MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

APRIL 2002

VOLUME 3A

REPORT OF THE
TASK FORCE ON COLLECTION, RECOVERY AND STORAGE

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The text of this report is composed in Times New Roman.

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Reproduction: UNON Nairobi

Date: June 2002

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UNITED NATIONS ENVIRONMENT PROGRAMME
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fax: + 44 1438 748844

This document is also available in portable document format from

http://www.teap.org

ISBN: 92-807-2229-8

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Acknowledgement

The Task Forces Co-chairs and members acknowledges with thanks the outstanding contributions from all of the individuals and organisations who provided support to Co-chairs and members. The opinions expressed are those of the Task Forces and do not necessarily reflect the reviews of any sponsoring or supporting organisation. The TEAP thanks GTZ, Eschborn, Germany, and the US EPA, Washington D.C., for hosting the meetings, where this report was discussed, and composed.

The TEAP thanks the Hungarian Ministry for Environment for hosting the TEAP meeting in Budapest, Hungary, where this report was reviewed, and finalised.

Foreword

The April 2002 TEAP Report

The April 2002 TEAP Report consists of three volumes:

Volume 1:   April 2002 TEAP Progress Report

Volume 2:   April 2002 TEAP Replenishment Task Force Report

Volume 3:   April 2002 TEAP Task Force on Collection, Reclamation and
Storage Report, together with the
April 2002 TEAP Task Force on Destruction Technologies Report

Volume 1

Volume 1 contains an Executive Summary of all TEAP Report topics, as well as
the Executive Summaries of Volumes 2 and 3.

Volume 1 contains

*   An accounting framework for ODS production, consumption and emissions
    (being developed in co-ordination with the SAP);
*   recommendations for essential use nominations;
*   an update on laboratory and analytical uses (as requested in Decisions XI/13,
    X/19);
*   a chapter on Campaign Production for MDIs (as requested in Decision
    XIII/10);
*   the annual update on nPB production, use and emissions (as requested in
    Decision XIII/7);
*   additional reports on process agent uses (as requested in Decisions X/14 and
    XIII/13).

Volume 1 also contains progress reports of TEAP Technical Options Committees
(according to Decision VII/34). Finally, it presents an update on TEAP's changing
membership and gives background and contact information for TEAP and TOC
members (Decision VII/34).

Volume 2

Volume 2 is the Assessment Report of the TEAP Replenishment Task Force of the
Funding Requirement for the Replenishment of the Multilateral Fund during 2003-
2005, in response to Decision XIII/1.

Volume 3

Volume 3 includes reports of the Task Force on Destruction Technologies (TFDT)
and the Task Force on Collection, Reclamation and Storage (TFCRS), in response
to Decision XII/8.

April 2002

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REPORT OF THE TASK FORCE ON
COLLECTION, RECOVERY AND STORAGE

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Executive Summary

The TFCRS assessed use patterns, associated emissions and aspects of collection and storage of ODS from all relevant use sectors. The assessment takes into account the different situations in Article 5(1) Parties, where production takes place for the Article 5(1) Parties (under "Basic Domestic Needs"), and in non-Article 5(1) Parties, where ODS production is still continuing.

This TFCRS Report also presents an overview of ODS inventories and their management in the different sectors and provides first estimates of historic and actual emission patterns from the different use sectors.

Types of Emission

ODS can be emitted at various stages in the lifecycle of production, distribution, use, and disposal. Emission estimates for any given year need to account for early emissions of recently 'consumed' ODS as well as delayed emissions of historically used ODS. This means that there are emissions from both developed and developing countries for many years after the phase-out of ODS production.

This Report splits the use sectors into those with early emissions and those primarily with delayed emissions. Where it concerns early emissions, the focus is on non-Article 5(1) Parties essential uses and on current and/or recent use in Article 5(1) Parties. Meanwhile, where it relates to delayed emissions the focus is on inventories of ODS originating from sustained non-Article 5(1) portfolios and the increasing inventories present in the same applications in Article 5(1) Parties.

Uses with early emissions include solvents, aerosol products including MDIs, methyl bromide, and flexible foams. Delayed emissions are found in refrigeration and air conditioning equipment, rigid foams, and halon equipment.

For self-evident reasons, the main focus of interest under any review of collection, recovery and storage issues is on those applications that lead to delayed emissions and that are therefore characterised by considerable ODS inventories.

Technical feasibility of Collection, Recovery & Storage

It is technically feasible to collect and recover all forms of ODS retained in inventories characterised by delayed emissions. In some cases (e.g. refrigeration and halon equipment) the ODS is already contained in readily accessible containers. In the case of other applications, the ODS can be in locations which are much more difficult to access (e.g. cavity wall rigid foam insulation).

For many rigid foams including those contained in refrigerators, the recovery and destruction steps can be combined and the decision may be made that it is more cost-effective to directly incinerate a product containing the ODS than to extract the ODS for subsequent destruction.

Methyl bromide used as a post harvest, structural or transport fumigation (about 30% of current methyl bromide uses) offers the broadest potential for collection and subsequent destruction. The surplus methyl bromide can be adsorbed and then directly treated for destruction either chemically or by incineration.

Inventories and Collection Potential

It is known for quite some time that the ODS inventories stored in delayed emission applications are substantial. For certain cases, this assessment has been able to quantify these amounts. Inevitably, the assessment has involved a combination of 'top-down' and 'bottom-up' modelling and will be the subject of continuous refinement as more information emerges.

- Between 350,000 and 400,000 ODP-tonnes of CFCs are estimated to be contained in refrigeration equipment in 2002;
- 1.25 million ODP-tonnes of CFC-11 are still remaining in installed foams in year 2010;
- 450,000 ODP-tonnes of halon 1301 and 330,000 ODP-tonnes of halon 1211 are installed in fire fighting equipment in year 2002.

However, it is important to recognise that not all of this material will be accessible for collection and recovery, since decommissioning at end-of-life needs to take place first. The annual quantities of refrigerants potentially available for destruction are estimated to be around 9,000 ODP-tonnes. The quantities of blowing agents expected to be recovered from domestic refrigerators are expected to reach a rate of between 10,000 and 11,000 ODP-tonnes per annum with the currently installed recovery capacity. This could be increased by further investment but is likely to require additional local legislation. Sizeable amounts of halon 1211 could be collected for subsequent destruction.

Economic Implications of Collection, Recovery & Storage

This report has not been able to make a detailed assessment of the costs of collection, recovery and storage at the global level, since the range of technical options available and the cost of local logistics are highly variable.

Economic feasibility is demonstrated by examples of established commercial infrastructures. These exist in several sectors and in several regions of the world.

The recovery of blowing agents from refrigerator cabinets costs approximately US$60-100 per kg of CFC-11. The cost equates to approximately US$25-35 per tonne of CO_2 equivalent. This is well within the range of investments being considered for CO_2 emission abatement in other sectors.

Barriers to Collection, Recovery & Storage

There are many barriers to the application of effective collection, recovery and storage. Examples of these can be listed as follows:

- Lack of appropriate legislation and infra-structures to ensure end-of-life decommissioning;
- Financial resistance where the 'polluter' (manufacturer or owner) has to pay;
- Installations of rigid construction foam can be within building structures that prohibit effective collection;
- Waste transportation management restricts movements within some countries and internationally.

Conclusions

The collection, recovery and storage of ODS is technically feasible and economically viable. The adoption of such measures depends to a large degree on the regulatory structures, the collection and recovery infrastructures and the way in which the financial burden is allocated.

Parties may wish to consider whether there is an over-arching role for the Montreal Protocol in stimulating this area of activity or whether, in fact, regional variations in both installed inventories and local logistics make action at the regional level more appropriate.

