grants to build factories to manufacture CFC substitutes or CFC-free refrigeration equipment). Such subsidies could be administered through a trust fund or independent financial corporation created by Parties to the Protocol; as a financing facility organized by multilateral lending institutions; or as a financial intermediary authorized to blend market-rate and concessionary funds.[8]

While adoption of any or all of these forms of assistance will be subject to political decision and negotiation between donor and recipient nations, these policies would be consistent with the relevant sections of the Montreal Protocol, including "Special Situation of Developing Countries" (Article 5), "Research, Development, Public Awareness and Exchange of Information" (Article 9), and "Technical Assistance" (Article 10). In addition, awareness of the importance of technology transfer in protection of the stratospheric ozone layer should be fostered in those multilateral and regional organizations that are involved in the promotion of economic development.

It is critical to translate the promises of technology transfer contained in the Montreal Protocol into concrete commitments, both in terms of real resources and in the establishment and development of institutional support. Given the phase-down targets announced by many of the Parties to the Protocol, it is likely that additional reductions in total world CFC emissions could be obtained at lowest cost by supporting and assisting the transfer of CFC-free technologies to developing countries. Both self-interest and the spirit of international cooperation to preserve the global environment point to policies that will facilitate transfer of the substitute technologies.

6.4.2 Capital Flows and the Developing Countries: Background

Investments such as CFC-free technologies are, in principle, economically productive: they yield products and services whose value over time, taking all benefits into account, will exceed the cost of investment. This economic return cannot be earned at once, however, because the stream of benefits stretches into the future. Thus, as a practical matter, financing is needed for investments. In the developing countries financing can be a crippling problem. The total external debt of the developing countries had reached approximately $1.3 trillion by the end of 1988 (World Bank, 1989). The seriousness of this debt problem is shown in the following table:

As these figures make clear, the burden of international debt has grown so large that net capital flow between the developing countries and the industrial economies is now negative: that is, capital is being transferred from the poor nations to the developed nations. The leading multilateral lender, the

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[8] Report of the Informal Working Group of Experts on Financial Mechanisms for the Implementation of the Montreal Protocol. Geneva, July 1989.

Table 6-1. Financial Flows to Developing Countries
(US $ billions)

	1986	1987
Commitments (official & private)	74.4	86.0
(Official)	(41.3)	(44.5)
((Multilateral))	((28.1))	((27.6))
Disbursements (official & private)	76.3	76.6
(Official)	(36.9)	(38.2)
((Multilateral))	((20.8))	((22.2))
Net Disbursements (after principal repayments)	27.4	17.7
(Official)	(19.3)	(17.6)
((Multilateral))	((5.7))	((3.0))
Net Transfers (after payment of debt service interest)	-19.1	-28.5
(Official)	(4.4)	(0.9)
((Multilateral))	((5.7))	((3.0))

Source: **World Debt Tables 1989**, International Bank for Reconstruction and Development, Washington, D.C., 1989. (Includes only debt-creating financial flows. See also, Organization for Economic Co-operation and Development, Development Co-operation Directorate, "Basic Aid Data," working document DC/89.1, Paris, 16 January 1989.)

International Bank for Reconstruction and Development, IBRD (known as the World Bank), experienced negative net transfers for the first time in its history in the fiscal year that ended in June 1988. According to the World Bank's Annual Report for 1988, net transfers by the Bank to its current borrowers on IBRD terms (i.e., excluding the soft loans to the poorer countries on International Development Association [IDA] terms) were negative by an amount of $ 1.9 billion in that year.

This means that investment capital is extremely scarce throughout the developing world. Domestic projects in infrastructure, manufacturing, and agriculture compete against one another, only to be squeezed out by the mounting burden of debt interest and repayment obligations. Those obligations must be met on commercial terms, even for funds borrowed from the World Bank, whose lending is conducted largely on a near business basis.

These facts suggest one reason why, despite the high long-term costs of depleting the ozone layer, some developing countries are reluctant to pay more to obtain CFC-free technologies than CFC-using technologies. The benefits, while real, do not appear for some time, while the needs to finance debt service are immediate.

Whatever one's stand on the problem of debt in the developing countries, it remains an indisputable reality that saving the ozone layer faces financial hurdles even though it can be accomplished on terms that are economically beneficial to all. The need for financing is a practical circumstance that affects the impending revision of the Montreal Protocol.

6.4.3 Financing Technology Transfer

It is in the interest of all humanity to preserve the ozone layer. Nevertheless, some developing nations are concerned that forgoing CFC technology may require sacrificing or deferring expansion of their economic well-being, particularly in areas such as refrigeration. The industrialized nations have an interest in assuring that their commitments to eliminate CFCs will not be undermined by expansion of CFC use in developing countries. Therefore, it is in the interest of both developed and developing nations to devise means by which technologies that do not harm the ozone layer can be adopted throughout the world.

Damaging the ozone layer is an external and unintended effect of CFC emissions. If the external costs to human health and environmental resources were reflected in the price of CFCs, CFC-free technology would be lower in relative cost. Thus, choosing CFC-free technology over a CFC-using alternative is economically sound in most cases. Assistance to facilitate this choice should therefore be viewed as financing in its basic sense of providing short-run means to achieve long-term ends beneficial to both lender or donor and borrower or recipient.

Bilateral and multilateral channels already exist that could be used for the purpose of advancing CFC-free technology transfer. Developed nations may choose to make voluntary contributions to foster ozone-friendly technologies in the developing world. The Economic Assessment Panel makes no recommendations as to the amounts or sources of the funds that might be made available for this purpose. However, several arrangements for funding global environmental protection have been proposed. Three examples of such arrangements are given below. While making no policy recommendations, the Panel believes that it is worthwhile to work out examples of this type to give an indication of the economic magnitudes being discussed.

Prime Minister Brundtland of Norway recently proposed that the industrialized countries of the world set aside 0.1 percent of their national product for an International Fund for the Atmosphere (Brundtland, 1989). If the developed countries that have signed the Montreal Protocol were to devote this fraction of their total annual output to such a fund, approximately $13 billion per year would be available. (See World Bank Atlas, 1988, for national product data.) Of course, not all of this sum could be devoted to protection of the ozone layer; Prime Minister Brundtland specifically mentioned global warming and sustainable utilization of the tropical forests (in addition to the ozone layer) as problems such a fund could address.

In a second example, The Netherlands has stated its intention of donating a fixed amount each year to solving global environmental problems. In the recently published National Environmental Policy Plan the Dutch government announced to allocate an amount of DFL 50 mln in 1990, growing to a structural amount of DFL 250 mln in 1994, to environmental protection in the context of development cooperation. This amount, financed from the annual growth of the development aid budget, will be specifically aimed at greenhouse problems, energy-efficient technology, less dependence on fossil fuel, and conservation of tropical forests. As soon as an international climate fund is operational, the money will be provided as a contribution to that fund. Because CFCs also have a greenhouse effect, part of this money could in principle also be used for meeting the problems of the developing countries in acquiring CFC-free technology. If the industrialised nations with national products larger than or comparable in size and similar in per capita level to that of The Netherlands were simply to match the Dutch commitment, at least approximately $1 billion per year could be raised by the year 1994. If the larger industrialized nations gave proportionately more, the amount would be substantially larger.

Other approaches are possible. Some countries, such as the United States, plan to comply with the Montreal Protocol through government issuance of permits to produce and/or use CFCs and halons. If the supply of CFCs is constrained in this fashion, prices of CFCs and products using them will rise. Whoever receives the rights to produce, import, or use CFCs will obtain a windfall transfer as a result of the increase in CFC prices. In this case, the government could impose a transition fee on the CFCs without increasing prices to consumers. One effect of such a transition fee would be to transfer some of the windfall to the government (DeCanio, 1988). (Of course, the government could capture the entire windfall for itself by auctioning to the highest bidder or selling the CFC permits initially.)

This mechanism for raising revenues without increasing CFC prices to consumers will not be available to all countries. Some may choose to implement their commitments under the Montreal Protocol by banning certain products and by restricting the expansion of ozone-depleting chemicals into new markets. In non-market economies, prices may be set administratively and therefore not reflect reductions in CFC availability. In both of these cases, CFC prices will not include a windfall transfer component.

A transition fee calculated per unit of CFC consumption or production could, however, serve to apportion voluntary contributions to an ozone protection fund in proportion to each country's production or consumption of CFCs. If a transition fee of \$.25 per kilogramme, weighted by ozone-depleting potential, were applied to the world output levels shown in Chapter 2, over \$300 million could be raised in the first year. If the same \$.25/kg fee were applied while CFCs and halons were being entirely phased out, it could raise approximately \$2 billion in total between the present time and the year 2000.

The amounts of financial aid for technology transfer that might be generated by any of these three proposals are modest relative to current levels of bilateral and multilateral development assistance. Additional aid could, however, be effective in promoting adoption of CFC-free technologies by developing countries. The cost to construct a 45 million kg per year capacity CFC plant has been estimated to be about \$21 million (Mooz, Wolf, and Camm, 1986; Farhad and Elkin, 1985). If a plant to produce CFC substitutes were more expensive, assistance amounting to the difference in cost between the substitute and CFC-producing plants would eliminate the economic incentive to invest in the CFC plant. Similarly, incentives for applications technologies (such as refrigeration) that use CFC substitutes would only need to be as large as the initial cost disadvantage of the substitute technologies.

Assistance for transfer of CFC-free technologies to developing countries may be cost-effective for the industrialized nations. The situation is analogous to that of some electric utilities in the United States, which find it economically beneficial to assist their ratepayers in purchasing energy-conservation improvements. Energy efficiency is worthwhile to the utilities because in certain instances conservation is substantially less expensive than building additional generating facilities. Financing reductions in ozone-depleting substances in the developing world may be the least costly way for both developing and industrialized nations to realize the joint benefits of protecting the ozone layer as rapidly as possible.

Enterprises in developing nations should not require special inducements to adopt CFC-free technologies if such technologies are cheaper and technically superior to ozone-depleting methods. In some cases, however, CFC-free technologies will be more expensive, at least initially. These are the situations in which the availability of assistance earmarked for protection of the ozone layer could be effective. Eligibility for these funds could be conditional on joining the Montreal Protocol, so that developing countries would have a positive incentive to join the worldwide effort to protect the ozone layer.

6.4.4 Learning from Experience

As the Panel has observed above, Parties to the Protocol will independently devise methods and policies to achieve national compliance with the target levels for CFC reduction. One theme will be common to all nations' efforts to reach the goals of the Protocol: the need to learn rapidly and efficiently from experience.

The history of CFC reductions thus far has largely been with low-cost, readily achieved technical substitutions, such as the ban on non-essential use of CFCs in aerosols in several nations. At the same time, it has become clear that some controlled substances such as fire-suppressant halons are not likely to have "drop-in" substitutes in the immediate future. Thus, the transition to a CFC-free world economy faces a mix of opportunities and barriers. Initially, it will be difficult or impossible to foresee all the barriers--or all the opportunities. Surprises will therefore be inevitable.

It is essential to take advantage of the fact that surprises can be a valuable source of knowledge (Holling, 1978). Unexpected outcomes are signals that the natural and social environments are responding in unanticipated ways to the transition away from CFCs. These lessons will be learned in different nations. It is important that they not be learned through excessive duplication of effort, and that they not be ignored. The lessons learned should be disseminated rapidly, so as to lower costs to all Parties as they move toward CFC-free economies.

One important technique for achieving these ends has already been developed in the management of living resources. This approach, called adaptive management, treats the implementation of policies as a set of experiments, probing the behaviour of the populations being managed. Thus, fisheries can be managed so that harvest methods and catch information yield information about the state of fish populations. These populations fluctuate because of changes in climate and environmental conditions, in addition to harvest pressures. Using scientifically designed data collection associated with harvests, it is possible to learn rapidly from the evolving natural history of the populations of interest (Walters, 1986). Adaptive management is now being applied in Canada and the U.S. to the management of forests and fisheries (Lee and Lawrence, 1986; Hilborn, 1987; Northwest Power Planning Council, 1987; TFW Final Agreement, 1987).

The adaptive concept is relevant to the ozone case in two senses. First, the persistence of significant levels of scientific uncertainty implies that accumulating knowledge may lead to revisions of policy. Certainly the growing appreciation of the extent of ozone depletion that has already occurred has been a principal force in the current round of revision of the Montreal Protocol. The idea of adaptive management is that policies to address uncertain circumstances must be flexible and able to benefit from increasing understanding (National Academy of Sciences, 1986; Orians, 1986). The need to revise control policies in light of advances in scientific knowledge was the reason for including Article 6, "Assessment and Review of Control Measures," in the Protocol. National policies and industrial practices should continue to preserve flexibility, given the uncertainties that remain.

Second, policies to implement commitments under the Protocol may be designed adaptively, so that the accumulating experience of CFC-free technologies can be studied and translated into wider action as quickly as possible. For example, the discovery that large fractions of CFC use as a solvent in electronics manufacturing could be eliminated simply through better housekeeping procedures is a lesson of substantial significance. In other cases, however, the lesson to be inferred from experience may be considerably more subtle. Vacuum panels have been proposed as a substitute for foam-insulated walls in refrigeration equipment, for example. Use of vacuum panels in some nations will provide valuable data on those aspects of vacuum panel manufacture and use that are the weak links in use of this non-CFC technology. By deliberately designing programs to promote the production and use of vacuum panels, national governments and consortia of firms can speed learning, producing knowledge of benefit to themselves and the global community. The joint testing to determine the toxicological acceptability of CFC substitutes in the U.S. illustrates the benefits available to chemical manufacturers of taking a deliberately experimental approach.

It should be noted, of course, that the response of the ozone layer itself to policy interventions is far too slow to be manageable by the adaptive method. Indeed, the Protocol itself is premised upon scientific analyses and projections of atmospheric conditions that might be observed in the future, but have not yet occurred. The high level of scientific consensus that these conditions will develop if CFC and halon emissions are permitted to continue, together with the very large social costs of depleting the ozone layer, have moved nations to agree upon and to join the Protocol. Because the preservation of the ozone layer depends upon global coordination, it is important to improve the ability to learn from the experience of nations as they implement the Protocol; it is in that context that adaptive management can be useful.

Adaptive management may also be appropriate in multilateral and bilateral assistance programs to facilitate transitions to CFC-free technology. In nations with large domestic markets for CFC-free technologies, such as Brazil or India, it will be important to learn whether CFC-free methods can be implemented more successfully by rapid diffusion of technical knowledge to a large number of firms, or by seeking to affect the technology choices of a small number of large firms or government ministries. Both strategies can succeed, depending upon industrial organization, regulatory structure, and other variables specific to each nation.