1 Introduction

1.1 Decision XII/8

The Twelfth Meeting of the Parties made the following requests to TEAP in Decision XII/8:

(a) *To evaluate the technical and economic feasibility for the long-term management of contaminated and surplus ozone-depleting substances in Article 5 and non-Article 5 countries, including options such as long-term storage, transport, collection, reclamation and disposal of such ozone-depleting substances;*

> *1. To consider possible linkages to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and other international treaties as appropriate regarding the issue of disposal;*

> *2. To report to the Parties on these issues at their Fourteenth Meeting in 2002.*

TEAP recognised that two separate task forces would be needed to cover all the issues covered by Decision XII/8 and set up the Task Force for Collection, Recovery and Storage (TFCRS) to cover these issues in the context of the Decision. TEAP complemented the expertise that was available from members of the TEAP and its TOCs with the inclusion of external experts. A balanced membership was sought from the various sectors and geographic regions. Members of the TFCRS are specialists on refrigerants, foams, halons, aerosols and solvents; their countries of origin are Australia, Belgium, Brazil, Canada, Denmark, Germany, Hungary, India, Japan, Netherlands, Switzerland, United Kingdom, United States, and Venezuela. A detailed list of members is presented in Annex 1. This report complements the report of the Task Force on Destruction Technologies.

The task forces met in Frankfurt on October 23rd- 24th, 2001 and in Washington on March 21st-22nd, 2002. Three experts (Paul Ashford, Lambert Kuijpers and Ronald Sibley) worked in both Task Forces to improve co-ordination between them and to avoid duplication effort.

The authors recognise that this work does not completely answer the requests contained in Decision XII/8. However, it is believed that the report discusses the most important issues raised in the decision.

1.2   Scope of Work

Production of halons and CFCs was phased out in non-Article 5(1) Parties in 1994 and 1996 respectively except for essential domestic uses. Some Parties are compelling the early decommissioning of equipment that uses ODS. This equipment may impose particular logistic requirements to safely recover, store and transport ODS to an intermediate collection centre and to their destruction facility. In many other Parties, substantial recovery and recycle activities are encouraged to keep operating the equipment that relies on these substances. These activities produce streams of contaminated ODS unsuitable for reuse which need to be destroyed. In Article 5(1) Parties recovery and recycling facilities and activities are being installed and implemented, preferably under comprehensive management plans. All these activities might affect the rate at which ODS from insulating foam, halon, and refrigeration and AC equipment are emitted and if not done responsibly could cause an unnecessary surge in atmospheric emissions.

The TFCRS had to identify and, if possible, quantify the inventories of ODS susceptible to be collected. Once inventory sizes were defined, it should be possible to estimate the requirements for destruction capacity. An analysis of use patterns in the different ODS-sectors reveals two distinctive groups. Firstly there are the "early-emission-uses" where the ODS are utilised in applications with direct emissions. Methyl Bromide, aerosols, MDIs and solvents fall into this category. The common characteristic of these uses is that there are only small to negligible amounts of surplus or contaminated materials. Recycling is not done nor does it appear to be practical in most cases; collection and disposal of remaining ODS after use is relatively simple.

Secondly there are the "late-emissions-uses" in foams, refrigeration and fire protection. Typically, the ODS here are enclosed for either the exploitation of there physical properties in closed systems (foams and refrigeration) or for their release in the case of a fire (halons). In some cases, such as in refrigerants these inventories are disperse in a great number of machines most of which are operating. In other cases, such as in halons, there has already been a collection effort in some Parties. In the case of foams the ODS may be trapped in appliances, buildings and insulated equipment whose useful life has ended and whose disposal may be controlled.

The report puts its main emphasis on the latter group where recycling of ODS occurs and where problems of collection, storage and aspects of contamination have to be dealt with.

ODS are in general, chemically stable substances, particularly when stored in a pure state. However, when they are recovered they are often contaminated with oils, water or other organic substances. The type and degree of contamination will determine whether they can be reused or not. If ODS are stored with these conta-

minants, chemical reactions may occur which can corrode containers and cause undesired emissions. There is also the possibility that if large amounts of ODS are stored in centralised locations a large undesired emission could occur as the result of a catastrophic failure or fire.

1.3   Meaning of Terms Used in the Report

Collection encompasses all activities related to bring ODS containing equipment or materials back to either destruction facilities or to recovery and/or reclamation facilities. Here factors from transport safety for transport of pressurised gases to practical aspects of collecting foams from building insulation for example have to be considered

Transport will include both collection of equipment which contains ODS for disassembly at specialised facilities as well as transport of recovered ODS to centres for storage and/or destruction. In this latter case the ODS may be either compressed gases or liquids with low boiling points. Applicable regulations will depend on whether the substances are considered goods or wastes. In some instances national and international transport regulations must be taken into consideration.

Recovery activities include all action that extract ODS from equipment or materials and bring it back in liquid or gaseous form. This ranges from adsorption at activated charcoal as in the case of Methyl Bromide to decanting of halons from portable extinguishers.

Reclamation is the process of bringing recovered ODS back to original specification so that the ODS in question can be used again for its originally intended purpose.

Storage of ODS is used in this report both for keeping recovered ODS for subsequent destruction (either in its application form or gas/liquid forms), and also for storage and management of newly produced or reclaimed ODS for later use in new or refilled applications.

1.4   Description of Chapters

Chapter 1: Introduction refers to Decision XII/8 which based this report and presents the setting of the Task Force and the Scope of Work

Chapter 2 - 7: Sectorial Descriptions, including a qualitative analysis of the use characteristics and specific circumstances for Refrigeration, Foams, Halons, Aerosols and MDIs, Solvents and CTC, and Methyl Bromide. The long term integrity and suitability of stored ODS is also dealt by sector in these chapters

Chapter 8: Transport and Exports, deals with relevant regulations and logistics. The Task Force unsuccessfully attempted to co-ordinate work in this area with experts form the Basel Convention.

Chapter 9: Basel Convention, with a short description of history and scope and information on the regulation of ODS under the Convention.

2 Refrigeration

2.1 Introduction

One of the most important sectors consuming ODS is the refrigeration sector. There is a major difference between the refrigeration sector and almost all other sectors where ODS are used: Refrigeration, being important for public health and food supply, needs CFCs not only for new equipment, but also to maintain existing equipment. In most other sectors, a phase-out of the use of CFCs in production of goods leads to an immediate phase-out of the consumption. The refrigeration sector is unique in the combination of two characteristics:

- In refrigeration, CFCs are needed many years after a product has been manufactured for its maintenance, or the product manufactured for use with CFCs needs to undergo a complicated conversion procedure (retrofit). There is still a considerable number of CFC contained in existing equipment in Article 2 Countries, and the bank in Article 5 countries is still increasing in several cases; consequently, the service needs are also significant.

- The amount of CFC per system or even per owner in the refrigeration sector is relatively small, making interactions very widespread and thus difficult to cover substantive parts of the very large affected populace.

These two characteristics in combination with other technical challenges make it difficult to address the total phase-out of CFCs..

An analysis of the CFC quantities which might be potentially available for destruction was performed. This potential defines the amount of CFCs which can reasonably be expected for destruction if logistics and incentives are existing to enable and encourage CFC recovery and collection for destruction. Consequently, in reality this potential will probably not be reached. Presently, only the European Union and Canada require destruction of all CFCs collected; the other countries use the bulk of refrigerant recovered to support existing CFC equipment. It was assumed that no additional medium and large CFC consuming countries will request mandatory destruction of CFCs recovered.

In Europe, it is actually not allowed to service CFC refrigeration equipment at all, and recovered CFCs have to be destroyed. Due to this regulation, there is a large potential for destruction until about 2005. From 2006 onwards, the estimated potential for destruction stabilizes at below 3000 tons of ODS world wide, to be reduced further in the beginning of the second decade of the century to values below 1000 tons per year. Comparing the amount of CFCs to be destroyed to the present bank of equipment, about 14% of that bank will be available for destruction. Given that the equipment will be in operation for many more years, with significant emissions during service and because of leakage, this result is not

surprising. The main contributors to the potential for destruction are the domestic, industrial refrigeration and the chiller sectors. In case of domestic refrigerators, waste incineration might be used as one alternative where recycling of other materials is not considered to be a priority objective. In all other cases, the refrigerant for destruction will be available only in its liquefied state, i.e. the destruction equipment used has to be able to handle such refrigerant streams. The refrigerant for destruction will be very likely contaminated by refrigeration oil, water, and other contaminants.

2.2   Bank of CFCs in the refrigeration sector

In order to provide an overview about the bank of CFC refrigerant on an world wide basis, published data[1] has been analysed and extrapolated into the future as part of the work for this report. This estimate has been performed by region and sub-sector based on known trends, regulations etc. Important considerations include the typical lifetime of equipment in the different regions and sub-sectors, legal requirements (in particular the ban of CFC use in the European Union from 2001 onwards[2]). The production of new equipment has been converted in Article 2 Countries to non-CFCs from 1994 onwards, alternative refrigerants have been used for the majority of new equipment in most applications latest from 1996 onwards. In Article 5 Countries, the production of new equipment using CFCs has ceased in many countries and sectors, with only small production of new equipment being left after 2003.

In several sub-sectors, CFC containing equipment will reach the end of its useful life soon. In addition, equipment with large service needs is likely to be replaced or retrofitted to ensure operation even if CFC is not available for service. Consequently, the bank of CFC equipment in most sub-sectors in Article 2 Countries will decrease rapidly, as shown in Figure 2-1.

The assessment of the remaining bank of refrigerant was performed in a variety of sub-sectors, shown in Figure 2-2. In particular, transport refrigeration, food processing and heat pumps are covered under "other uses", jointly with industrial

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[1] Clodic, D.: Estimation of World-Wide Fleets of Refrigeration and Air Conditioning Equipment in order to Determine Refrigeration Emission Forecasts; Presentation at „The Earth Technology Forum and Exhibition"; Washington, DC., USA, March 2002

Clodic, D., and Kuijpers, L.: „Global Inventories and Emission Projections of Refrigerants: A Case Study of Mobile Air Conditioning Systems"; Presentation at „The Earth Technology Forum and Exhibition"; Washington, DC., USA, March 2002

[2] As per EU regulation 2037/2000

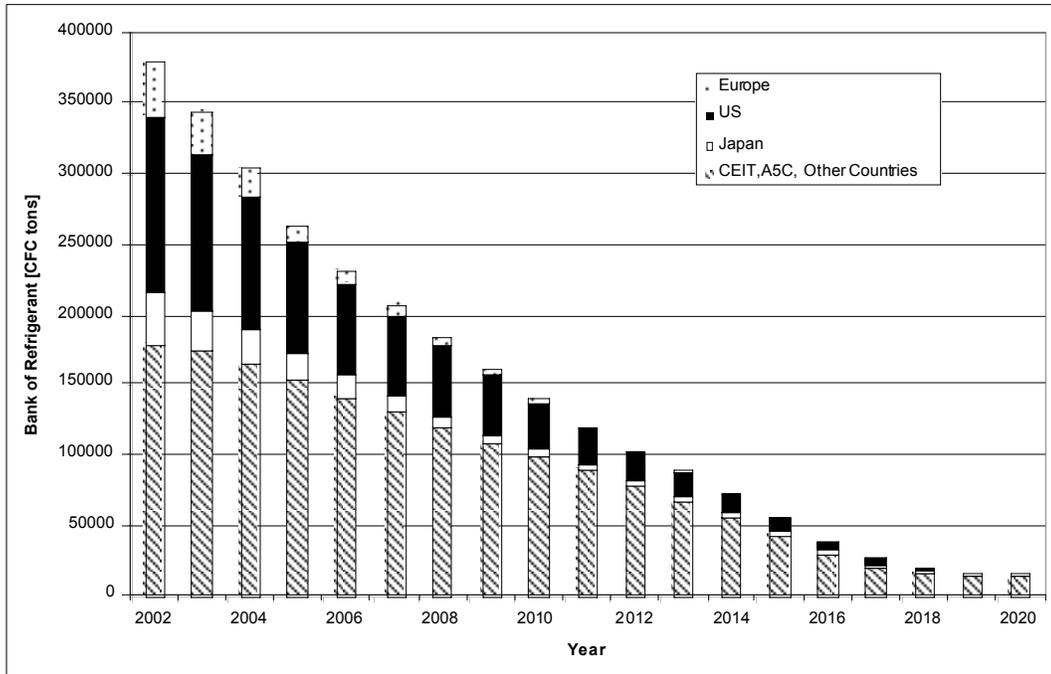***Figure 2-1****: Bank of CFC contained in refrigeration equipment by region*
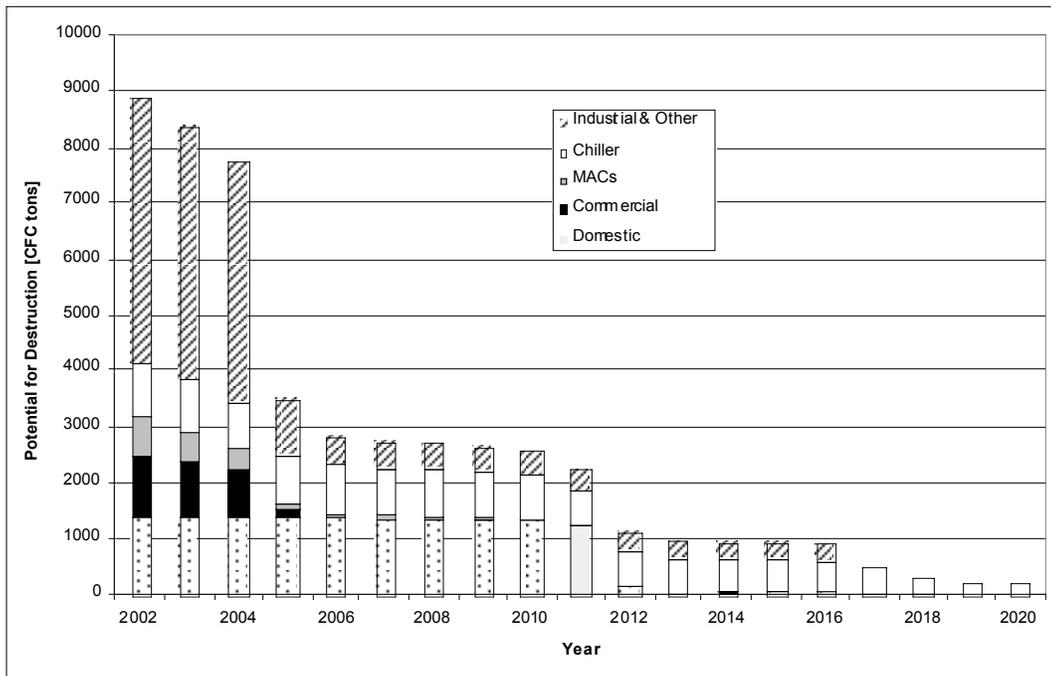
Figure 2-2*: Bank of CFC contained in refrigeration equipment by sub-sector*

refrigeration. More detailed information specifically about the mobile air-conditioning sector (MAC) sector can be found in annex 1 to this chapter. In terms of CFCs contained in the systems, industrial and food processing contain more

than 85% of the CFCs in this group. It was assumed that in Article 2 Countries, larger systems would be rapidly phased out, while systems in Article 5 Countries and small systems are likely to remain in operation for several more years. Chillers, the more modern ones being typically fairly leak tight systems, are likely to remain in operation in the US (67% of the total bank in chillers) for several years; the same is valid for Article 5 Countries, CEIT and the remaining countries (23% of the total bank in chillers).Until 1996, all major manufacturers of mobile air conditioning systems including all suppliers in Article 2 Countries and CEIT converted their production to HFC-134a, and also a large part of the manufacturers in Article 5 countries. Limited production remained in some Article 5 Countries until today, but on a global scale, most CFC-12 equipment in cars is reaching the end of its useful life within the next 6 years. Commercial CFC equipment in Article 5 Countries (less than 20% of the total bank in commercial refrigeration systems world wide is CFC in Article 5 Countries) is expected to decline from 2003, while in the other countries a strong decline is already existing resulting in a CFC phase-out in the commercial sub-sector before 2007. The domestic market has a very large and considerable bank of refrigerant within its systems. It was assumed that systems have a lifetime of 15 years on average and decrease according to their production numbers in earlier years.