Assistance programs should provide planning funds to support the design of government programs and technology transfer projects that can learn from experience which institutional strategies are most effective (Reid, Barnes, and Blackwelder, 1988). The experimental design of such projects is normally difficult because planning funds are insufficient and because explicit objectives (hypotheses, in the experimental framework) must be identified. Stating hypotheses means taking the chance that one or more implementations will turn out to be wrong. Acceptance of the risk of failure is difficult and requires explicit encouragement from government leaders, multilateral agencies, and others (Lee and Lawrence, 1986).

The essential element in adaptive management is to learn from experience, a process that can range from the most sophisticated use of statistical experimental design to the most simple awareness of which products and processes meet the test of consumer acceptance.

6.5 CONCLUSIONS

The global ozone protection effort will be advanced by measures that make adoption of CFC-free technologies economically sensible at the local level in all countries. Achieving the aims of the Montreal Protocol with techniques, equipment, and products that in some cases have only partially been introduced at commercial scale even within the advanced industrial economies will be a large challenge, especially in light of the tight schedules now contemplated by many Parties to the Protocol. The Panel urges both sensible targets and ambition upon the Parties in revising the timing for reduction of controlled substances in the Protocol: sensible targets so that economic realities are not ignored, and ambition in committing Parties to achievable goals.

This chapter has reviewed economic issues associated with the dynamic nature of the ozone problem and the consequent need to consider the diffusion of technological knowledge. New technologies are being developed as substitutes for CFCs, halons, and processes using these substances. New markets, which have been dominated by CFCs and CFC-using technologies, are opening up. Both of these are, from an economic perspective, important opportunities for innovation and trade expansion. National and international policies should facilitate rather than hinder these technological changes. Policies that foster rapid learning from experience in this dynamic environment will be of particular value.

One of the most encouraging developments since the signing of the Protocol in 1987 is the realization that substantial reductions in CFC use can be achieved at no cost or with low costs. This is unlikely to be true of all reductions in CFC use, however. For that reason, barriers that hinder the substitution of new CFC-free technologies for existing products and methods must be addressed. Bilateral and multilateral assistance to the developing countries are critical in this connection. Technical assistance, financing, and economic incentives to adopt CFC-free technologies will all be necessary to realize the commitment of the Protocol "to control equitably total global emissions" of controlled substances while "acknowledging that special provision is required to meet the needs of developing countries."

The global community faces a common threat in the depletion of stratospheric ozone. Responding to that threat will require unusual cooperation among the governments, state-run enterprises, and private business firms of the planet. The task is nothing less than to sustain economic progress while protecting the long-run habitability of the environment (World Commission on Environment and Development, 1987). CFCs and halons are not the most serious threat to the global community, but they are where our most promising start has been made. Protection of the stratospheric ozone layer can be a milestone in the slow but vital growth of international cooperation.

REFERENCES

Arthur, W. Brian. "Competing Technologies, Increasing Returns, and Lock-In By Historical Events." **Economic Journal** (March, 1989): 116-131.

Arthur, W. Brian. "Competing Technologies and Economic Prediction." **Options**, International Institute for Applied Systems Analysis, Laxenburg, Austria (April, 1984): 10-13.

Brundtland, Gro Harlem. "Global Change and Our Common Future." Benjamin Franklin Lecture, Washington, D.C., May 2, 1989.

Conseil Européen Des Fédérations De L'Industrie Chimique. "Community CFC Producers Agree Not To Transfer Technology For Production Of CFC To Non-Signatories To The Montreal Protocol." Press Release. Brussels: November 9, 1988.

David, Paul A. "CLIO and the Economics of QWERTY." **American Economic Review** (May 1985): 332-337.

DeCanio, Stephen J.. "Allocated Quotas and Regulatory Fees: A Mixed Strategy for CFC and Halon Control." Paper prepared for the U.S. Environmental Protection Agency. March 30, 1988.

Farhad, Niloofar and Lloyd M. Elkin. "Integrated Solvents Analysis: Production of Fluorocarbons 11 and 12 from Carbon Tetrachloride." Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency. Washington D.C.: 1985.

Frankel, Marvin. "Obsolescence and Technological Change In a Maturing Economy." **American Economic Review** 45 (June 1955): 296-315.

Gee, Sherman. **Technology Transfer, Innovation, and International Competitiveness**. New York: John Wiley & Sons, 1981.

Hardin, Garrett. "The Tragedy of the Commons." **Science** 162 (1968): 1243-48.

Hilborn, R. "Living With Uncertainty in Resource Management." **North American Journal of Fishing Management** 7 (1987): 1-5.

Holling, C.S., ed. **Adaptive Environmental Assessment and Management**. New York: John Wiley & Sons, 1978.

International Bank for Reconstruction and Development. **World Debt Tables, 1989**. Washington, D.C.: 1989.

Ko, Ming. "Comparison of Freon With Water Cleaning Processes for Disk-Drive Parts." In **Particles on Surfaces II: Detection, Adhesion, Removal**, edited by Kash Mittal. New York: Pellum Press, 1989.

Krugman, Paul R., ed. **Strategic Trade Policy and the New International Economics**. Cambridge, Mass.: M.I.T. Press, 1986.

Kruse, H., K.H. Hawks, R.J. Evans and D.J. Walukas, eds. "Advantages of Non-Azeotropic Refrigerant Mixtures for Heat Pump Application." Conference on Waste Heat Recovery for Energy Conservation: Residential and Light Commercial Heat Pumps. NTIS Report No. CONF-800966, 1980.

Lee, Kai N. and Jody Lawrence. "Adaptive Management: Learning From the Columbia River Basin Fish and Wildlife Program." 16 **Environmental Law** 431, 1986.

Mansfield, Edwin. "International Technology Transfer: Forms, Resource Requirements, and Policies." **American Economic Review** (May 1975): 372-376.

McLaughlin, Charles C. "The Stanley Steamer: A Study In Unsuccessful Innovation." **Explorations In Entrepreneurial History** 7 (October 1954): 37-47.

Mooz, William E., Kathleen A. Wolf and Frank Camm. **Potential Constraints on Cumulative Global Production of Chlorofluorocarbons**. Prepared for the U. S. Environmental Protection Agency. Santa Monica, C.A.: Rand Publishing Corp., 1986.

National Research Council, Committee on the Applications of Ecological Theory to Environmental Problems. **Ecological Knowledge and Environmental Problem-Solving**. Washington D.C.: National Academy Press, 1986.

Northwest Power Planning Council. **Northwest Conservation and Electric Power Plan**. Portland, Oregon, 1986

Northwest Power Planning Council. **Columbia River Basin and Wildlife Program**. Portland, Oregon, 1987.

Organization for Economic Co-operation and Development, Development Co-operation Directorate. "Basic Aid Data," working document DC/89.1. Paris, January 16, 1989.

Orians, Gordon H. "The Place of Science in Environmental Problem-Solving." **Environment** 28, 9 (November): 12-17, 38-41.

Perlmutter, Howard V. and Tagi Sagafi-nejad. **International Technology Transfer: Guidelines, Codes and A Muffled Quadrilogue**. New York: Pergamon Press, 1981.

Reid, Walter V., James N. Barnes, and Brent Blackwelder. **Bankrolling Successes**. Environmental Policy Institute: Washington, D.C., 1988.

TFW Final Agreement. "Timber/Fish/Wildlife - A Better Future in Our Woods and Streams." Seattle: Feb. 17, 1987. Unpublished.

Tyson, James L. "Why China Says Ozone Must Take Back Seat in Drive to Prosperity." **Christian Science Monitor**, March 23, 1989.

United Nations Environment Programme, "Pursuant to Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer under the Auspices of the United Nations Environment Programme," (publication information), 1989.

United States Environmental Protection Agency. "Regulatory Impact Analysis: Protection of Stratospheric Ozone Volume I: Regulatory Impact Analysis Document." Washington, D.C.: August 1, 1988.

United States Environmental Protection Agency. "Volume III Addenda to the Regulatory Impact Analysis - Protection of Stratospheric Ozone." Washington, D.C.: May 20, 1989.

Walters, Carl. **Adaptive Management of Renewable Resources**. New York: Macmillan, 1986.

Whitney, Craig R. "80 Nations Favour Ban to Help Ozone." **New York Times** (May 3, 1989).

World Bank. "Conable: Goal Is Development In Harmony With Nature: Toxic Wastes Must Be Controlled." Press release. Washington D.C.: February 16, 1989.

World Bank Atlas, 1988. The World Bank, Washington, D.C., 1988.

World Commission on Environment and Development. **Our Common Future**. New York: Oxford University Press, 1987.

CHAPTER 7

INDUSTRY POLICY FOR PROTECTION OF THE OZONE LAYER[9]

The Montreal Protocol requires a 50 percent reduction in CFC-11, -12, -113, -114, and -115 by 1998 and a freeze in halon production at 1986 levels in 1992. Some national reduction plans are proposed that are even more stringent than the Protocol (Figure 7-1).

Industries and financial institutions also are working to reduce the use of CFCs and halons because protection of the stratospheric ozone layer has become an important policy objective. 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 global and national regulation.

These industry and government efforts are aligned with and strengthen positions taken by governments regarding CFC and halon use reductions or phase-outs. Industries are reacting to government warnings, responding to the market needs for CFC and halon substitutes, and utilizing alternative products and processes. These actions reflect forecasts that CFCs and halons may not be available in desired quantities at affordable prices in the future. They substantiate the view that large markets already exist and will continue to develop for substitutes and alternatives even at higher prices. Finally, many of these industry policies offer assistance in technology transfer to developing countries, while committing to not sell or license CFC or halon production technology to countries that are not members of the Montreal Protocol.

This chapter presents selected examples of industry actions and policy positions that will help protect the stratospheric ozone layer.

7.1 CFC/HALON PRODUCER PHASE-OUTS

Akzo, Allied-Signal, Du Pont De Nemours (DuPont), Hoechst AG, ICI Chemicals & Polymers Ltd. (ICI), Kali-Chemie AG, Montefluos SpA, and Pennwalt have announced policies to phase out production of CFCs as soon as safe alternatives are available. Hoechst AG has a goal of 1995 for halting CFC production and DuPont has committed to a phase-out as soon as possible but no later than 2000. DuPont has taken the further step of committing not to sell Halon-1301 for discharge testing after 1989.

The Fire Protection Industry Association of Australia recommends the phase-out of halons when viable, ozone-benign alternatives become available and supports

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[9] This chapter is based on a collection and survey of international corporate policy on protection of the ozone layer by Chris E. Kaczmarek, ICF Incorporated for the U.S. EPA. Corporations are encouraged to submit additions and elaborations to Stephen Andersen, U.S. EPA.

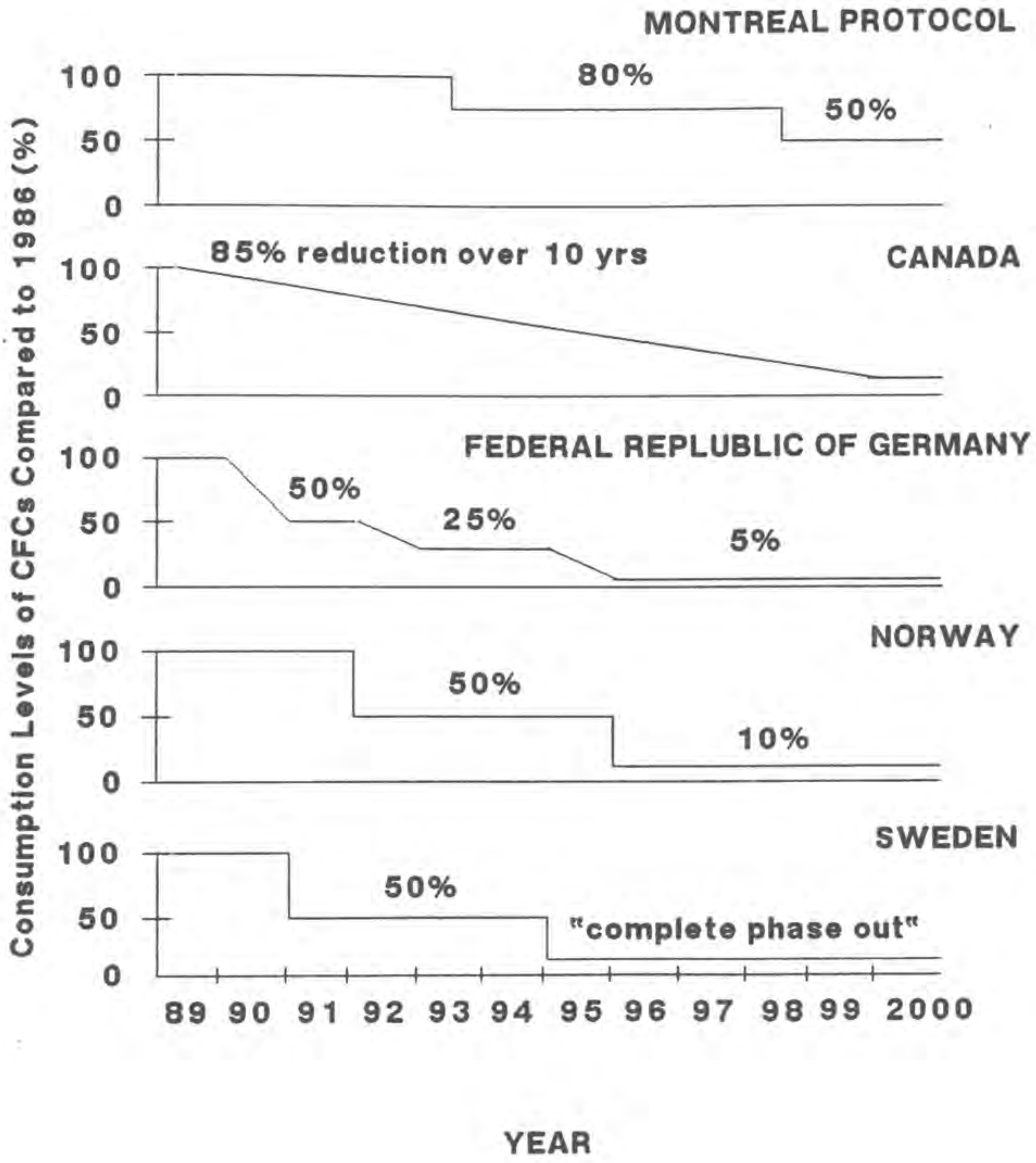

Figure 7-1. Montreal Protocol and Proposed National Reduction Plans

an 85 percent reduction in the halon ODP-weighted basket by 1998. The Australian Association of Fluorocarbon Consumers and Manufacturers (AFCAM) has outlined a voluntary plan to phase-out ozone-depleting substances by 1998.

These phase-out policies send customers a strong message to seek alternatives and substitutes. More importantly, they create solid markets as customers seek new products and services that reduce and eliminate CFC and halon use.