2.3   ODS flow in the refrigeration sector

The flow of ODS in refrigeration systems is very complicated, its collection for destruction, reuse or emission caused by a number of events and decisions. In order to enable interpretation of the numbers for refrigerant potentially available for destruction, it is important to visualize the possible ramifications in the flow of refrigerant. Several events and decisions (such as occurrence of a leak or an accident, decision of the technician how to handle unusable, contaminated refrigerant) determine if there might be potential for refrigerant destruction, or if the refrigerant is being emitted.

2.3.1   Equipment Manufacturing

The Original Equipment Manufacturer (OEM) produces the system – typically associated with some emission of the refrigerant used. In its lifetime, the refrigeration system emits ODS through leakages and service needs. The service – aside from unintended refrigerant use like cleaning – might not be in the position to perform recovery of the refrigerant; and even if the service is capable of doing so, it might be uneconomical, too time consuming etc. Consequently, there are a number of possible scenarios leading either to refrigerant reuse, emission or availability for destruction. Similar considerations apply to the end of life of the equipment, where

again a number of scenarios are possible, only some of them making refrigerant available for destruction. A detailed overview is provided in Figure 2-3.

Main ODS uses in refrigeration are:

- CFC-11 (centrifugal chillers),
- CFC-12 (general purpose, normal refrigeration, tropical ambient temperatures, mobile air conditioning) and
- HCFC-22 (air conditioning).

Other ODS refrigerants which are used to a lesser extent are

- CFC-114 (high temperature applications, heat pumps),
- CFC-115 (within R-502 refrigerant, used mainly in European low temperature commercial refrigeration),
- HCFC-123 (in centrifugal chillers as CFC-11 replacement),
- BFC-13B1 (low temperatures, laboratory equipment)
- CFC-13 (low temperatures, laboratory equipment, only in combination with a second refrigerant in a cascade system)

These refrigerants, the first three covering the vast majority of systems, are being used by the manufacturer or assembler to charge new refrigeration systems at the beginning of the systems lifetime. The charging process is typically associated with a minor leakage.

During the lifetime of the product, refrigerant is emitted through unintended leaks to the atmosphere. These leaks might be small, caused by the assembly of the product, seals or other leaking connections; they might also be very significant, caused by accidents or ruptures. Typically, stationary, OEM controlled systems such as refrigerators or chillers can be built with very little leaks, while systems assembled on site (commercial equipment), installed in mobile environments (cars, trucks, trains, …) tend to leak more, often substantially.
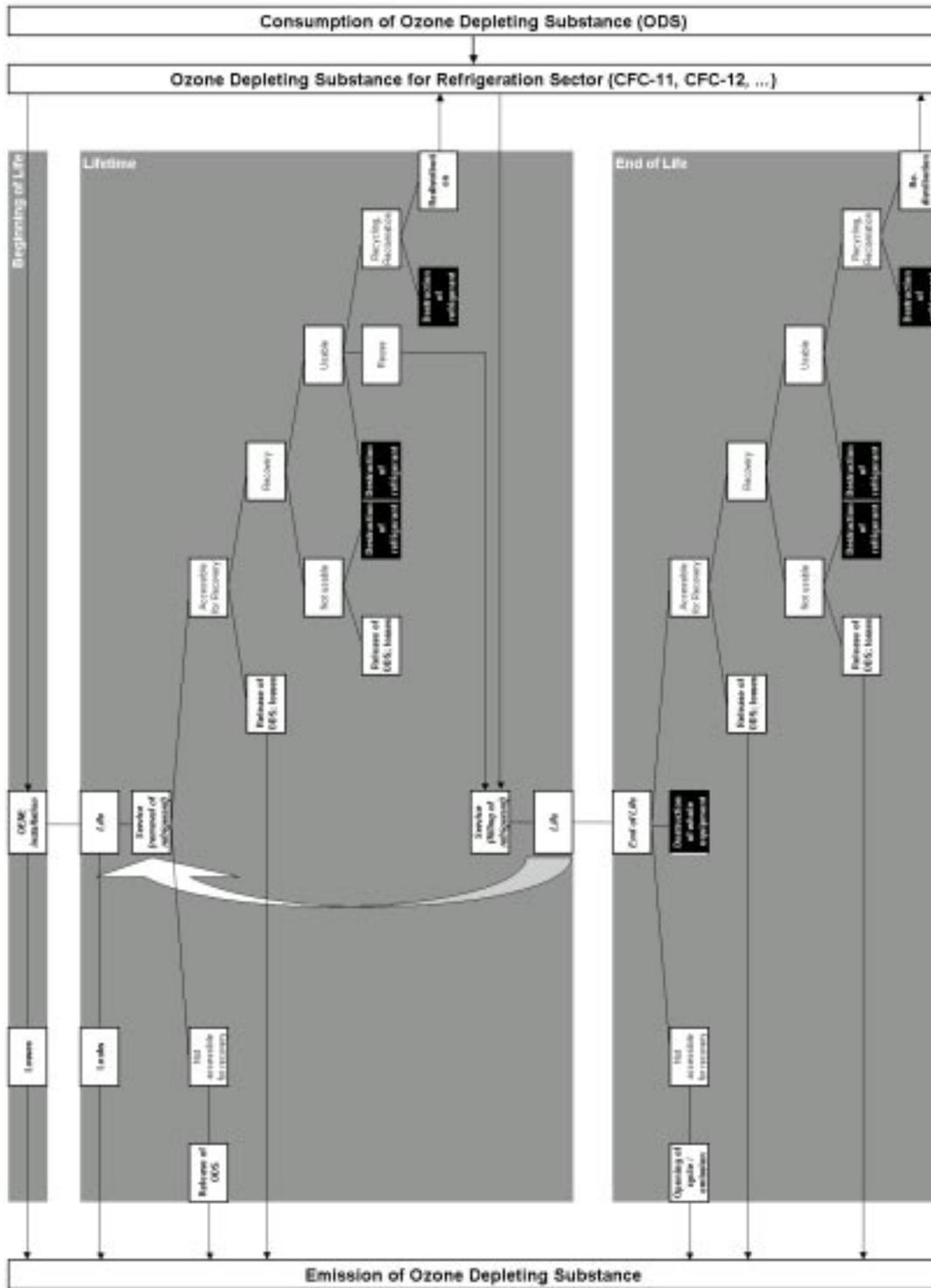
Figure 2-3: *Schematic of CFC supply, emission and destruction in refrigeration equipment*

2.3.2   Service and Maintenance

Over the lifetime of the system, some service might be necessary. Service refers here to maintenance which includes work on the refrigeration cycle. Such maintenance might be necessary due to malfunction of components (compressor burnout due to voltage fluctuations, valve problems, ...), repair of leaks, changes in system configuration etc. Before the end of the 1980s, it was customary to release the refrigerant contained in a system before service, and to recharge with new refrigerant (well designed refrigeration systems in some sub-sectors also allowed to trap refrigerant in some parts of the system, thus necessitating only some refill in case of service). Today, it is in many countries attempted to recover the refrigerant mainly for immediate or later reuse. This is limited by some factors, in particular availability of recovery equipment and refrigerant specific recovery containers (mobility!), as well as time constraints – mid and

large size refrigeration systems, typically connected to an enterprises turnover, can not be stopped over prolonged periods of time. In these cases, release of refrigerant to the atmosphere is still not uncommon, although some countries, in particular the US, have reported good success with stringent enforcement measures. A small quantity of refrigerant will remain in the system and will not be recovered, causing some losses.

Certain defects such as compressor burnout, incorrect charging of the equipment (e.g. mixing of CFC-12 and HCFC-22 or HFC-134a in one refrigeration cycle) or other contamination might render recovered refrigerant unusable by heavy contamination. This poses a logistical problem for the refrigeration technician, since he can not use the recovery bottle for further recoveries until the contaminated refrigerant has been removed. Depending on the set-up of a recovery and recycling system in the different countries (if any), contaminated refrigerant – being often only of negative commercial value since it usually has to be destroyed – offers little incentive for collection. Nevertheless, in several countries, legal or artificial commercial incentives are provided to recover unusable refrigerant and collect it for later destruction.

If the refrigerant is recovered and is not heavily contaminated, it might be reused immediately by charging the system after repair with the same refrigerant, it might be collected for destruction, or it might be recycled or reclaimed. Recycling machines allow cleaning of the refrigerant, removal of minor contaminants, in particular water and most of the refrigeration oil. Recycling machines are in many cases owned by service shops with a certain refrigerant turnover, in particular in the MAC sector – though they are often used for HFC-134a recycling. Reclamation is a difficult reformulation and de-contamination of the refrigerant back to the original specifications, requiring major efforts. Reclamation is typically carried out only in case of good logistics for refrigerant and refrigerant bottle exchange as well

as sufficient transport means. Both recycled as well as reclaimed refrigerant reduce the need for consumption of ODS in the refrigeration sector. In case of both recycling as well as reclamation, unusable refrigerant or remains from the process might be collected for destruction.

Refrigerant available for recovery will typically be less than the refrigerant charged due to the refrigerant losses between the beginning of the lifetime or the last service and this current service. Typically, recovery of refrigerant in case of service plays a certain role for centrally serviced or mobile equipment (central repair facilities for refrigerators or air conditioners, mobile air conditioners) as well as for large equipment serviced by highly skilled and well equipped technicians (chillers, large commercial systems), since there are often inherent economical benefits from the recovery. The recovery from other systems depends mainly on incentives such as legal requirements combined with enforcement measures, deposits for refrigerants etc. In many cases there are only limited incentives for collection of unusable refrigerant during service.

At the end of the lifetime of refrigeration equipment, different options are available. Specifically domestic refrigerators or similar systems of limited outside dimensions might be incinerated completely in specific waste incineration plants suitable for that purpose. This allows for this limited sector the complete destruction of the refrigerant remaining in the refrigerator, without prior recovery of refrigerant. While Japan intends to use such systems, the European Union requires recycling of the plastics etc., leading to a destruction of the refrigerator (crushing) and a manual recovery of refrigerant before destruction. While in Europe all CFCs recovered have to be destroyed, it can be assumed that the incineration might lead to a slightly higher yield in terms of destroyed CFCs (no CFC remains in oil etc.), provided that the refrigeration cycles are not damaged during the loading of the incineration plant. The amount of CFCs in the refrigeration cycle of domestic refrigerators and freezers to retire until 2011 will be approximately 1650 tons per year in Western Europe, 950 tons in the US 450 tons in Japan; in Article 5 Countries, Countries with Economies in Transition and in other countries, the amount of CFC refrigerators retiring is likely to increase until 2016, from around 2000 tons to more than 9000 tons. This increase is caused by the very significant increase in refrigerator production for developing country markets, now being almost a third of the refrigerator market. Until recently, the majority of these refrigerators were containing CFCs. Limited accessibility, illegal dumping and similar problems will lead to a smaller amount available for destruction than actually retiring. Detailed information about the situation in Article 5 Countries and Countries with Economies in Transition is provided in Annex 2 to this chapter.

All other refrigerant to be destroyed will only be available after recovery of the refrigerant from the refrigeration system. Retired systems will have experienced

some leakage, some – like automotive air conditioners – will hardly have refrigerant left for recovery, since typically the systems are not serviced in the last 6 years of the cars life. It is assumed that in most economies, usable refrigerant is actually recycled, reclaimed or reused in order to service existing CFC refrigeration systems. According to experience, about 10% of the recovered refrigerant reaching recycling or reclamation facilities is reported to be unusable and is therefore available for destruction. Important exemptions are e.g. the European Union and Canada, where recycled refrigerant can not be reused and has to be destroyed.

2.4   Potential for Destruction of ODS from the Refrigeration Sector

The potential for CFC destruction is shown in Figure 2-4 to Figure 2-6. They represent a realistic estimate of the potential for destruction. Nevertheless, in order to utilise this potential, extensive logistics as well as sufficient incentives for recovery and collection also of unusable refrigerant have to be in place in the different regions. Looking at the present situation, the potential given below will therefore probably not be fully utilised.

The potential for CFC destruction consists of refrigerant recovered during service and refrigerant recovered at the end of life of the equipment. Except for Canada and the European Union, it was assumed that the first priority for recovered refrigerant was to reuse it in existing CFC systems (directly or after recycling), rather than destroying it. In order to calculate the potential amounts of refrigerant for destruc-tion, sector and region specific data and realistic assumptions were combined, consisting of typical service rates, resp. typical retirement rates, the refrigerant remaining in the system when the service/retirement occurs, the share of recovery expected in the sector, and the share of the destruction vs. reuse of refrigerant. Such calculations have been performed separately for service and retirement of equipment.

2.4.1   Regional Patterns

Figure 2-4, showing a distribution of the potential for CFC destruction by region, clearly displays the result of the European regulation 2937/2000, which does not allow charging of refrigeration equipment after service with CFCs, nor export of recovered CFCs. Consequently, it is expected that CFC phase-out in Europe will be rapid, with 100% destruction of the recovered refrigerant. In most sectors in other parts of the world, the bank of refrigerant is reduced more slowly, and the refrigerant recovered is reused instead of being destroyed.

Once the large potential in Europe has ceased in 2005/2006, the remaining potential for destruction of CFC refrigerant is likely to stay below 3000 tons per year,

decreasing further after 2012. Article 5 Countries, being – due to data availability – combined in these graphs with CEIT and Other Countries, have very significant amounts of CFCs banked in larger refrigeration systems, such as chillers or food processing equipment. These amounts, being accessible for recovery and later destruction, are the main contributors to the potential for destruction. Other sectors will contribute only to significantly smaller extents to the potential for CFC destruction.
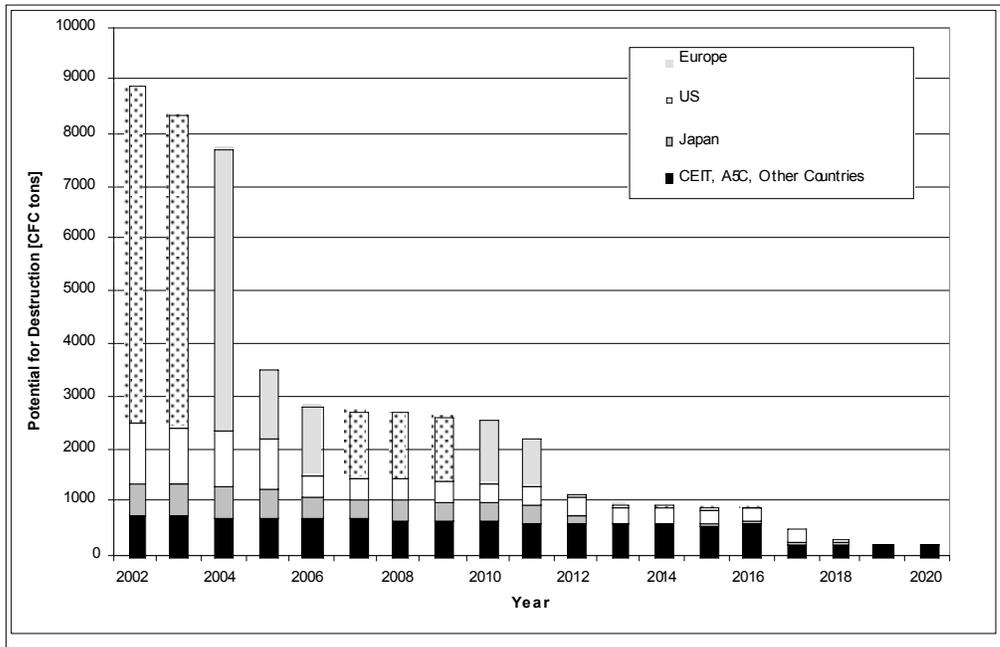
Figure 2-4: Potential for CFC destruction from refrigeration sector by region