7.2 CFC/HALON USER PHASE-OUT POLICIES

Some industry associations and individual companies have already phased out the use of controlled ozone-depleting substances. Others have pledged either individually or through their trade associations to phase out CFCs and halons and have announced specific corporate goals.

The Alliance for Responsible CFC Policy, a coalition of several hundred companies and trade associations in the United States that use or produce CFCs, is a strong supporter of the Montreal Protocol. In September 1988 the Alliance called for the renegotiation of the Protocol through UNEP to achieve a phase-out of CFCs to the maximum extent feasible, consistent with the availability of acceptable substitutes and assuming the needs of existing installed equipment.

Voluntary national phase-down and phase-out programs have been pursued and accomplished for foam blowing and non-essential aerosol uses in less than one year.

For instance, the American Foodservice and Packaging Institute (FPI), with technical leadership from Du Pont, Dolco Packaging and Fort Howard, negotiated a formal voluntary program with the Environmental Defense Fund (EDF), Friends of the Earth (FOE), and the Natural Resources Defense Council (NRDC) (public interest environmental organizations) in the Spring of 1988 to phase-out all use of CFC-11 and CFC-12 in food packaging clam-shells, trays, and cups no later than December 1988. FPI completed the phase-out on time and has already published the technical details of the plant conversions. In addition, the agreement includes a pledge that the industry will convert to an environmentally superior, cost-effective, foam-blowing agent within 12 months of Food and Drug Administration (FDA) approval. This creates a prompt market for a substantial amount of chemical and acts as an incentive to more rapid chemical commercialization.

The Polyurethane Foam Association (PFA), the trade association representing U.S. makers of flexible polyurethane foam cushioning, intends to achieve at least a 20 percent reduction from 1986 levels in the use of CFC as an auxiliary blowing agent in the manufacture of flexible slabstock polyurethane foam by the end of 1989. Their ultimate goal is complete elimination of CFC usage by the turn of the century. This represents a faster timetable than scheduled through the Montreal Protocol.

Accelerated phaseouts have also been announced by other associations. The Polyisocyanurate Insulation Manufacturers Association (PIMA), representing U.S. manufacturers of rigid polyisocyanurate insulation board, has announced a target of December 1993 to eliminate all use of CFCs in its products. The total phase-out is contingent on the commercial availability of acceptable CFC substitutes.

In Europe, the Flexible Foam Group of the British Rubber Manufacturers' Association Ltd. (BRMA) announced an objective of phasing out the use of CFC-11 in flexible foam manufacture by 1993. These reductions are dependent upon the industry's continuing ability to use methylene chloride and the availability of new HFAs by 1993.

In Europe, all domestic appliance manufacturers will implement a 50 percent CFC-11 reduction in polyurethane foam by the end of 1989. The European Isocyanate Producers Association (ISOPA) has stated that a 60 percent CFC reduction in polyurethanes should be achievable by the end of 1993, based upon 1986 usage. In some applications, it is believed that higher reductions, up to 100 percent, could be expected. Such a phase-out schedule is dependent on the commercial availability of HFAs.

Aerosol associations in several countries have also agreed to voluntary reductions or phase-outs. For example, in April 1989 the Aerosol Association of Australia agreed to phase-out the use of all controlled substances except approved "essential use" items by December 31, 1989.

The Japan Laundry & Drycleaning Association supports a phase-out of CFC-113 by the year 2000, shifting primarily to HCFC and other solvents of the fluorine system. Sainsbury's supermarkets in the United Kingdom will use no CFCs in their refrigerator systems (using HCFC-22 only), will use no CFC-blown foam meat trays, and will not sell CFC aerosols.

In some cases, user support for a phase-out takes the form of an endorsement of government policy. For example, Volvo Car Corporation supports strict Swedish legislation requiring the complete phase-out of CFC in soft plastic foam by 1991, in hard plastic foam by 1995, and in automobile air conditioning units by 1995.

Other phase-out policies concern the products used to contain CFCs. For example, the Goodyear Tire & Rubber Company has established a new company goal to reduce the leakage and permeation of CFC-12 from flexible hoses sold for automobile air conditioners. Goodyear will promptly complete development and market hoses that will reduce CFC leakage by a factor of 10. They have pledged to offer new technology in all applications of rubber hoses and seals and will conduct research and development in the area of low permeation hose products.

Several multinational corporations have announced prompt goals to reduce and eliminate CFC and halon use. In January 1988, AT&T announced a goal of a 50 percent reduction in CFC-113 solvent use within 3 years and has just announced that they will eliminate CFC in their manufacturing processes by 1994. Seimens has a goal to eliminate CFC by 1989, Northern Telecom to eliminate CFC-113 and halon purchases by 1991, and Seiko-Epson to phase out CFC-113 by 1993. Sharp Corporation foresees a 20 percent reduction in CFC use from 1986 levels this year. Toshiba has decided to work towards a 50 percent reduction below 1986 levels for CFCs used for solvent, blowing agent, and refrigerant by 1993. DEC, Hitachi, Matsushita, NEC, and other important electronics manufacturers have announced similar policies.

In the cases of the Northern Telecom, Seiko-Epson and AT&T phase-out goals, top management was involved in setting this policy. For example, the full Board of

Directors of Seiko-Epson voted on the phase-out policy and appointed a Board member whose primary responsibility it would be to supervise the phase-out.

Phase-out policies by very large CFC and halon customers who produce vital computer, communication, and defense products serve as a goal for other companies and express confidence that alternatives and substitutes will be available.

7.3 CFC/HALON PROCUREMENT POLICIES

The U.S. military has a new policy to protect the ozone layer and is moving quickly to change procurement procedures to discourage or prohibit the purchase of CFC and halon products while encouraging development and purchase of alternatives.

The U.S. Department of Defense (U.S. DoD), AT&T, and Siemens have new policies that set high priority on ozone layer protection. The U.S. Secretary of Defense has directed the U.S. Armed Forces to reduce the use of CFCs and halons as well as avoid the purchase of products that depend on these chemicals. The DoD policy is primarily in support of environmental protection but recognizes the strategic importance of avoiding dependence on chemicals that may be unavailable or may be very expensive. The DoD 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 products should be more readily available in all markets and easier to use.

The United Kingdom Ministry of Defence (U.K. MoD) has also accepted a new standard for flux used in electronic circuit assembly that will allow elimination of CFC used in U.K. military production.

AT&T recently notified their worldwide suppliers that ozone layer protection was a top corporate priority. As such, they requested the suppliers to notify AT&T whether their products were made with CFCs, and identify their plans 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 supplied by companies that do not use CFCs.

Siemens' production facility in Erlangen, Germany, is one of the largest electronic manufacturing plants in the world, producing one billion dollars (U.S.) worth of electronics annually. Siemens made a corporate decision to replace CFC-113 solvent cleaning with alternatives including new alcohol solvents. Siemens had the technical necessity of finding circuit board components that are compatible with alcohol. Siemens notified all suppliers that the parts they furnished must be fully compatible with alcohol. Due to Siemens' strong market clout, their suppliers complied promptly. This procurement change was not only important to Siemens' strategy, but is also valuable to smaller manufacturers who can now take advantage of Siemens' initiative and buy alcohol-compatible components for the products they produce.

7.4 COOPERATIVE APPROVAL OF RECYCLING AND NEW TECHNOLOGY

In some cases formal government and industry approval is necessary before new technology can be used to protect the ozone layer. For example, recycling of CFC-12 would be difficult if car manufacturers did not approve this service under new car warranties. Car owners might be reluctant to accept recycling if it were not endorsed by credible experts.

To facilitate recycling, a joint committee of industry and government representatives was organized by the U.S. EPA to create a voluntary standard of purity for recycled refrigerant. Participants included the Motor Vehicle Manufacturers Association (MVMA), the Automobile Importers Association (AIA), American, Japanese, and European automobile manufacturers, the Society of Automotive Engineers (SAE), the Mobile Air Conditioning Society (MACS), the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), Underwriters Laboratory (UL), manufacturers of small recovery/reclamation/recycle devices, other automotive industry representatives and individuals, and the public interest organizations Friends of the Earth (FOE) and the Natural Resources Defense Council (NRDC).

EPA sponsored an engineering study to test the quality of refrigerant in different make and model cars, in different geographical regions, and under various driving and weather conditions. Based on the study, automakers worldwide have agreed to allow recycling under new car warranty and to include recycling in service manuals and training programs. To meet the standard, equipment must be certified to clean moisture and impurities from used refrigerant. UL will certify equipment that meets product safety requirements and whose performance achieves the refrigerant standard.

The success of this cooperative endeavour is reflected in the recent actions of two major automobile manufacturers. General Motors will make available new recovery/recycling equipment, developed by GM's Harrison Radiator Division, Research Laboratories and Service Technology Group, to all GM dealers starting in the 1990 model year. The recovery/recycling equipment, which features a "continuous loop recycling" process that will purify refrigerant for reuse, will become required equipment for the 1991 model year. The new equipment will also be placed in GM assembly plants and fleet garages where vehicle air conditioning repairs are made. Nissan Motor Company, in a significant move, plans by the mid 1990's to make its car air conditioners and manufacturing processes completely free of CFC. CFC-11 will be eliminated by 1990, CFC-113 by 1993, and CFC-12 as soon as possible. A second major Japanese automaker, Toyota, has also decided to totally eliminate the use of CFCs in car air conditioners and manufacturing processes. Toyota's goal is to eliminate CFCs in these areas by 1995.

In Australia, the Commonwealth Industrial Gases Limited (CIG), the leading supplier of refrigerant gases to the Air Conditioning and Refrigeration Industry there, will be installing refrigerant-reclaiming equipment at all their major filling sites as a step towards reducing CFC emissions.

Another example of prompt action to approve new ozone-safe alternatives involves the U.S. Armed Forces. As noted earlier, U.S. and other military authorities have worldwide influence over the way that electronic products are manufactured because they are large customers and because others often use military standards to assure quality. In the past, U.S. and U.K. defense departments have had procurement standards that encouraged the use of CFC-113 solvent and virtually prohibited the use of other alternatives. Experts estimated that up to half of the world's use of CFC-113 resulted directly or indirectly from these military specifications.

When the U.S. EPA and industry met with the U.S. military they promptly agreed to accept any cleaning process that could be shown to clean as well or better than CFCs and joined the voluntary industry/government work group to change the specification. This ad hoc solvents working group includes representatives from the U.S. DoD, Air Force and Navy, the U.S. EPA, the Institute for Interconnecting and Packaging (IPC), CFC solvent producers, alternative chemical producers, flux/equipment manufacturers, defense contractors, civilian electronics manufacturers, and others.

The group has tested the effectiveness of CFC-113 and established a "benchmark" of cleaning performance against which substitutes can be compared. The U.S. military will use this to promptly approve alternatives that clean as well or better. A similar voluntary approach has led to revision of military standards in the U.K. The constructive cooperation of the military will eliminate barriers to the implementation of alternatives that are safe to the ozone layer, while maintaining or improving electronic performance.

The Association of Home Appliance Manufacturers (AHAM), representing the manufacturers of almost every refrigerator and freezer sold in the United States, has also joined with government in seeking new compounds to replace CFCs. In cooperation with the U.S. EPA and the U.S. Department of Energy (U.S. DOE), AHAM and the American appliance industry are seeking acceptable alternatives and accompanying technologies that not only shift dependence away from CFCs, but also meet federally mandated energy efficiency standards. Chemical producers are supplying samples and available technical data on promising alternatives that EPA, DOE, and the other participants are evaluating. Again, this serves as a positive example of what can be attempted through a cooperative strategy.

Iceland and Bejam (British refrigerator manufacturers) have established a free program to pick up home refrigerators and remove the refrigerant prior to disposal. The program is already running at capacity of 1,000 units per week. In the United States, ICI and Amerex have established a program that pays dealers to return used halon for recycling. They will establish similar programs throughout the world.

European CFC producers, as members of the European Chlorofluorocarbon Technical Committee (EFCTC), a Sector Group of the European Council of Chemical Manufacturers Federations (CEFIC), have jointly committed to recover and recycle contaminated product where technically feasible in support of a phase-out.

7.5 TOXICITY TESTING AND OTHER RESEARCH CONSORTIUM

It is faster and less expensive to cooperatively test the toxicity of new chemicals. There are three consortium organized to test the toxicity of the principal new chemical alternatives to CFCs, and one organized to investigate the environmental acceptability of new chemical substitutes for CFCs and halons.

Fourteen companies have initiated a collaborative study Program for Alternative Fluorocarbon Toxicity Testing (PAFT 1) to evaluate the toxicity of new chemicals: 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), Montefluous SpA. (Italy), Racon (United States), Showa Denko (Japan), and Ulsan Chemicals (Korea). PAFT 1 began testing the toxicological effects of HCFC-123 and HFC-134a on December 1, 1987.

A second consortium (PAFT 2) includes the following companies: Akzo (Netherlands), Allied Signal (United States), Asahi Glass (Japan), Atochem (France), Daikin (Japan), Du Pont (United States), ISC Chemicals (UK), Pennwalt (United States), Showa Denko (Japan), and Solvay and Company (Belgium). PAFT 2 was established to accelerate the toxicity testing of HCFC-141b. 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 newly formed third consortium (PAFT 3) includes seven companies: Allied-Signal (United States), Atochem (France), Daikin (Japan), Du Pont (United States), ICI (UK), ISC Chemicals (UK), and Montefluos (Italy). PAFT 3 convened to develop toxicity profiles on the substitutes HCFC-124 and HFC-125. Additional compounds may be considered later.

The following group of 14 companies is collaborating on an "Alternative Fluorocarbon Environmental Acceptability Study" (AFEAS): Akzo (Netherlands), Allied Signal (United States), Atochem (France), Daikin Industries (Japan), Du Pont (United States), Hoechst AG (Germany), ICI (UK), ISC Chemicals (UK), Kali-Chemie AG (Germany), La Roche Chemical (United States), Montefluos SpA. (Italy), Pennwalt Corp. (United States), Racon (United States), and SICNG (Greece). AFEAS is exploring calculated ozone-depletion potential (ODP); calculated global warming potential (GWP); mechanisms for atmospheric decomposition; and 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.

There are also research consortia to develop new products. For example, the U.S. EPA and the U.S. DoD are organizing a government/industry project to develop new ozone-safe fire-extinguishing agents as alternatives to halons. The project will coordinate resources for timely development of halon replacements, and will establish selection criteria for fire-fighting effectiveness, human safety, materials compatibility, and the ozone-depletion and calculated greenhouse warming potentials. Clear performance and environmental selection criteria will assist in timely development of safe replacements. Participants include the U.S. EPA, DoD, Air Force, Navy, Army, Coast Guard, NASA, National Science Foundation (NSF), the National Institute of Science and Technology (NIST), the Halon Research Institute (HRI), Factory Mutual (FM) Research, the National Fire Protection Association Research Foundation (NFPA-RF), DuPont, ICI, Great Lakes, Underwriters Laboratory (UL), and Wormald Inc.