2.4.2   Sector Distribution

The sector wise distribution as shown in Figure 2-5 shows that the sectors covered in industrial and other as well as the chiller sector have the ability to provide the most steady flow of CFC refrigerant to be destroyed. The low potential in domestic refrigeration after 2012 is not only based on the assumption of a lower average collection rate in the remaining countries than in Western Europe, Japan and US, but also on the fact, that most of the refrigerant will be reused, while in case of Japan and Europe it will be destroyed. The refrigerant coming back from MACs for destruction will be minimal because of the little refrigerant remaining in the system and its typically sufficient quality for reuse (no motor burn-outs). On the other hand refrigerant coming back from commercial refrigeration is limited because of leakage rates and relatively short life of the equipment.
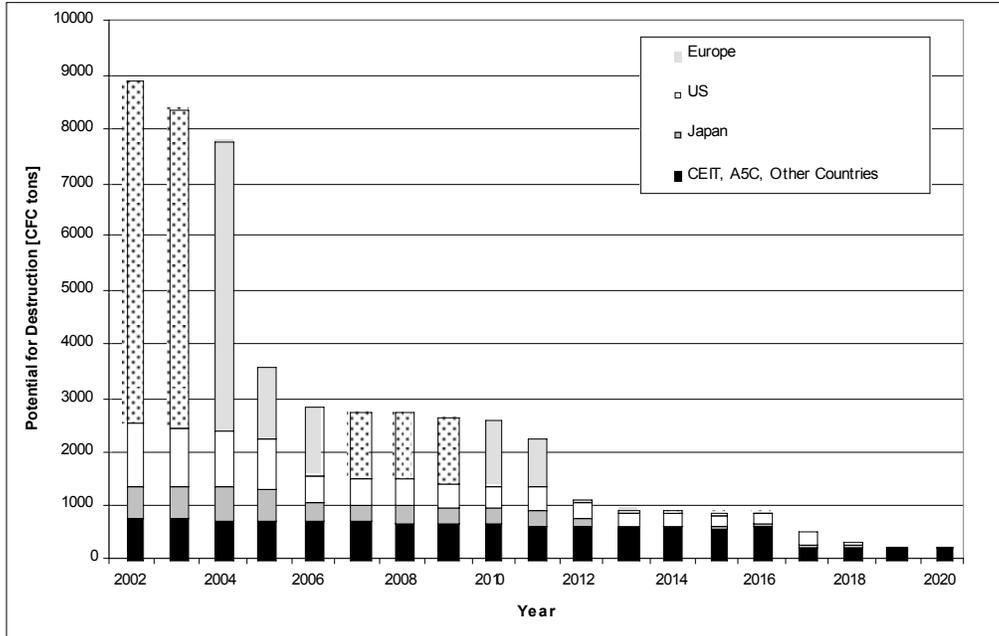
Figure 2-5 *Potential for CFC destruction from refrigeration sector by sub-sector*

A comparison between the destruction potential of refrigerant for destruction collected during service and refrigerant for destruction collected from retired refrigeration equipment is given in Figure 2-6.

It shows that the highest potential for refrigerant for destruction is likely to be in the retirement of equipment. It is due to the limited repairs in several sub-sectors as well as the high leakage rates and poorer recovery conditions in case of service than in case of a (pre-planned) retirement. Nevertheless, it remains to be seen to which degree the potential shown might be utilised.
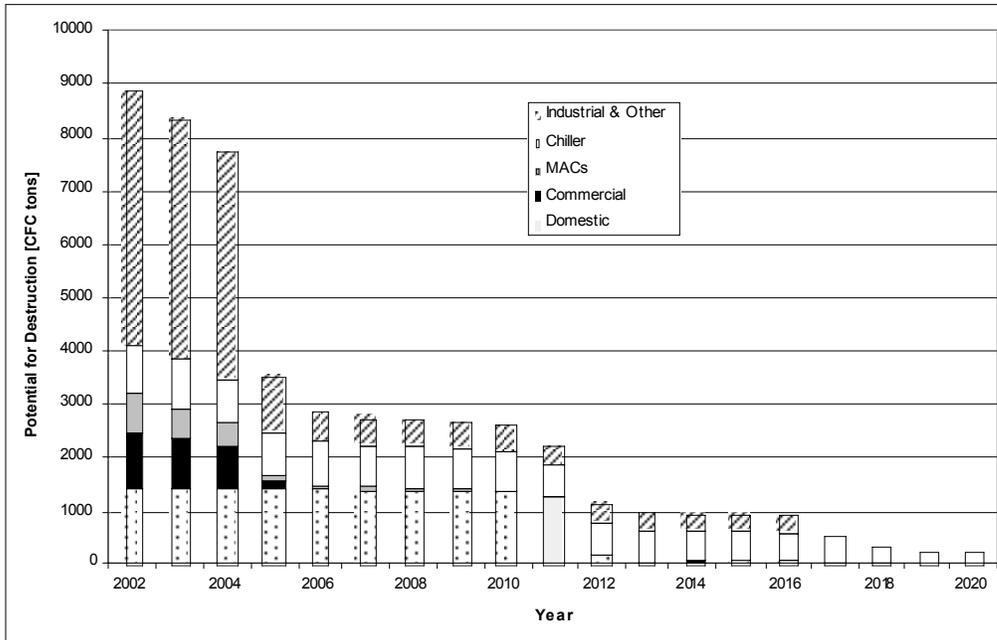
Figure 2-6 *Potential for CFC destruction from refrigeration sector by source*

2.5   Mobile Air Conditioning

In response to the Montreal Protocol, all new vehicles sold after 1995 in developed countries and equipped with A/C have used ozone-safe HFC-134a as the refrigerant. HFC-134a was the global choice to replace CFC-12 because it has no ozone depleting potential, is non-flammable, has low toxicity, and has cooling capacity and energy efficiency comparable to CFC-12. Each year fewer of CFC-12 using vehicles remain in service, reducing the opportunity for recovery at service, retrofit, and disposal.

Efforts in the United States in the early 1990's by SAE, industry, and the US EPA led to the development of equipment and procedures to recover and recycle refrigerant used in vehicle A/C systems and has formed the basis for similar developments world wide. The Mobile Air Conditioning Society-Worldwide (MACS-W) 2000 Field Survey of member shops indicates that sixty-eight percent of vehicles in for service had recoverable charge that averaged 88% of the original specified charge and the average for all vehicles serviced (including those coming in with no residual charge) was 66% of the original charge. Assuming 6% refrigerant losses during the recycling process, the amount of refrigerant recycled and ready for reuse averages 60% of the original charge. Therefore, the average need for new refrigerant for recharging at service would be 40% of the original charge. Consequently, the amount of refrigerant available for destruction would be less than 4% of the original

charge, depending on how much refrigerant is being emitted during recycling and how much is being separated for later destruction. The average amount of refrigerant charge in current vehicles is 1.05 kg for CFC-12 systems.

It is technically and economically feasible to substantially reduce global emissions of CFCs from vehicle air conditioning (A/C). CFC recovery at the time of AC retrofit to another refrigerant or at system deactivation or disposal can result in substances available for disposal. However, so far worldwide, very little CFC recovered from vehicles has been destroyed; almost all is recycled to vehicle AC use.

Recycling is currently required in the European Union, Japan, the United States, and some other nations of the world. In the past, 50% of the world's population of vehicles with A/C was located in the U.S. As the world vehicle population reaches the anticipated one billion by 2015, over 2/3 of these vehicles will reside outside of the United States. Given this, refrigerant recovery/recycling in all developed and developing countries must be considered, and, where possible, should be made mandatory to minimize the release of refrigerant to the atmosphere.

Recovery and reuse by vehicle service personal is the least costly strategy, with the value of reclaimed refrigerant higher than the cost of equipment and labor in developed countries where CFC-12 frequently sells for higher prices (currently up to US$14 per kilogram). Costs of collection and off-site storage and destruction are not documented, since this rarely occurs.

Refrigerant management can substantially reduce emissions by:
- not allowing service recharging without repairing leaking systems,
- recovery and recycle at service and vehicle disposal,
- prohibiting small disposable cans that encourage car owners to recharge their own systems without repair,
- encouraging that only quality parts be used for repair, and
- creating incentives to recover CFC from inoperable AC systems before it all leaks out.

The situation in developing countries differs significantly from that of developed countries. Developing countries tend to have older vehicles with air conditioners that are not as well maintained. A/C service often consists of simply adding refrigerant to a leaky system without repairing the leak. Service without recovery and recycle equipment means refrigerant must be vented into the atmosphere. CFC-12 is sometimes used to refill HFC-134a systems, due to its lower price and greater availability.

The low cost and availability of CFC-12 in developing countries discourages recovery and recycle. Mandatory programs can result in increased use of recovery and recycle, but may be difficult to enforce. It is expected in the future that the decreasing supply of CFC-12 and the higher cost of HFC-134a, combined with international political pressure to limit emissions, will provide added incentives.

2.6 Recovery and Recycling in Article 5 and Countries and Countries with Economies in Transition

The designation "Recovery and recycling" for certain types of projects in CEIT and A5C describes today a variety of different measures. It ranges from procurement of equipment, set-up of logistics, and training. Not exactly in line with the original definitions, the use of the designation "Recovery and Recycling" covers sometimes also simpler measures such as reuse of refrigerant, and more complicated ones such as reclamation. Reflecting this reality, this chapter uses a wide definition of Recovery and Recycling, which includes Reuse and Reclamation. All these measures are meant to conserve refrigerant already within refrigeration systems instead of releasing it.

Recovery designates the extraction of refrigerant from the system into a separate container, which could be e.g. a suitable refrigerant bottle or a refrigerant bag. The (minimum) equipment needed for recovery of small amounts (up to a kg) is very simple and can be assembled for low costs within minutes from a refrigeration technician, potentially even using to a large extent used refrigeration components.

Reuse designates the use of recovered refrigerant with no or absolutely minimal purification for charging of a refrigeration system, often the same from which the refrigerant was recovered in the first place. This combination of recovery and reuse should be common practice for service calls, e.g. in case of repair of parts of the refrigeration cycle itself. Nevertheless, in many countries, this is typically not done due to the transport need of the recovery machine as well as the increase in downtime of the system.

Recycling is defined similar to reuse, except that the refrigerant undergoes a purification process to remove oil, moisture and acids. The recycling equipment provided under the MLF funded projects is typically performing refrigerant recovery and can increase the speed of that process greatly, allowing also evacuation of equipment etc. In addition, these machines typically allow also for recycling of refrigerant recovered elsewhere.

Reclamation requires complicated thermophysical purification processes, since it is the objective to deliver refrigerant meeting the original specifications. Due to the

investments involved, reclamation clearly requires a centralized set-up of R&R systems.

R&R systems can be set up in a dispersed or a centralized way. Centralized systems provide typically better refrigerant quality with similar investment levels in comparison to dispersed systems, since only a few systems have to be financed, and quality control of incoming and outgoing refrigerant as well as maintenance of the equipment is better. The disadvantage of centralized systems are the higher operational costs on the side of the service enterprises because of

Increased logistics are necessary, including significant transport capacities on the side of technicians

- Loss of work time, often in the peak season
- Quality control of incoming refrigerant necessary
- Disincentive in case of delivery of unusable refrigerant (disposal costs have to be buried, often by technician)
- Disputes with the customer because "valuable" refrigerant is carried away from the site, leading to an suspected income for the technician.

If centralized systems are envisaged, the need for logistics might require a limitation to areas with a large population of refrigeration equipment attractive for R&R. Thus, centralized systems are largely found in urban areas; in the countryside, either decentralized equipment is used, or only recovery and reuse is being performed.

The alternative to centralization is to establish a dispersed, decentralized system. This can be achieved e.g. by providing one recycling machine per company, or several companies located close to each other can share one machine. The latter possibility turned out to be relatively ineffective, since the owner of the equipment often tries to limit access of his competitors.

Systems where only recovery and reuse was carried out have not been widely supported, maybe largely due to political reasons, but are a valid alternative reducing costs and achieving an excellent CFC saving in comparison to the funding used.

Recovery machines are typically smaller than recycling machines, but even these compact designs add very significantly to the equipment that a technician has to carry to the customer. Taking into account the lower mobility in many A5C and CEIT, the additional equipment plus one refrigerant container per refrigerant used on top of the necessary repair equipment are not easily carried and thus are a disincentive for recovery and reuse on site, or subsequent transport to a recycling machine/reclamation center. In absence of strong legislation and enforcement of

requirements for recycling, this disincentive is only overcome if a system contains even in case of a failure sufficient refrigerant of acceptable quality and if the owner can wait for the recovery (downtime of system – threat to perishable products, turnover, …). Compressor burnout, being quite frequent in case of small equipment and unstable electric grids with voltage fluctuations, cause the refrigerant filling to be completely unusable. All these points lead to recovery and recycling on site being economically clearly unattractive for systems below approximately 10 kg (border varies depending on the conditions in the individual country), and being clearly attractive for systems containing more than approximately 100 kg (border varies depending on the conditions in the individual country). Such an amount of filling can be found e.g. in large air conditioning systems, industrial and food storage applications and some commercial equipment. In the industrial and food storage equipment, other refrigerant than CFCs have frequently been used.

The alternative to carrying a recovery machine to the equipment is to bring the equipment to the recovery machine. This is possible for almost all mobile equipment (car, bus and train air conditioning, refrigerated road and rail transport, …). Domestic refrigerators and small commercial equipment are sometimes also transported to a repair facility. This is insofar problematic as there is a high risk involved of damaging the equipment during transport, releasing the filling in the ambient. In addition, the filling to be recaptured is limited: The refrigerant originally contained in the system is small (approximately 200g CFC for large refrigerators), from this amount, leaked refrigerant has to be deducted. In addition, another 20g to 30 g might remain dissolved in the compressor oil, leaving very limited potential for recovery.

In several African countries, it was observed that nearly 60 to 70% of domestic refrigerators are serviced due to leaking or burnt out compressors, leaving all refrigerant within the system unusable. The remaining need for servicing is due to blockage in capillaries (rare) or due to electrical faults which do not require the refrigerant side to be touched.

In case of recovery and recycling, there is actually only a small margin between conditions which are economically unattractive and those economically attractive. This margin is where projects of institutions like GEF or Multilateral Fund should support enterprises, where support in equipment will provide the increment in costs to make out of a non-profitable a profitable project. But this role is difficult to define, since recovery equipment can be built by the individual entrepreneur with little effort and minimum costs basically from leftovers of prior repairs, if R&R is economically feasible. The role of training in that regard is important, since it raises awareness and can provide important information concerning design considerations for recovery equipment.

While recycling machines might be used with different refrigerants, switching between refrigerants requires some major cleaning effort and replacement of a number of consumables. Thus, recycling machines are typically used only for one type of refrigerant at a time. For any shop owner, it is most economical to concentrate on the highest value refrigerant. HFC-134a recovered from systems other than MAC is comparably small because stationary HFC containing systems have only been introduced into the markets recently. Consequently, cases are known where recycling equipment meant for CFC-12 has actually been used either for HCFC or for HFC. While this can be seen as a certain positive effect in general environmental terms, it does not reduce the consumption of virgin CFCs.