A second U.S. research consortium will evaluate polyisocyanurate insulation utilizing CFC substitutes in roofing applications. Both thermal and mechanical performance characteristics will be studied, including physical properties such as insulation value, foam density, water vapour transmission, dimensional stability, compressive strength, shear strength, water adsorption and flexural strength. Testing will be carried out by a Joint Research Team comprised of the Polyisocyanurate Insulation Manufacturers Association (PIMA), Oak Ridge National Laboratory (ORNL), U.S. EPA, U.S. DOE, and the National Roofing Contractors Association (NRCA). The program is estimated to run approximately 3 years.

7.6 VOLUNTARY LABELLING, EDUCATION, AND POLICY POSITIONS

A substantial number of business, labour, and professional associations and private companies are supporting protection through voluntary labelling, education, and policy positions.

The North American halon community began efforts to reduce emissions as soon as they learned that halons might be significant factors in the depletion of stratospheric ozone. They formed committees to investigate emissions and formally involved the fire protection industry in problem-solving workgroups. They rejected proposals for mandatory full-discharge testing of halon systems using halon agents, worked with testing laboratories to avoid emissions during manufacturing, and developed programs to recycle. The U.S. Air Force developed alternatives to training with halons including computer simulators. In September 1987 representatives of the civilian and military halon community went to Montreal to explain that halons could be safely included in the Montreal Protocol.

Since 1986 the National Fire Protection Association (NFPA) has been working with the U.S. EPA, Environment Canada, and the North American fire protection community to develop strategies for halon emission reduction, management of halon banked, and to reduce dependence on halons while maintaining fire protection. A voluntary, consensus standards committee rejected mandatory full-discharge testing of halon systems in the NFPA 1301 fire-extinguishing systems standard (NFPA 12A). NFPA standards have been revised to include an ozone-depletion advisory, a requirement for container labelling to encourage reuse and recycling, and guidelines on environmentally acceptable test procedures to avoid full-discharge tests of halon systems.

NFPA co-sponsored, and the U.S. EPA and Environment Canada supported, the international conference, "Fire Protection Halons and the Environment," in Lugano, Switzerland, June 1988. Some 270 participants from 23 countries met to address the halon/ozone issue; a follow-up conference will be held in Geneva in October 1990. The NFPA continues to publish technical articles on the ozone problem and solutions, and provides information through its technical advisory services.

Several fire-protection companies are already placing labels on all the halon systems they install or maintain, instructing owners to return the halon for reuse if the system is scrapped. The Fike Corporation responded to the ozone issue by developing new fire-detection technology that uses analog sensors (rather than smoke detectors) with a microprocessor that recognizes the profiles of real fires and completely avoids false halon discharges. These new systems are already marketed worldwide.

DuPont, Fike, the Fire Protection Industry Association of Australia (FPIAA), the Halon Research Institute (HRI), the National Fire Protection Association (NFPA), ICI and others are distributing video tapes, slide shows, and publications explaining the environmental effects of halon on the stratospheric ozone layer, urging prudent halon use, and advocating the elimination of unnecessary emissions.

Other specific policy positions have been put forward by the Chartered Institution of Building Service Engineers (CIBSE) and Electrovert. CIBSE, of the United Kingdom, has published new guidelines that encourage natural and mechanical ventilation instead of air conditioning and explain ozone-safe alternatives to CFC-blown foams. Electrovert, a Canadian manufacturer of cleaning machines that use flammable solvents, no longer offers halon extinguishers in the equipment they sell.

In Australia, voluntary phase-downs and phase-outs of halons are supported by halon manufacturers, the fire-protection industry, the unions, and the government.

The Fire Protection Industry Association of Australia (FPIAA), and the Australian Association of Fluorocarbon Consumers and Manufacturers (AFCAM) have issued policy recommendations to cease the manufacture and import of small household portable halon extinguishers, to ban aerosol and non-refillable extinguishers, to require mandatory maintenance of halon systems, to halt unnecessary testing and training, to implement alternative test agents and alternative test methods as they become available, and to promote detection systems capable of reducing false activations. Similar policy has been announced by the Fire Industry Council (FIC) on behalf of the U.K Fire Protection Industry, the European Fire Protection Industry, and Eurofeu.

The fire department in Victoria, Australia, amended its charter to "protect the environment" in addition to life and property, placed a ban on the purchase of new halon, and prohibited training and demonstrations utilizing halons. Similarly, the Australian national fire fighters union has halted the purchase of halon extinguishers and will remove halon from emergency response vehicles in September 1989. The fire service in Tasmania, Australia, is now operating a halon recycling facility. The Australian federal department for the environment has removed portable halon extinguishers from their building and is storing them in a toxic waste facility pending development of safe destruction technology. The Australian Plumbers and Gasfitters Employees Union (PGEU) has proposed a policy of not installing any new halon system after July 1989 and proposes to halt the servicing of halon systems after July 1991. Furthermore, PGEU members will not perform discharge testing using halon gas after May 1989.

Many industry associations are engaged in extensive education and training programs. In Japan, the Association of Refrigeration and Air Conditioning Contractors (J-ARACC) has collected information on CFC phase-outs, alternative refrigerants, government policy, etc., and distributed it to their approximately 3500 members. This information included case studies of system retrofits, surveys of emissions, and coordination of recycling proposals. The Japan CFC Gas Association has published the "Manual for Proper Use of Controlled CFCs," which explains the content of "the Guideline for Restriction of Emission and Rationalization of Use" established by the Japanese Government. Moreover, in cooperation with the Ministry of International Trade and Industry (MITI), Japanese CFC manufacturers and users organized the "Federation for Promoting Rationalization of Use of Specified CFCs" in June 1989, and designated the month of July 1989 as "CFC Reduction Month" to conduct a campaign to promote the reduction of use of CFCs throughout Japan. In the United States, Igloo has developed a communications program of newsletters, formal presentations, and continued informal contact by sales representatives.

7.7 FINANCIAL STRUCTURE AND INSURANCE

The World Bank has recently pledged to screen all loans for environmental acceptability and U.S. government lending institutions are already redirecting applications for CFC technology to investments in ozone-safe technology.

Investment companies, such as the New Alternatives Fund, employ a screening process to affirmatively focus investment in companies that provide protection to the environment. They also avoid investment in companies that contribute to the depletion of the ozone layer.

Factory Mutual (FM) is emphasizing alternatives to halon when fire protection is required as a condition of insurance, and they are no longer requiring discharge testing of Halon-1301 systems when other methods can satisfy reliability concerns. Industrial Risk Insurers (IRI) no longer accepts systems of complex design, thus eliminating the need for any discharging of agent during the acceptance test. IRI has also called for the immediate cessation of all recommendations requiring halogenated fire extinguishing agents. IRI loss prevention management will consider alternatives to halon even in the case of catastrophic loss potential.

Insurers of Northern Telecom (N. Telecom) have agreed to cover fire risk in electronic installations valued at up to $10,000,000 (U.S.) <u>without</u> requirements for halon.

7.8 CODES OF PRACTICE AND OTHER MEASURES

Underwriters Laboratories (UL) has been a world leader in ozone layer protection. They have eliminated testing procedures related to product safety certification such as requirements to test discharge portable halon fire extinguishers. They have also developed performance testing of CFC-12 recycling machines for automobile air conditioners and are working to prescribe practical engineering measures that will allow refrigerator manufacturers to safely use highly efficient chemicals with different flammable properties.

7.9 WORLDWIDE TECHNOLOGY COMMITMENTS

Chemical producers in the European Economic Community (EEC), including Akzo, Atochem, DuPont, Hoechst AG, ICI, ISC Chemicals Ltd., Kali-Chemie Ag, Montefluos SpA, and SICNG, were the first to declare a joint commitment to not sell or license CFC or halon chemical manufacturing technology to countries that are not members of the protocol. Du Pont U.S.A. and Australian manufacturers have joined these pledges. Together, these companies represent a large portion of world CFC production and may help block access to CFC and halon production technology.

So far, no company has pledged to not dump or sell CFC/halon products, such as CFC-12 aerosol products, or production facilities, such as aerosol filling stations, to other countries. Dumping of these old products and technologies could prolong dependence on ozone-destroying CFCs and halons and could result in financial hardship to countries that receive the old technology but underestimate the expense of equipment that depends on parts and chemicals that are going out-of-stock. Developed countries could later find that a phase-out in developing countries is more expensive than necessary if these developing countries need to depreciate the technology that was dumped on them by developed countries. Careful consideration should be given to cooperative international policy to evaluate, educate, and possibly restrict the dumping of CFC and halon products and their manufacturing equipment.

AT&T and Northern Telecom are implementing corporate policy to phase out use of CFC and halon at all their worldwide 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 and that corporate financing will be available in their countries.

Many companies are making new ozone-safe technology available worldwide. Most companies will consider options to accommodate developing countries' needs such as licensing or selling alternatives technology. For example, Du Pont has announced that as world markets develop they will supply customers worldwide and will evaluate the feasibility of building alternative production facilities in the market regions they serve. In many cases profit and market-share motives of suppliers and manufacturers will support technology transfer objectives, but corporate concern for the world environment has probably also been a strong driving force.

The American Foodservice and Packaging Institute (FPI) has organized its members to provide free technical assistance on changing in food packaging from CFC-12 to HCFC-22. This technology is proven in the American market to produce substitute food packaging with very small investment and equivalent manufacturing costs.

AT&T has commercialized equipment to use ozone-safe terpene cleaning solvents and pledged to share the technology worldwide. The U.S.EPA is helping to organize and coordinate industry to transfer new technology to other countries.

The European Fluorocarbon Technical Committee (EFCTC) has announced the intent of the European Chemical Industry to make alternatives equally available to the industries of all countries, as the technology becomes established. Methods to accomplish this include providing information and technical assistance on the use of alternative products, offering alternatives for sale, and building and operating production facilities for alternatives where appropriate. Table 7-1 summarizes the various policies discussed above.

Table 7-1. Summary of Policies to Protect the Stratospheric Ozone Layer

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
AFCAM	Producer/Consumer Assoc. (Australia)	1998	85 percent reduction in the Halon ODP weighted basket with eventual phase-out when viable alternatives available
AHAM	Appliance Mfg. Assoc. (U.S.)	NA	Research consortia
AIA	Automobiles	NA	Approve recycling, change service manuals, train mechanics
ASHRAE	Refrigeration/Air Conditioning	NA	Approve recycling, change service manuals, train mechanics
AT&T	Electronics	1991 1994	50 percent reduction in CFC-113 use Phaseout CFCs in manufacturing Change in procurement policy Board of Directors Decision Benchmark test CFC-113 to establish standard for products that clean as well or better
Akzo	CFC Producer	Yes	PAFT 1 & 2; AFEAS
Alliance for Responsible CFC Policy	Producer/Consumer Assoc. (U.S.)	Yes	Phaseout of CFCs to maximum extent feasible
Allied-Signal	CFC Producer	Yes	Benchmark test CFC-113 to establish standard for products that clean as well or better PAFT 1, 2, and 3; AFEAs
Amerex	Halon Community	NK	Establish program that pays dealers to return used halon for recycling
All Japan Laundry & Drycleaning Assoc.	CFC Consumer	2000	Phase-out and shift to HCFC and other alternatives as they become available
Asahi Glass	CFC Producer	NK	PAFT 1 and 2; AFEAS
Atochem	CFC Producer	NK	PAFT 1, 2, and 3; AFEAS
Australian National Firefighters Union	Fire Protection	NK	Halt purchase of halon extinguishers; Remove halon from emergency response vehicles in September 1989
BRMA	Br. Flexible Foam Group	Yes	Phase-out CFC-11 by 1993

Table 7-1 (Continued)

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
Beham	Br. Refrigeration Manuf.	NA	Free program to pick-up home refrigerators and remove refrigerant prior to disposal
CIBSE	Building Engineers	NA	Encourage natural and mechanical ventilation; Explain ozone safe alternatives
CIG	Refrigerant Supplier	NA	Install refrigerant reclaiming equipment
DEC	Electronics	2000	Phase-out
DOD (U.S.)	All Products	ASAP	Reduce CFC use, eliminate dependence, change specifications and procurement Benchmark test CFC-113 to establish standard for products that clean as well or better
DOE (U.S.)	All Products	NA	Research consortia
Daikin	CFC Producers	NK	PAFT 1, 2, and 3; AFEAS
Dolco	Packaging	1988	Technical leadership in food service phase-out
DuPont	CFC/Halon-1301 Producer	2000	Will not sell halon for discharge testing after 1990 PAFT 1, 2, and 3; AFEAS; halon consortium Technical leadership in food service phase-out Benchmark test CFC-113 to establish standard for products that clean as well or better
EDF	Public Interest	NA	Negotiated a voluntary program with FPI to halt CFC-11 and -12 in food service
EFCTC and CEFIC	European CFC Producers	Yes	Recycle programs
Electrovert	Cleaning Machines	Yes	No longer offer Halon extinguishers in equipment Benchmark test CFC-113 to establish standard for products that clean as well or better
European Domestic Appliance Manuf.	Appliance	1989	50 percent CFC-11 reduction in polyurethane foam
FIC	Fire Protection	NK	Policy recommendations such as halting unnecessary testing
FIKE Corp.	Fire Protection	NA	New fire detection technology
FOE	Public Interest	NA	Negotiated a voluntary program with FPI to halt CFC-11 and -12 in food service Approve recycling, change service manuals, train mechanics

Table 7-1 (Continued)

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
FPI	Packaging Association	1988	Halt CFC-11 and -12 in food service Pledge to use new chemicals within 12 months of approval
FPIAA	Australian Fire Protection	1998	85 percent reduction in the Halon ODP weighted basket Policy recommendations include alternative test agents and methods, and a halon recovery and recycling scheme
Factory Mutual	Insurance/Research	NA	Alternatives to halon, discourage tests Halon consortium
Fort Howard	Packaging	1988	Technical leadership in food service phase-out
General Motors	Automobiles	NK	Recycle/recovery equipment required in service shops, assembly plants, and fleet garages by 1991
Goodyear	A/C Hoses and Seals	NA	Reduce CFC leakage, research for alternatives
Great Lakes	Halon-1211, -1301 Producer	No	Halon consortium
Hitachi	Electronics	2000	Phase-out
Hoechst AG	CFC Producer	1995	Earliest producer phase-out goal PAFT 1 AFEAS
HRI	Halon Community	NK	Halon consortium
ICI	CFC, Halon-1211 Producer	Yes	Halon consortium PAFT 1 and 2; AFEAS Benchmark test CFC-113 to establish standard for products that clean as well or better
IPC	Electronics Assoc.	NA	Benchmark test CFC-113 to establish standard for products that clean as well or better
IRI	Insurance	NA	No longer accepts systems of complex design; Immediate cessation of all recommendations requiring halogenated fire extinguishing agents
ISC	CFC Producer	NK	PAFT 1, 2, and 3 AFEAS

Table 7-1 (Continued)

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
ISOPA	Isocyanate Producer Assoc.	1993	60 percent CFC reduction in polyurethanes by the end of 1993 based upon 1986 usage
Iceland	Br. Refrigeration Manuf.	NA	Free program to pick-up home refrigerators and remove refrigerant prior to disposal
Igloo	Refrigeration Products	NK	Communications program
J-ARACC	Refrigeration and Air Conditioning (Japan)	NK	Information collection and distribution
Japan CFC Gas Association	CFC Consumer	NK	Published informational material explaining government position
Japanese CFC Manuf. and Users	CFC Producer/Consumer	NK	Conducting national campaign to promote the reduction of CFC use
Kali-Chemie AG	CFC Producer	NK	PAFT 1; AFEAS
La Roche	CFC Producer	NK	AFEAS
MACS	Automobiles	NA	Approve recycling, change service manuals, train mechanics
Matsushita	Electronics	2000	Phase-out
Montefluos SpA	CFC Producer	NK	PAFT 1; AFEAS
MVMA	Automobiles	NA	Approve recycling, change service manuals, train mechanics
NASA	All Products	NA	Halon consortium Benchmark test CFC-113 to establish standard for products that clean as well or better
NEC	Electronics	2000	Phase-out
NFPA	Fire Research	NA	Halon consortium
NIST	Research/Standards	NA	Halon consortium
NRCA	Roofing Assoc.	NK	Polyisocyanurate insulation testing

Table 7-1 (Continued)

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
NRDC	Public Interest	NA	Negotiated a voluntary program with FPI to halt CFC-11 and -12 in food service Approve recycling, change service manuals, train mechanics
NSF	Research	NA	Halon consortium
New Alternatives Fund	Investment	NA	Screening process to focus investment in companies providing protection to the environment
Nissan Motor Co.	Automobiles	1990 1993	Eliminate CFC-11 Eliminate CFC-113 . Eliminate CFC-12 as soon as possible Goal is to make car air conditioners and manufacturer processes free of CFC by mid 1990s
N. Telecom	Electronics	1991	Phase-out including halon; Board of Directors decision Benchmark test CFC-113 to establish standard for products that clean as well or better Halon alternatives testing
ORNL	Research	NA	Polyisocyanurate insulation testing
PFA	Flexible Polyurethane Foam (U.S.)	1990 2000	20 percent reduction in CFC use Phase-out
PGEU	Australian Plumbers and Gasfitters	NA	Will not install new halon systems after July 1989; Halt servicing of halon systems after July 1991
PIMA	Insulation Manufacturers Assoc.	Yes	20 percent reduction from 1986 levels in the use of CFC by end of 1989 Complete elimination by turn of century
Pennwalt	CFC Producer	Yes	AFEAS
Racon	CFC Producer	NK	PAFT 1; AFEAS
SAE	Automobiles	NA	Approve recycling, change standards, train mechanics
SICNG	CFC Producer	NK	AFEAS
Sainsbury's	Br. Supermarket Chain	Yes	Will use no CFC in refrigeration systems, no CFC-blown foam meat trays, no sales of CFC aerosols

Table 7-1 (Continued)

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
Seiko-Epson	Electronics	1993	Phase-out Board of Directors decision
Siemens	Electronics	1989	Phase-out; change in procurement
Sharp	Electronics, A/C, Refrigeration	1989 1998	20 percent reduction in CFC use Phase-out
Showa Denko	CFC Producer	NK	PAFT 1 and 2
Solway and Co.	CFC Producer	NK	PAFT 2
Tasmania Fire Service	Fire Protection	NA	Recycling facility
Toshiba	Electronics	2000	Phase-out
Toyota	Automobiles	1995	Eliminate CFCs in car air conditioners and manufacturing processes
Ulsan Chemicals	CFC Producer	NK	PAFT 1
U.K. Defence	All Products	NA	New procurement specifications
UL	Automobiles	NA	Certify safety and performance of recycle equipment Halon consortium Benchmark test CFC-113 to establish standard for products that clean as well or better
U.S. Air Force	Military	NA	Benchmark test CFC-113 to establish standard for products that clean as well or better Alternatives to halon testing and training Halon consortium
U.S. Army	Military	NA	Halon consortium Benchmark test CFC-113 to establish standard for products that clean as well or better
U.S. Coast Guard	All Products	NA	Halon consortium
U.S. Navy	Military	NA	Benchmark test CFC-113 to establish standard for products that clean as well or better

Table 7-1 (Continued)

	Area of Involvement	Phase-Out Goal/Year	Activities/Comments
Victoria Fire Department	Fire Protection	NA	Ban purchase of new halon, prohibit training and demonstrations using halon
Volvo	Automobile	1991	Phase-out CFC in flexible foam
		1995	Phase-out CFC in rigid foam and air conditioners
Wormald	Fire Protection	NA	Halon consortium
World Bank	Investment	NA	Screen all loans for environmental acceptability

NA = Not Applicable

NK = Not Known

CHAPTER 8

CONCLUSIONS

8.1 CONSUMPTION OF CFCS AND HALONS

In the absence of regulation such as the Montreal Protocol, demand for products and services based on CFCs and halons would continue to grow, especially in developing countries.

With the exception of some foam products, CFCs and halons constitute only a small part of the final consumer price.

North America, Europe, and Japan are responsible for about 80 percent of total consumption of controlled chemicals. The per capita consumption in developed economies is in many cases more than 10 times the per capita consumption in the developing nations.

8.2 ASSESSMENT FRAMEWORK

There are significant health, agricultural, productivity and environmental benefits from the elimination of CFC and halon emissions. However, only very few of these benefits can be quantified in economic terms.

Assessments of the costs of reducing or eliminating CFCs and halons must consider a variety of factors. These include capital costs, research and development costs, operational costs (such as energy and labour costs), and safety and toxicity risks. Differences in stages of national development and in the extent of development of CFC- and halon-producing and -using industries from country to country result in very different transition costs for each country.

The development of new options for replacing CFCs and halons is progressing very rapidly. A static cost analysis based on current knowledge therefore might overestimate the costs and underestimate the reduction in use achievable in the transition to CFC-free technologies.

Several national studies have been conducted and these have concluded that substantial reductions of CFC and halon use are technically and economically feasible. These studies estimate that benefits coming from avoiding ozone depletion will be higher than costs.

8.3 THE COSTS OF TECHNICAL SUBSTITUTION

Technical options to phase out production and use of CFCs within the next 10 to 15 years and to phase down the production and use of halons have been identified by the UNEP Technical Panel. The Technical Options Reports estimate the approximate costs and the eventual problems of transition to CFC- and halon-free technologies for each application. Detailed estimates of the changeover costs, however, cannot at present be made for many potential options. Consequently, global cost estimates are difficult to make with accuracy.

Different technical options will be available in the short, medium, and long term. The actual costs of each of these options will depend on the outcome of technical development and the speed with which they are adopted.

Analysis of options in the domestic refrigerator sector demonstrates that the costs of reducing CFC and halon use vary greatly. Net costs increase if less energy-efficient options are selected, while net cost savings can be achieved if the most energy-saving options are selected. The ability to achieve maximum energy and cost savings will depend on the resources and the time available to review and test options and redesign products.

An example of a solvent replacement option demonstrates that some technical options are interdependent in implementation. This means that a technical option that is cost effective when used alone may not be economically justified when other technical changes are undertaken.

There has been a rapid increase in the availability of technologies to reduce CFC and halon use. These new technologies have generally lower costs and increase the capability to reduce total use.

The total costs for the world of reducing or phasing out CFCs and halons cannot be precisely estimated at this time. However, current evidence suggests that net costs for the first 50 percent of the global reduction will be low. Cost estimates for the remaining reduction--mainly in the fields of industrial refrigeration, rigid foam, solvents and halons--vary widely and depend mainly on the availability of drop-in substitutes, re-engineering costs of equipment and products, and the (higher) price and energy efficiency of the substitutes.

The time-path for phasing out CFCs is critical with respect to costs. A too rapid transition may raise costs as a result of capital abandonment. Individual governments and industries face significant opportunities to save money if the best reduction strategy is chosen.

8.4 ECONOMIC/ENVIRONMENTAL BENEFITS OF REDUCED CFC/HALON USE

Reducing the use of CFCs and halons could have enormous beneficial impacts on human health and the environment. In many instances, the current state of scientific knowledge makes it very difficult to quantify the magnitude of many of these impacts. Nevertheless, mounting scientific evidence predicts that stratospheric ozone depletion will cause increased levels of skin cancer, cataracts, immune suppression, and other adverse health effects, as well as adverse effects on plants and animals.

In attempting to value these impacts there are many issues associated with proper valuation procedures varying from one region of the world to another and between people alive today and generations to come. These issues make it inherently difficult, if not impossible, to assign a monetary worth to the harmful impacts avoided as a result of reduced CFC and halon use.

Notwithstanding the problems of quantifying the benefits, the basic conclusion is that the monetary value of the benefits is undoubtedly much greater than the costs of CFC and halon reductions.

8.5 TECHNOLOGY TRANSFER

Global diffusion of CFC and halon replacement technology (including recovery and recycling) is crucial for protecting the ozone layer and is in the interests of both developed and developing countries alike.

Priority should be given to reducing demand by CFC/halon-using industries. This can be accomplished in many ways, for example, through a tax on production or use, restrictions on productions, public education, or regulation of the use of CFCs and halons. Developed countries may also assist in activities to educate people on the importance of ozone layer protection and may provide information to guide industries toward phase-out of CFCs.

Current information and financial resources of developing countries are inadequate for adoption of CFC replacement technologies and for defining and implementing the national options for the transition to CFC-free technologies.

Some CFC replacement technologies will be adopted in the usual course of economic growth but at a slow rate. Development assistance will be required in other cases.

Means are needed to implement the Montreal Protocol commitment to prevent the transfer of discarded CFC/halon-producing and CFC/halon-using technologies to developing countries.

Developed countries that have signed the Protocol may choose different methods to financially assist developing countries. These methods vary from increasing overseas development assistance, to raising funds by charging for CFC use or contributing a small percentage of their GNP as a contribution to an international fund. Substantial financing can be generated using any of these techniques. These arrangements can be bilateral or as a contribution to an international fund.

Multilateral development institutions, which include organizations such as the World Bank, the Inter-American Development Bank, the Asian Development Bank and the African Development Bank, can, by virtue of their development activities and established connections with developing countries, play a crucial role in facilitating the transfer of technology needed during the transition period. Special funding mechanisms or arrangements are needed for this purpose because currently available resources are already strained as a result of the world debt problem and the dire economic situation of many countries. Such institutions should be urged to develop internal guidelines in support of explicit policies to facilitate the implementation of the Montreal Protocol.

APPENDIX I

MEMBERS OF THE ECONOMIC ASSESSMENT PANEL

Chairman

NAME: **Strongylis, George**
ORGANIZATION: Commission of the European Communities
Directorate General XI/Service XI/A/2
ADDRESS: 200, Rue de la Loi
B-1049 Bruxelles, Belgique
TELEPHONE: 02 235 72 60
TELEFAX: 02 235 01 44
TELEX: 21877 COMEU B

Secretary to Chairman

NAME: **Makridis, Christos**
ORGANIZATION: Commission of the European Communities
Directorate General XI/Service XI/A/2
ADDRESS: 200, Rue de la Loi
B-1049 Bruxelles, Belgique
TELEPHONE: 02 235 93 68
TELEFAX: 02 235 01 44
TELEX: 21877 COMEU B

Vice-Chairman (Coordination with Technical Panel)

NAME: **Andersen, Stephen O.**
ORGANIZATION: U.S. Environmental Protection Agency
ADDRESS: 401 M Street, SW (ANR 445)
Washington, DC 20460, USA
TELEPHONE: 202 475 9403
TELEFAX: 202 382 6344
TELEX: 892758 (Confirm: EPA-WSH)

Vice-Chairman (Coordination with Environmental Effects Panel)

NAME: **Hoffman, John S.**
ORGANIZATION: U.S. Environmental Protection Agency
ADDRESS: 401 M Street, SW (ANR 445)
Washington, DC 20460, USA
TELEPHONE: 202 382 4036
TELEFAX: 202 382 6344
TELEX: 892758 (Confirm: EPA-WSH)

Consultant

NAME: **Christensen, Stig P.**
ORGANIZATION: COWIconsult, Consulting Engineers and Planners AS
ADDRESS: 19, Parallelvej, DK-2800 Lyngby, Denmark
TELEPHONE: 42 88 37 88
TELEFAX: 45 93 17 88
TELEX: 37 280 Cowi dk

Members

NAME: **Ahmad, Yusuf J.**
ORGANIZATION: UNEP, Senior Advisor to the Executive Director
ADDRESS: United Nations Environment Program
P.O. Box 47074, Nairobi, Kenya
TELEPHONE: 333930 or 520600
TELEFAX: 2542 520711
TELEX: 22068 UNEP KE

NAME: **Bouchitte, Alec**
ORGANIZATION: B.D.P.A.
ADDRESS: 27, Rue Louis Vicat
F-75738 Paris Cedex 15, France
TELEPHONE: 1 46 38 34 75
TELEFAX: 1 46 38 34 82

NAME: **Coleman, Daphne Lynn**
ORGANIZATION: Department of Trade and Industry
Economic Adviser
ADDRESS: Ashdown House, Room 131
123 Victoria Street, London SW1, Great Britain
TELEPHONE: 01 215 6605
TELEFAX: 01 828 0931

NAME: **Corkindale, John**
ORGANIZATION: Department of Economics
ADDRESS: Romney House, Room RH B251
43 Marsham Street, London SW1P 5EB, Great Britain
TELEPHONE: 01 276 3000 ext. 8414
TELEFAX: 01 276 0818

NAME: **DeCanio, Stephen**
ORGANIZATION: University of California
Professor, Department of Economics
ADDRESS: University of California
Santa Barbara, California 93106, USA
TELEPHONE: 805 961 3130
TELEFAX: 805 964 2812

NAME: **Deschamps, Pascal**
ORGANIZATION:
ADDRESS: 14, Boulevard General Leclerc
F-92524 Neuilly-sur-Seine, France
TELEPHONE: 47 56 12 12

NAME: **Jansen, Huib**
ORGANIZATION: Institute for Environmental Studies
ADDRESS: Free University, Box 7161
1007 MC Amsterdam, Netherlands
TELEPHONE: 20 54 83 827
TELEFAX: 20 44 50 56

NAME: **Katao, Kazuo**
ORGANIZATION: Ministry of International Trade and Industry
Deputy Director of Chemical Products Division
ADDRESS: 131 Kasumigaseki
Chiyoda Ku, Tokyo 100, Japan
TELEPHONE: 03 501 1737
TELEFAX: 03 501 2084

NAME: **Klerken, Wiel**
ORGANIZATION: Ministerie van Economische Zaken
Plv. Hoofd Stafafdeling
Coordinatie Milieuzaken
ADDRESS: Bezuidenhoutseweg 2, Postbus 20101
2500 EC-Gravenhage, Netherlands
TELEPHONE: 70 79 6878 (79 6411)
TELEFAX: 70 79 6167

NAME: **Kukhar, V.P.**
ORGANIZATION: Executive Secretary, Ozone Committee
ADDRESS: c/o Mr. Serge Stepanov
12 P. Morogov
123 376 Moscow, USSR
TELEPHONE: 255 2161
TELEX: 411 117 zums su

NAME: **Langdau, Serge**
ORGANIZATION: Commercial Chemical Branch
Conservation and Protection Service
Environment Canada
ADDRESS: 14th Floor, Place Vincent Massey
351 St. Joseph Blvd.,
Hull, Quebec K1A OH3, Canada
TELEPHONE: 819 997 1243
TELEFAX: 819 997 0547
TELEX: 503 4567 EPSEED-HULL

NAME: **Lee, Kai N.**
ORGANIZATION: University of Washington
Associate Professor, Department of Political Science and
Institute for Environmental Studies, FM-12
ADDRESS: University of Washington
Seattle, Washington, USA
TELEPHONE: 206 543 1812 or 2498
TELEFAX: 206 543 9285
TELEX: 4740096 UW UI

NAME: **Mintzer, Irving**
ORGANIZATION: World Resources Institute
ADDRESS: 1735 New York Avenue, NW; Suite 400
Washington, DC 20006, USA
TELEPHONE: 202 662 2549
TELEFAX: 202 638 0036

NAME: **Nader, Franz**
ORGANIZATION: Professor, Dr., Verband der Chemischen Industrie e.V.
ADDRESS: Karlstrasse 21, 6000 Frankfurt/Main 1, W.Germany
TELEPHONE: 069 25 56 448
TELEFAX: 069 255 6471
TELEX: 411 372 VCIF-D

NAME: **Otieno, Gilbert**
ORGANIZATION: Division of Industry
ADDRESS: P.O.Box 30418, Nairobi, Kenya
TELEPHONE: 34 00 10

NAME: **Philips, Dotun**
ORGANIZATION: Professor, Director-General
Nigerian Institute of Social and Economic Research
(N.I.S.E.R.)
ADDRESS: Ibadan, Nigeria
TELEPHONE: 22 41 10 51
TELEFAX: 22 41 43 04

NAME: **Rault, Sylvain**
ORGANIZATION: Unité d'Enseignement et de Recherche de Sciences
Pharmaceutiques, Université de Caen
ADDRESS: 1, rue Vaubenard, F-14032 Caen, France
TELEPHONE: 31 45 55 00
TELEFAX: 31 45 56 00

NAME: **Sato, Masahiro**
ORGANIZATION: President
Environmental Science Research Institute Inc.
ADDRESS: Environmental Science Research Institute Inc.
3-16-3, Hongou,
Bunkyo-Ku, 113, Japan
TELEPHONE: 03 816 7691
TELEFAX: 03 816 7692

NAME: **El Serafy, Salah**
ORGANIZATION: World Bank
ADDRESS: 1818 H Street NW, Washington, DC 20433, USA
TELEPHONE: 202-477-8072
TELEFAX: 202-477-1569
TELEX: 248423

NAME: **Uhlenbrock, Peter**
ORGANIZATION: Hoechst AG
ADDRESS: Frankfurt, W.Germany
TELEPHONE: 069 305 6284
TELEFAX: 069 30 91 79

Observers

NAME: **Mills, John**
ORGANIZATION: ICI, Monde Division
ADDRESS: P.O. Box 13 Heath, Runcorn,
Cheshire, WA 74 QF, Great Britain
TELEPHONE: 09 28 51 32 13
TELEFAX: 09 28 58 11 55

NAME: **Von Schweinichen, Joachim**
ORGANIZATION: c/o Montefluos S.p.A.
ADDRESS: via P. Eugenio, 1/5
20155 Milano, Italy
TELEPHONE: 39.2.6270-3438
TELEFAX: 39.2.6270-3412
TELEX: 310679 MONTED I

APPENDIX II

PEER REVIEWERS

NAME: **Abbott, J. Godfrey**
ORGANIZATION: Dow Europe SA
ADDRESS: CH-8819 Horgen, Switzerland
TELEPHONE: 41 1728 2708
TELEFAX: 41 1728 2935
TELEX: 826940

NAME: **Ambler, Mark**
ORGANIZATION: Coopers and Lybrand Associates Ltd.
ADDRESS: Plumtree Court, London EC4A 4HT, Great Britain
TELEPHONE: 01 583 5000
TELEFAX: 01 822 4652 (groups 11/111)
TELEX: 887470

NAME: **Ansari, Z.R.**
ORGANIZATION: H.E., Minister of Environment and Forests,
Ministry of Environment and Forests
ADDRESS: Paryavaran Bhavan C.G.O. Complex
Lodi Road, New Delhi 110003, India
TELEX: W-66185 DOE IN

NAME: **Buxton, Victor**
ORGANIZATION: Chief, Chemical Controls, Environment Canada
ADDRESS: Ottawa, K1A 0E7, Canada
TELEPHONE: 953-1675
TELEFAX: 819-997-0547

NAME: **Cartmell, Michael J.**
ORGANIZATION: ISOPA
ADDRESS: Avenue Louise 250, Bte 52
B-1050 Brussels, Belgium
TELEPHONE: 32 2 640 4023
TELEFAX: 32 2 642 9155
TELEX: 29369

NAME: **Carvalho, Suely M.**
ORGANIZATION: Director, Departamento de Fisica Experimental,
Instituto de Fisica da USP
ADDRESS: Caixa Postal 20516
01498 - Sao Paulo - SP, Brazil
TELEX: 1180923 ifsp br

NAME: **Chowdhury, Anwarul Karim**
ORGANIZATION: Ambassador, Director General (Economic Affairs),
Ministry of Foreign Affairs, Government of Bangladesh
ADDRESS: Dhaka, Bangladesh

NAME: **Cooper, Peter J.**
ORGANIZATION: J. Sainsbury plc
ADDRESS: Wakefield House, Stanford Street
London SE1 9LL, Great Britain
TELEPHONE: 44 1 921 6301
TELEFAX: 44 1 921 6178
TELEX: 264241

NAME: **Dasgupta, Partha**
ORGANIZATION: Professor of Economics
King's College, University of Cambridge
ADDRESS: Cambridge, United Kingdom
TELEPHONE: 223 6 18 63
TELEFAX: 223 33 52 99

NAME: **Doniger, David D.**
ORGANIZATION: Senior Attorney, NRDC
ADDRESS: 1350 New York Ave. N.W.
Washington D.C., U.S.A.
TELEPHONE: 202-783-7800
TELEFAX: 202-783-5917

NAME: **Gerkin, S.**
ORGANIZATION: Professor, University of Wyoming
Department of Economics
ADDRESS: University Stat. Box 3985
Laramie, WY 82071, USA
TELEPHONE: 1-307-7664931

NAME: **Goh, Kiam Seng**
ORGANIZATION: Director-General, Department of Environment
ADDRESS: 13th Floor, Wisma, Sime Darby
Jalan Raja Laut
50662 Kuala Lumpur, Malaysia
TELEPHONE: 03 293 8955

NAME: **Hueting, R.**
ORGANIZATION: Dr., Central Bureau of Statistics
ADDRESS: Box 959
2270 AZ Voorburg, Netherlands
TELEPHONE: 70-694341
TELEFAX: 70-694341

NAME: **Jensen, Bent**
ORGANIZATION: CEFIC
ADDRESS: Avenue Louise 250, Bte 72
B-1050 Brussels, Belgium
TELEPHONE: 32 2 640 2095
TELEFAX: 32 2 640 1981
TELEX: 62498

NAME: **Jernelov, Arne**
ORGANIZATION: UNIDO
ADDRESS: 10/11P, Vienna International Centre
Vienna 1 300, Austria
TELEPHONE: 2631 x 5079
TELEFAX: 1 232 156

NAME: **Kerr, Andrew**
ORGANIZATION: Campaign Coordinator, Greenpeace
ADDRESS: Kaizergracht 176
1016 DW Amsterdam, Netherlands
TELEPHONE: 26 523 6555
TELEFAX: 26 523 6500

NAME: **Kesseba, Abbas M.**
ORGANIZATION: Director, IFAD
ADDRESS: Via del Serafico 107
I-00142 Roma, Italy
TELEPHONE: 39 6 54 59 1
TELEFAX: 50 43 46 3
TELEX: 620 330

NAME: **Kismadi, M.S.**
ORGANIZATION: Special Assistant to Minister
Ministry of Population and Environment
ADDRESS: Jakarta, Indonesia
TELEPHONE: 21 35 75 79

NAME: **Kojima, Naoki**
ORGANIZATION: Director, CFCs Policy Office, Basic Industries Bureau,
Ministry of International Trade and Industry
ADDRESS: 3-1, Kasumigaseki 1-Chome
Chiyoda-Ku, Tokyo, Japan
TELEPHONE: 81-3-501-4724
TELEFAX: 81-3-580-6348

NAME: **McCarthy, Peter J.**
ORGANIZATION: Vice-President, Pennwalt Corp.
ADDRESS: 3 Parkway, Philadelphia, U.S.A.
TELEPHONE: 215-587-7617
TELEFAX: 215-587-7930

NAME: **Orfeo, Robert S.**
ORGANIZATION: Allied Signal Inc.
ADDRESS: 20, Pembody Street
Buffalo, N.Y. 14210, U.S.A.
TELEPHONE: 716 827 6243
TELEFAX: 716 827 6207

NAME: **Osafo, Seth A.**
ORGANIZATION: Secretary, Legal Advisor
Environmental Protection Council
ADDRESS: Box M 326, Accra, Ghana
TELEPHONE: 662 626

NAME: **Reyes-Lujon, Sergio**
ORGANIZATION: Undersecretary of Ecology
ADDRESS: Rio Elba 20-16, 06500 Mexico, D.F.

NAME: **Scharer, Bernd**
ORGANIZATION: Umweltbundesamt
ADDRESS: Bismarck Platz 1
1000 Berlin 33, Bundesrepublik Deutschland
TELEPHONE: 030 89 03 ext. 2368
TELEFAX: 030 89 03 - 22 85
TELEX: 183 756

NAME: **Underwood, Bernard**
ORGANIZATION: Electronic Engineering Association
ADDRESS: 8 Leicester Street
London WC2H 7BN, Great Britain
TELEPHONE: 44 1 437 0678
TELEFAX: 44 1 434 3477
TELEX: 263536

NAME: **Yangtzu, Wang**
ORGANIZATION: Deputy Administrator
National Environmental Protection Agency
ADDRESS: Beijing, China
TELEPHONE: 653-681
TELEX: 222359 nepa cn

APPENDIX III

APPROACH FOR ESTIMATING COSTS OF REGULATION[1]

This appendix describes the general framework economists used in the United States, Canada, and the Nordic countries to estimate the capital and operating costs of options for modifying the manner in which products are produced and/or used in order to reduce the use and/or emissions of CFCs and halons. Options for reducing CFC and halon use and/or emissions include using alternative production methods, using alternative chemicals, installing equipment to collect and recycle CFCs and halons, and switching to non-CFC products. The public and corporate concern for ozone layer protection, direct regulation, and increased prices of CFCs and halons (caused by the restrictions imposed for stratospheric ozone protection) drive the adoption of these steps by firms.

The steps used to estimate costs are:

1. Identify Major CFC and Halon Applications. The major CFC and halon applications are identified and divided into key product areas. The patterns of CFC and halon use in each application is defined.

2. Specify Control Possibilities Applicable in Each Application. A wide range of control possibilities have been identified for each of the application categories. Some controls are available today, while others are expected to become available in the future. For each of the control possibilities, the potential cost of undertaking the control and the influence that the control may have on CFC and halon use and emissions is defined.

3. Estimate CFC and Halon Use Reductions Achievable with Each Control Possibility. The annual reduction in CFC and halon use that can be achieved if the control possibility were implemented is estimated for each control individually.

4. Estimate Annualized Costs of the Control Possibilities. Social and private annualized costs of the control possibilities are estimated from the capital and operating data. One-time costs (such as capital costs) are converted into equivalent annual costs using a standard annualization factor. The annualized costs are expressed in terms of dollars per kilogram of CFC and halon use avoided by dividing the annualized cost estimate by the number of kilograms of

---

[1] This general methodology was developed concurrently in North America and Europe. This text was written by James Hemby, Kevin Hearle, Stephen Andersen, and Stig Christensen.

CFC and halon use that are avoided by implementing the control.

Each of these steps is described below.

III.1 IDENTIFY MAJOR CFC APPLICATIONS

The major uses of CFCs and halons are in:

- refrigeration;
- foam blowing;
- fire extinguishing;
- solvent cleaning;
- sterilization; and
- miscellaneous applications.

These broad end-uses can be divided into more detailed application categories that differentiate the types of products made with CFCs and halons. A list of these applications is shown in Figure III-1.

The applications are defined as products (e.g., insulating foam) or services (e.g., metal cleaning). In some cases it may be useful to divide a single product into separate application categories. For example, two applications could be defined for boardstock rigid polyurethane foams -- construction and industrial. Although the manufacturing processes and firms producing foams for both applications are similar, a division between the two can be made in order to capture possible differences in control options available for each.

The applications are analyzed to account for all CFC and halon use associated with manufacturing, installation, and use of the application. Refrigerators, for example, require CFCs during manufacturing and for replacing CFCs and halons lost during product use. Manufacturing, installation, and service use of CFCs are each analyzed within this application, recognizing that the control possibilities may influence each portion of the CFC and halon use.

For some applications, the output produced can best be described as a "service." Examples include solvent and sterilization uses. For service uses, applications were defined by the entity performing the service (e.g., hospitals sterilizing surgical equipment) or the type of service being performed (e.g., conveyorised vapour degreasing).

III.2 SPECIFY CONTROL POSSIBILITIES APPLICABLE IN EACH APPLICATION

The next step defines the set of control possibilities that may be undertaken to reduce CFC and halon use within each application. The following types of control possibilities were identified:

- Product substitutes -- replace CFC-consuming products with non- (or less-) CFC-consuming substitute products. An example is substituting packaging materials manufactured using CFC-blown foam with paper-based packaging materials.

Figure III-1. List of CFC Applications Used in Typical Cost Analysis

Application	Compound
FOAM BLOWING	
Rigid Polyurethane Foam	
Laminated-Construction	CFC-11
Boardstock-Construction-Building	CFC-11
Boardstock-Construction-Industrial	CFC-11
Poured-Refrigeration	CFC-11/CFC-12
Poured-Packaging	CFC-11/CFC-12
Poured-Transportation	CFC-11/CFC-12
Poured-Construction-Building	CFC-11/CFC-12
Poured-Construction-Industrial	CFC-11/CFC-12
Poured-Construction-Building	CFC-11/CFC-12
Poured-Construction-Industrial	CFC-11/CFC-12
Sprayed-Transportation	CFC-11/CFC-12
Flexible Polyurethane Foam	
Slabstock	CFC-11
Moulded	CFC-11
Phenolic Foam	CFC-11/CFC-113
Polypropylene Foam	CFC-11/CFC-114
Polyethylene Foam	CFC-11/CFC-114
PVC Foam	CFC-11/CFC-12
Extruded Polystyrene Foam	
Sheet	CFC-12
Boardstock	CFC-12

Figure III-1 (Continued)

Application	Compound
REFRIGERATION	
Mobile Air Conditioners	CFC-12
Retail Food	CFC-12
Cold Storage	CFC-12
Centrifugal Chillers	CFC-12
Refrigerators	CFC-12
Transport	CFC-12
Process Refrigeration	CFC-12
Freezers	CFC-12
Reciprocating Chillers	CFC-12
Dehumidifiers	CFC-12
Ice Machines	CFC-12
Water Coolers	CFC-12
Vending Machines	CFC-12
Centrifugal Chillers	CFC-11
Centrifugal Chillers	CFC-114
Centrifugal Chillers	CFC-500
Retail Food	CFC-502
Cold Storage	CFC-502
SOLVENTS	
Conveyorised Vapour Degreasing	CFC-113
Open Top Vapour Degreasing	CFC-113
Cold Cleaning	CFC-113
Dry Cleaning	CFC-113
STERILIZATION	
Hospitals	CFC-12
Medical Equipment	CFC-12
Contract Sterilization	CFC-12
Pharmaceutical	CFC-12
Spice Fumigant	CFC-12
Commercial R&D Labs	CFC-12
Libraries	CFC-12
Non-commercial R&D Labs	CFC-12
Animal Labs	CFC-12
Bee Hive Fumigant--DOA	CFC-12

Figure III-1 (Continued)

Application	Compound
FIRE EXTINGUISHING	
Total Flooding Systems	
Civilian Electronic	1211
Military	1211
Civilian Flammable Liquid	1211
Civilian Other	1211
Civilian Electronic	1301
Military	1301
Civilian Flammable Liquid	1301
Civilian Other	1301
Portable Systems	
Civilian Electronic	1211
Military	1211
Civilian General	1211
Civilian Residential	1211
Civilian Flammable Liquid	1211
Military	1301
Locally Applied Systems	1211
Locally Applied Systems	1301
MISCELLANEOUS	
Skin Chiller/Cleaner	CFC-113
Liquid Food Freezing	CFC-12
Blower Cleaner	CFC-12
Warning Devices	CFC-12
Heat Detectors	CFC-12
Whipped Topping Stabilizer	CFC-115
Aerosol Propellant	CFC-11/CFC-12

- Chemical substitutes -- replace CFCs used in the manufacture, installation, or use of products with less ozone depleting chemicals.
- Process substitutes and other controls -- process changes, use of add-on recovery/recycling equipment, and other kinds of controls for reducing CFC use or emissions (e.g., recovery of CFCs from existing products).

In the United States, EPA has identified a total of nearly 550 control possibilities have been identified that effectively reduce CFC or halon use and have acceptable risk/toxicity, technical feasibility, and cost. These controls form a "menu" of options from which firms within each of the application areas may choose to reduce their consumption of CFCs and halons. Additional options are quickly becoming available as concern for protecting the ozone layer increases.

Not all of the options identified are available immediately. For each control option an estimate was made of its expected future availability over time. The following definitions have been used:

- short term -- available in 0 to 3 years;
- medium term -- available in 4 to 7 years; and
- long term -- available in more than 7 years.

III.3 ESTIMATE CFC/HALON USE REDUCTIONS ACHIEVABLE WITH EACH CONTROL POSSIBILITY

The potential effectiveness of each control possibility to reduce CFC and halon use can be estimated within its application category based on three or more factors including:

- the portion of the application for which the control is effective;
- the reduction potential of the control; and
- CFC/halon use and emissions within the application.

The portion of the application for which the control is effective defines the opportunity to reduce CFC and halon use through the implementation of the control. For example, the control being analyzed may be applicable for the service use segment of the application, but may not be applicable for the other segments. This case could be further refined if the control applies only to a portion of the service use segment (e.g., only larger repair shops).

An alternative example is the case of a chemical substitute that may be applicable to only a portion of the total application's use of CFCs and halons. The portion for which the chemical substitute is not applicable may have certain product characteristics or manufacturing requirements that preclude the use of the substitute.

Reduction potential refers to the extent to which a control reduces CFC and halon use in its applicable segment of the application. For example, recovery equipment used during air conditioning servicing will reduce total use in the application. The reduction potential is generally less than 100 percent for engineering controls. The reduction potential for many chemical substitutes is 100 percent when for particular segments of an application.[2] Similarly, the reduction potential for product substitutes is often 100 percent.

The final factor to be considered in material analysis is the use and emissions of the compound in the applications. Use in the application is divided into manufacturing use, installation use, service use, other use, and unallocated use. The total use in the application equals the sum of these component uses. The total use in some applications cannot be allocated to manufacturing, installation, or service. In this case, an amount can be identified as "other or unallocated."

Emissions are divided into emissions during manufacturing, installation, product use and servicing, product disposal, and "other" emissions. Engineering controls are assumed to reduce CFC and halon emissions in these categories.

Given these definitions, the approach used to estimate the potential for control options to reduce CFC and halon use differ by the type of control as follows:

- <u>Product substitutes</u> are assumed to reduce CFC and halon use during the manufacturing and installation of the CFC and halon consuming products they replaced. Therefore, the use reduction of product substitute controls are estimated by multiplying the compound use during manufacturing and installation in the application category by the estimated portion of the manufacturing and installation use to which the product substitute applies.

- <u>Chemical substitutes</u> may be capable of replacing CFC and halon use in: (1) manufacturing and installing new products (e.g., making a new refrigerator) and/or (2) servicing existing products (e.g., replacing CFCs while servicing an old refrigerator). Therefore, separate use reductions were estimated for chemical substitutes in new products and in existing products. The use reduction associated with a chemical substitute in new products was estimated by multiplying the portion of new production that may adopt the chemical substitute by the CFC and halon use during manufacturing and installation. Similarly, for

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[2] Some of the chemical substitutes are themselves potential ozone depleters. The increase in the use of these compounds as a consequence of the undertaking of the control option is identified as well.

existing products, the reduction potential was estimated by multiplying the portion of existing products for which the substitute may be applicable by the CFC and halon use for servicing existing products.

- For process substitutes, add-on engineering controls, and other kinds of controls, use reduction potentials are calculated as the sum of the reductions possible in each of the emissions categories.

The estimates of the portion of the application to which each control applies are allowed to change over time. A maximum level is defined, indicating the likely full extent to which the control would be implemented in the application, given time for the firms in the application to implement the controls. The time required to implement the controls is also estimated (and is generally in the order of 3 to 10 years), so that the estimated use reduction changes over time as the level of applicability of the control increases. The increase in the applicability of the control over time is most simply modelled using linear interpolation, so that the maximum likely penetration is reached in the time required for firms to adopt the control.

III.4 ESTIMATE ANNUALIZED COSTS OF THE CONTROL POSSIBILITIES

For each control possibility, both social and private annualized costs can be estimated. These annualized costs reflect the capital, operating, and other costs that are incurred when the control is undertaken. These costs are based on engineering estimates and are defined as the costs that are incremental relative to continuing to manufacture and use the CFC and halon related products in their current forms. The social costs reflect the total resource costs to society, and the private costs reflect the costs faced by firms, including appropriate adjustments for tax liabilities and costs of capital.

To enable the controls to be compared and analyzed in relation to a policy of restricting the use of CFCs and halons, the annualized costs can be expressed on a per kilogram of use avoided basis. This "per kilogram" estimate is made by dividing the annualized cost of undertaking the control by the amount of the compound use that may be reduced by the control. The resulting value (based on private costs) is taken as an indication of the increase in the price of CFCs and halons that would be required in order for firms to be indifferent between undertaking the control or continuing to use the CFCs and halons. If the price of the CFCs and halons exceeds this annualized value, the firm would be better off to reduce its use of CFC and halon and undertake the control.

The following types of costs have been reported (where applicable) for each control possibility:[3]

- capital costs -- such as the acquisition cost of equipment required to convert production capacity to

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[3] Not all of these cost categories apply to all of the controls. Some chemical substitutes, for example, can be used without additional capital investment.

use substitute chemicals. Capital costs are one-time costs that are subject to depreciation.

- <u>non-recurring costs</u> -- transitional, one-time costs such as research and development, reformulation, or training required to implement a control. For purposes of computing private annualized costs, non-recurring costs were considered not to be depreciable.
- <u>annual operating costs</u> -- incremental materials and labour required to implement the control.
- <u>salvage of capital equipment</u> -- residual value of equipment used to implement a control.[4]
- <u>annual offsetting savings</u> -- reduced expenditures due to lower use of CFCs and other factors.

In addition to the costs identified above, several special costs are reported for product and chemical substitutes:

- <u>Product substitutes</u>
  - -- the price differential between the CFC- and halon-using product and its replacement product is included as a cost (or possibly a savings); and
  - -- for insulating foams, estimates can be made of the potential stream of annual energy losses caused if less-insulating products are used.
- <u>Chemical substitutes</u> -- the expected future price per kilogram of CFC-replacing chemicals is estimated along with the amount of the substitute needed to replace a single kilogram of CFC and halon.

III.4.1 Methods for Computing Social Annualized Costs

Estimates of capital and non-recurring costs are annualized by multiplying these costs by:

$$\frac{r}{1 - [1/(1+r)]} \; t$$

where r is the real social discount rate and t is the estimated economic life of capital. This factor is used to spread capital and non-recurring costs over

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[4] A salvage value for necessary capital equipment was included in only a few instances.

the economic life of the capital to which a control is applied. The economic life of the capital equipment for each control is estimated, ranging between 5 and 20 years.

Non-recurring costs (such as research and development costs) represent one-time costs which, in practice, will not be replicated in future years. Using this interpretation, such non-recurring costs should not be included in annualized costs because they will not recur at a constant scale (i.e., the costs only occur once, regardless of how long the control is undertaken). Nonetheless, non-recurring costs are included with capital costs so that the annualized cost estimates would reflect the full social costs of controls.

To compute total annualized costs, annualized capital and non-recurring costs are added to estimates of other annual pre-tax costs as follows:

- <u>annual operating costs</u> -- annual operating costs such as labour and utilities are added directly.

- <u>salvage of control equipment</u> -- few controls are expected to have salvageable capital. The present salvage value of control equipment can be estimated as:

  $$S * C/(1+r)^t$$

  where S is the percentage of capital costs estimated to be recoverable on salvage, C is the original capital cost, t is the useful life of capital, and r is the real social discount rate. This present value salvage amount was annualized in the same manner as described above for capital and non-recurring costs. The resulting annualized salvage value is then deducted from total annualized costs.

- <u>annual savings</u> -- the estimated annual savings due to reduced CFC and halon use, operating efficiencies, or other factors associated with implementing a control are subtracted from total annualized costs.

In addition to these cost components, adjustments are required for product substitute and chemical substitute controls. For product substitutes, the differential costs of the products and their differences in lifetimes must be reflected.[5] The annualized cost associated with replacing one CFC and halon related product is estimated as:

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[5] The difference in the lifetimes of the CFC-related product and the substitute product must be incorporated so that the relative cost of switching to the substitute can reflect the costs over the full lifecycle of the products. If the substitute product lasts longer than the current CFC-related product, then the cost of switching is reduced; if the product life of the substitute is shorter, then the cost of switching is increased. In general, the reported lifetime differences were small, so that the lifetime adjustment had a small impact on the cost estimate.

$$-Pc + Ps * \frac{r/(1-(1/(1+r)ts_{))}}{r/(1-(1/(1+r)^{tc}))}$$

where: Pc = the price of the CFC and halon based product;
Ps = the price of the product substitute;
tc = the average useful life of the CFC and halon based product;
ts = the average useful life of the product substitute; and
r = real social discount rate.

This annualized cost was added to the annualized costs computed above.

For substitute insulating materials, the costs of reduced insulating capacity can be reported in terms of the annual incremental energy costs experienced per metric ton of CFC blown foam replaced. Because these energy costs occur during each year for which alternative insulating materials are used, annual energy costs are aggregated to reflect the stream of costs incurred over the useful life of the product as follows:

$$PV(E) = E * \frac{1-1/(1+r)^{t}}{r}$$

with r representing the real social discount rate, t the life of the CFC-blown foam product, and E the real before-tax annual energy penalty. This energy cost value is added to the annualized cost estimates described above.

The adjustment to the annualized cost estimate for chemical substitute controls is based on two factors: (1) the price of the chemical substitute compared to the price of the CFC and halon it replaces and (2) the amount of substitute required to replace a unit of the CFC and halon. These factors were combined to estimate the relative cost of replacing one kilogram of the CFC and halon with the substitute as:

$$Ps * R - Pc$$

where Ps is the price of the chemical substitute, R is the number of kilograms of substitute required to replace one kilogram of the CFC and halon, and Pc is the price of the displaced CFC and halon. Separate estimates of R were made for chemical substitutes in new and existing products. Annual chemical replacement costs are added to annualized capital, operating, and other costs of chemical substitutes (if any). As a final step, the annualized costs were adjusted to reflect differences in the basis for expressing the engineering cost estimates, which included:

- Costs reported for the maximum fraction of the application expected to take the control. In this case the cost estimates are based on the segment of the application expected to implement the control, and consequently no adjustment is required.

- Costs reported per unit of application (e.g., per metric ton of foam produced). In this case the costs must be multiplied by the number of units (e.g., the number of metric tons of foam) expected to be affected by the control. The number of units is estimated as the total units in the application times the expected fraction of the application that could undertake the control.

- Costs reported as if the entire application adopted the control. In this case the costs were multiplied by the maximum fraction of the application expected to implement the control (if the entire application was expected to implement the control, then no adjustment is required).

Once these adjustments are made, the total annualized costs for the control is divided by the reduction potential for the control to produce a social annualized cost per kilogram of use avoided. Detailed examples of social annualized cost calculations are shown in Figure III-2 and III-3 for product substitute and chemical substitute.

III.4.2 Methods for Computing Private Annualized Costs

For purposes of assessing firms' potential reactions to restrictions on CFCs and halons, the costs faced by the firms must be estimated. These costs are referred to as private costs. As discussed in Section 1, private costs will differ from social costs because of tax effects, differences in discount rates, and possible differences in the kinds of costs incurred.

To estimate private costs, a discounted cash flow analysis is used. This cash flow analysis: (1) computes annualized before-tax costs using a before-tax private discount rate, (2) estimates incremental cash flows incurred by private entities including the effects of depreciation and taxes on cash flows, and (3) computes an annual cost as the net of all annualized cash flows.

In general, the methods used to compute private annualized costs follow those described to compute social annualized costs. The methods used to estimate private annualized costs are comprised of the following steps:

1. The magnitude and timing of pre-tax costs (i.e., capital and operating costs) are specified. Assumptions regarding the timing of the costs and expenses (relative to the initiation of the control) are:

    - capital and non-recurring costs occur in year 0;

    - capital salvage occurs at end of the capital's operating life;

Figure III-2. Example Social Cost Estimate for a Product Substitute

Control Description:	Use Fibreglass as an alternative to CFC foam insulating material
Application Category:	Rigid Polyurethane Foam -- Boardstock Building Construction
Ozone-Depleting Compound:	CFC-11

1. Estimated Use Reduction Potential for Application Category

	CFC-11 Use (Metric Tons)	*	Market Penetration (Percent)	=	Use Reduction for Application (Metric Tons)
During Manufacturing	2,700		10		270
During Installation	0		10		0
During Product Use or Servicing	0		--		--
Other Use	0		--		--
Unaccounted For	0		--		--
TOTAL	2,700				270

2. Estimated Annualized Costs per Metric Ton of Foam Replaced

			Annualized Costs ($)
Capital Cost	0 * 0.062[a]	=	0.00
Annual Operating Cost		=	0.00

Salvage of Capital

0 % Salvageable Capital
x $ 0 Capital Cost
x 0.673[b]
x 0.062[c] = 0.00

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[a] Represents annualization factor used to spread capital costs. Calculated as:

$$0.02/(1-(1/(1+0.02)^{20})) = 0.062.$$

[b] Present value factor calculated as: $1/(1+0.02)^{20} = 0.673$.

[c] See footnote a/

Figure III-2 (Continued)

	Annualized Costs ($)
Product Substitution Costs	
+ <u>$11,820</u> Price of Fibreglass Required to Replace One Metric Ton of Rigid PU Foam	
x 1.0[d]	
= $11,820	
- $4,600 Price per Metric Ton of Rigid PU Foam =	$7,220
Present Value Energy Cost	
<u>$0</u> Annual Energy Cost	
x 31.42[e] =	<u>$ 0</u>
TOTAL ANNUALIZED COST	$7,220

3. Cost Adjustment to Industry-Wide Values

<u>19,100</u> Consumption of Rigid PU Foam for Application (Metric (Tons)
x <u>10%</u> Estimated Market Penetration for Fibreglass
= 1,910 Metric Tons of Rigid PU Foam Potentially Replaced
x $7,220 Annualized Cost Per Metric Ton of Foam
= $13.8 Million

4. Annualized Cost Per Kilogram of CFC Use Reduction

$13.8 Million Adjusted Annualized Costs
270,000 Use Reduction for Application (Kilograms)

Social Annualized cost Per Kilogram = $51

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[d] Factor that accounts for differences in useful lives of fibreglass and rigid polyurethane foam in this application. In this case, the lives are the same, so the factor equals 1.0.

[e] Annuity factor calculated as: $(1-1/(1+0.02)^{50}) = 31.42$ where 50 years is the estimated useful life of fibreglass board.

Figure III-3. Example Social Cost for a Chemical Substitute

Control Description:	FC-123
Application Category:	Rigid Polyurethane Foam Boardstock -- Building Construction
Ozone-Depleting Compound:	CFC-11

1. Estimated Use Reduction Potential for Application Category

	CFC-11 Use (Metric Tons)	*	Market Penetration (Percent)	=	Use Reduction for Application (Metric Tons)
During Manufacturing	2,700		90[a]		2,430
During Installation	0		90[a]		0
During Product Use or Servicing	0		0[b]		0
Other Use	0		0[b]		0
Unaccounted For	0		--		--
TOTAL	2,700				2,430

2. Estimated Annualized Costs per Metric Ton of Foam Replaced

					Annualized Costs ($)
Capital Cost and Non-Recurring Cost	92	*	0.062[c]	=	5.70
Annual Operating Cost				=	0.00

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[a] Estimated market penetration for new products.

[b] Estimated market penetration for existing products. Not relevant for foams.

[c] Annualization factor used to spread capital and non-recurring costs. Calculated as:

$$0.02/(1-(1/(1+0.02)^{20})) = 0.062.$$

Figure III-3 (Continued)

Annualized Costs ($)

Salvage of Capital
0 % Salvageable Capital
x $ 0 Capital Cost
x 0.673[d]
x 0.062[e] = 0.00

Chemical Substitution Costs

	New Products	Existing Products	
	4.14	NA	Price of FC-123
x	1.25	NA	Kilograms of FC-123 Blowing Agent Needed to Replace 1 Kilogram of CFC-11
=	5.18	NA	
-	1.41	NA	Price of CFC-11 ($/kg)
=	3.77	NA	Cost of Substituting 1 kg of CFC-11
x	141[f]	NA	
=	531.57	NA	

Total Annualized Costs (New Products) 537.27
Total Annualized Costs (Existing Products) NA

3. Cost Adjustment to Industry-Wide Values (New Products Only)

19,100 Consumption of Rigid PU Foam for Application (Metric (Tons)
x 90% Market Penetration for FC-123
= 17,190 Metric Tons of Foam
x $537.27 Annualized Cost Per Metric Ton of Foam
= $9.2 Million

4. Annualized Cost Per Kilogram of CFC Use Reduction

$9.2 million Adjusted Annualized Costs
2,430,000 Use Reduction for Application (Kilograms)

= $3.80 Social Annualized cost Per Kilogram = $51

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[d] Present value factor calculated as: $1/(1+0.02)^{20} = 0.673$.

[e] See footnote c/.

[f] Estimated number of kilograms of CFC-11 used per metric ton of foam.

   - depreciation expense occurs over seven years; operating costs and offsetting savings are incurred during the technical substitute's operating life.

2. Total pre-tax costs are calculated for each year over the control's operating life.

3. Taxes are applied to costs incurred after year 0 by multiplying the costs by (1-tax rate). Annual offsetting savings were also multiplied by (1-tax rate).

4. Depreciation is "added back" to net after-tax costs to account for the tax savings attributable to this non-cash expense.

5. The stream of after-tax cash flows is discounted using the private cost of capital to compute a net present value of the costs of the control over its entire life.

6. The present value of the after-tax costs is annualized using the private cost of capital as the discount rate. This present value is then divided by the total reduction in CFC and halon use that can be achieved by the control to produce an annualized private cost per kilogram of use avoided.

Annual depreciation expenses are calculated using the straight line method over the appropriate interval. Because depreciation is based on initial acquisition costs, annual depreciation expense is deflated by an inflation index to calculate real depreciation.

Little consensus exists among the experts who have studied the selection of an appropriate rate of private discount. The range of estimated values for the real rate of return on private investments was from 4 to 9 percent. Six percent can be selected as a median estimate.

The costs of energy losses due to reduced insulating abilities of product substitutes may not be incurred by firms. Instead, these costs (or a portion of these costs) may be incurred by consumers if the reduced insulating value of the product substitutes is not capitalized into their market price. The analysis assumes that the reduced insulating value of the substitutes is capitalized into the price of the substitutes, meaning that consumers are left unaffected, and the firms making the substitutes "incur" these costs.

III.5 LIMITATIONS

The methods used to assess the social and private costs of proposed restrictions on CFC and halon use are limited in terms of the data available and the manner in which the method is applied. The primary limitations of the data include:

- Identification of Control Possibilities. By definition, only those control possibilities that are currently known are included in the analysis. It is likely that as the concern for stratospheric ozone increases and prices of CFCs and halons rise in response to the constriction of supply that additional control possibilities will be identified. The inability to incorporate unknown control possibilities biases the estimates of costs upward. The extent of the bias is very large at present because technological progress is so rapid.

- Aggregation of Control Possibilities. The aggregation of the control possibilities to reflect the impacts of taking groups of controls is subjective. Alternative views of aggregation could lead to alternative estimates of control costs and achievable reductions.

- Uncertainty Surrounding New Chemical Substitutes. Many of the data estimates are very uncertain, and consequently ranges of values should be used, and sensitivity analysis performed.

Two types of costs not considered are transition costs and risks. Transition costs (e.g., temporary unemployment or premature retirement of capital equipment) are generally small over the long-term, but may be important when reductions are initially required. Because significant phase-in times are contemplated, transition costs are likely to be small if parties to the protocol cooperate on technology transfer. Also many of the control options are compatible with existing equipment (thereby avoiding the premature retirement of capital).

The additional worker safety and environmental risks posed by a few control options should be carefully evaluated. Numerous options can be deleted from consideration due to risks, so that the options used in the analysis do not result in significant risks. However, some examples of risks are evident, and additional analysis to assess these risks may be warranted.[6]

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[6] For example, pentane is listed as an alternative blowing agent. Although the costs of equipment to address its potential fire hazard are included in the cost estimates, the potential impact of pentane emissions on smog conditions has not been evaluated, except as it adds costs to that option.

APPENDIX IV

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 IV-1. 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 during service, which is estimated to represent a value of approximately US$4 million a year at the current price level.

Table IV-1. Possible Reduction in CFC Consumption Industrial Refrigeration (Reference Table 8-2)

Measure	Estimated Reductions (percent) 1994	Estimated Reductions (percent) 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

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 00 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.

[redacted]

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

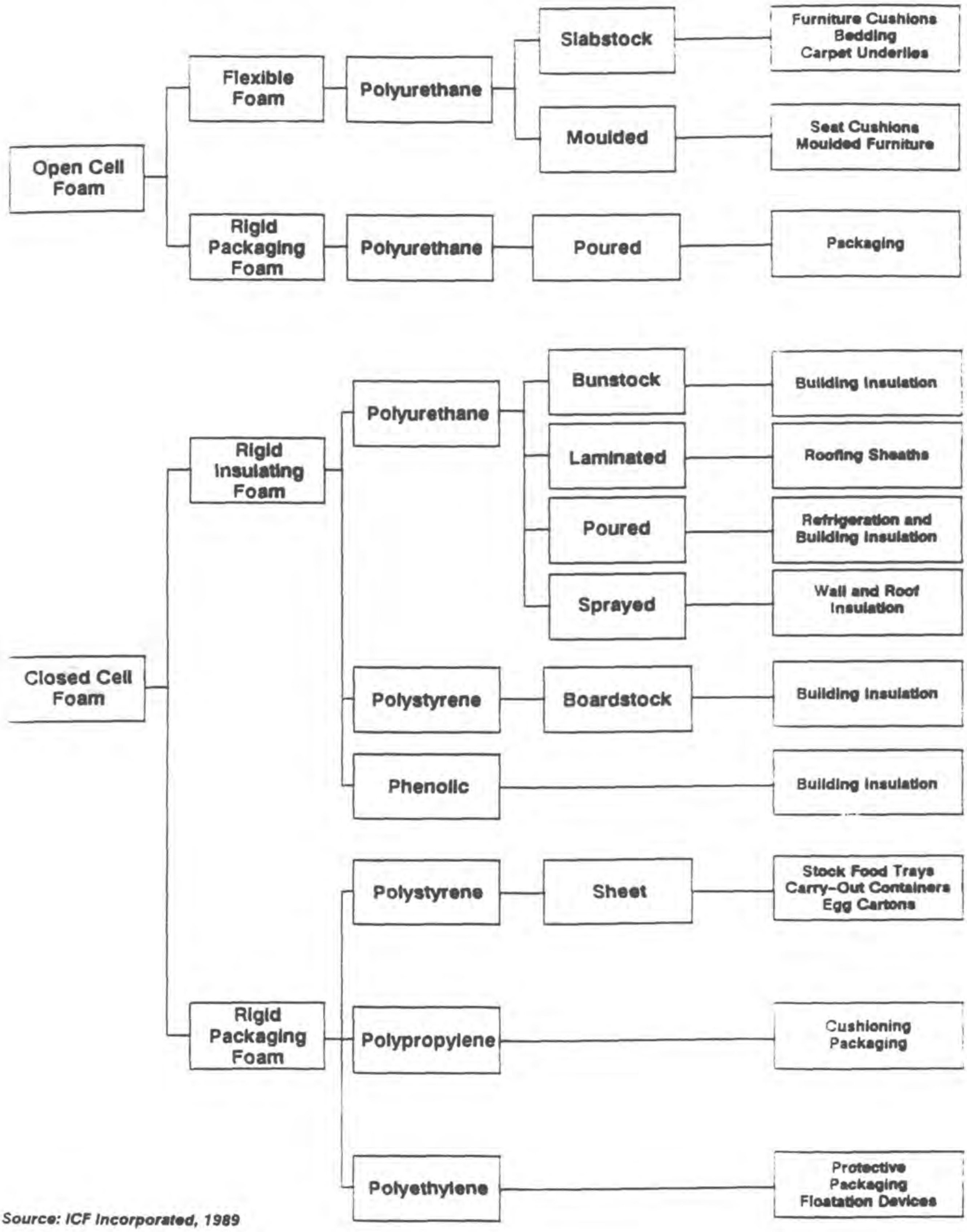
The foam industry used approximately 267,000 tonnes (metric tons) of CFCs worldwide in 1986. This represents approximately 25-30 percent of the total annual global use of controlled CFCs. The CFCs are used to make products of polyurethane/ polyisocyanurate, polystyrene, polyolefin and phenolic plastics 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 IV-1).

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 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

FIGURE IV-1
TYPES AND MAJOR USES OF CFC-BLOWN FOAM



Source: ICF Incorporated, 1989

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 IV-2 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 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.

Table IV-2. 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 IV-2 (Continued)

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 IV-2 (Continued)

[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.

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.

Table IV-3 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

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

Table IV-3. **Technically Feasible Reduction Schedule**

Year	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.

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 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.

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

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 IV-4 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 IV-5 summarises some of the advantages and disadvantages of the CFC-113 alternatives discussed in this report.

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.

Table IV-4. Comparison of CFC-113 Solvent Alternatives Consumed 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/cm³) @ 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.

Table IV-4 (Continued)

\+ Toxicity testing is in progress.

[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 IV-5. 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.

Electronics Cleaning

The electronics industry is the largest worldwide user of CFC-113. An estimated 8.00 x 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 electromigration. 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 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

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

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 IV-6 presents the Sharp Corporation's CFC

Table IV-6. 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.

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.

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 diffculty 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.

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