The limited economic incentive for R&R in some countries is also illustrated by cases where the government, in its efforts to ensure that the equipment would be properly utilised, required security deposits from the enterprises interested in utilizing the equipment. Since no interest was shown on the part of these enterprises to follow this procedure, the project did not start.

But there are also positive signs. In some countries, it was found in evaluation missions that there was good utilization of equipment and the equipment was well maintained, typically in the MAC sub-sector.

A number of interesting lessons were presented by U.S. EPA concerning lessons learnt in commercial refrigeration servicing projects in China and the Dominican Republic which presented a number of obstacles in comparison to MAC projects:

(a) "Equipment owners and service technicians may be resistant to the use of recycled refrigerant. This does not seem to be an unreasonable position, given owners' substantial investments in refrigeration equipment, the economic importance of reliable system performance in most commercial refrigeration applications (i.e. the risk of spoiled food, unhappy customers), and the fact that refrigerant is a relatively small part of each repair bill. This appears to be a distinctly different situation than in the MAC sector, where recycled refrigerant is widely accepted, partly through the efforts of automobile manufacturers. Business owners may also find the potential cost savings of recycled refrigerant less attractive than automobile owners.

(b) The percentage of repair jobs, which involve a recovery opportunity, seems to be substantially less than in the MAC sector.

(c) Because the recovery equipment tends to be cumbersome, and refrigeration equipment is often inconveniently located, it is difficult to motivate the technicians to take a recovery machine to every repair job. In the MAC

sector, the recovery/recycle machine is readily available on the shop floor and can be easily brought over to each car being repaired.

If the recovered refrigerant must be recycled before re-use, this means that the refrigerant must be transported to a recycling machine, recycled, then transported again to refrigeration equipment before it can be re-used. It is difficult to structure incentives to assure that this will be done, particularly if the economic value of the recycled refrigerant is low. No movement of refrigerant is required in the MAC sector."

3 Foams

3.1 Use of Ozone Depleting Substances in Foams

The use of CFCs and HCFCs as foam blowing agents spans several generic product types. These can be summarized as:

Table 3-1: Generic Foam Types Using CFCs and HCFCs

Generic Product	Typical Blowing Agents	
	CFCs	*HCFCs*
Polyurethane Elastomers	CFC-11	HCFC-141b
Flexible Polyurethane	CFC-11	Little used
Rigid Polyurethane	CFC-11	HCFC-141b, 22
Extruded Polystyrene Sheet	CFC-12	Not used
Extruded Polystyrene Board	CFC-12	HCFC-142b, 22
Polyethylene	CFC-12	HCFC-142b, 22
Phenolic	CFC-11/CFC-113	HCFC-141b

In the base year for the Montreal Protocol (1986), the consumption of CFCs in foams was as follows:

CFC Usage by Product Type in the Foam Sector (1986)
(total 267,400 tonnes)

- Polyurethane 78%
- Polyolefin 7%
- Extruded Polystyrene 14%
- Phenolic 1%
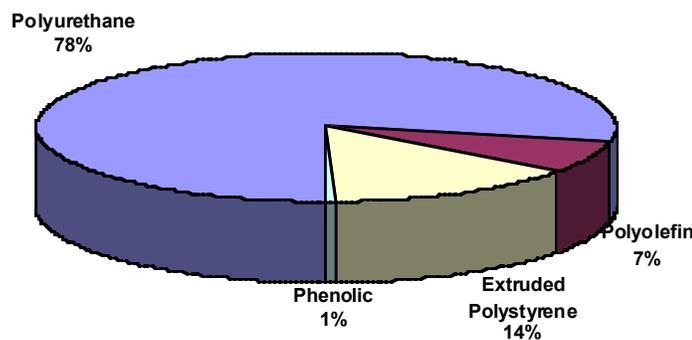
Figure 3-1: CFC Consumption in the foam sector in 1986

As illustrated in Table 3-1, the polyurethane sector splits into two prime sub-sectors: - flexible and rigid. Flexible foams include foams for furniture, bedding

carpet underlay and vehicle seats. In addition, flexible integral skin systems (elastomeric) provide shoe soles, furniture mouldings and automotive fascias and steering wheels.

3.1.1 Polyurethane Elastomers

CFC-11 has been used for several applications in this sector. When CFC-11 was phased-out in the EU, HCFCs were only allowed in integral skin transportation safety applications. In the US this use was only allowed until 1996. In other counries and in developing countries, the use of HCFCs has continued, albeit at a low level. Non-ODS technology is becoming dominant in these sectors too. The application is fairly emissive and little blowing agent remains in the foam after one to two years (see Table 1-2).

3.1.2 Flexible Foams

Although flexible polyurethane foams represent the largest polyurethane sector (65%), the use of CFC-11 was primarily as an auxiliary blowing agent, which meant that the consumption of blowing agent was always significantly lower than that for rigid polyurethane foams. This is illustrated in Figure 3-1 below:

Use of CFCs in Foams (1976-1999)
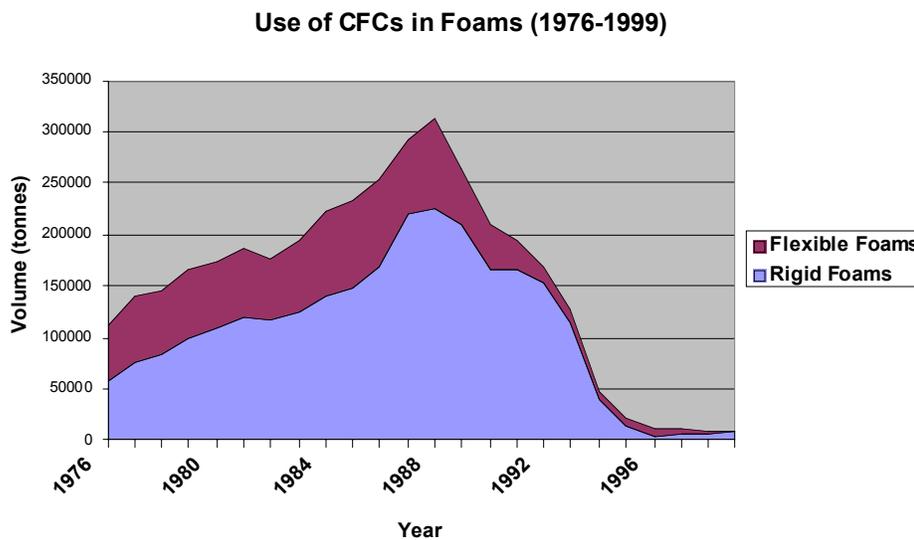
Figure 3-2: *Comparative consumption of CFCs in rigid and flexible foams*

As can be seen from Figure 3-2, the use of CFCs in flexible foams was virtually eliminated by the early 1990s as the industry moved to methylene chloride and latterly to liquid CO_2 technologies. Since the application was essentially emissive in nature, there is now no opportunity to minimise emissions from existing foam stocks. This is in strong contrast to the situation with rigid foams.

3.1.3   Rigid Foams

CFCs have been used in rigid foams since the late 1950s. They have provided the following:

- Lower thermal conductivity than other blowing agent alternatives
- Stable thermal conductivity performance with time
- Ease of processing (suitable boiling points, non-flammability, low toxicity etc.)
- Good product properties (fire performance, dimensional stability, strength etc.)

However, the emergence of ozone depletion as an issue, singled out CFCs for early action and the foam sector in developed countries was obliged to phase out their use by 1996 under the Montreal Protocol. Foam manufacturers in developing countries have longer to respond to the requirements of the Montreal Protocol with CFC phase-out not mandated until 2010. The regional variation in phase-out is shown in Figure 3-3.

Phase-out of CFC Blowing Agents in Rigid Foams
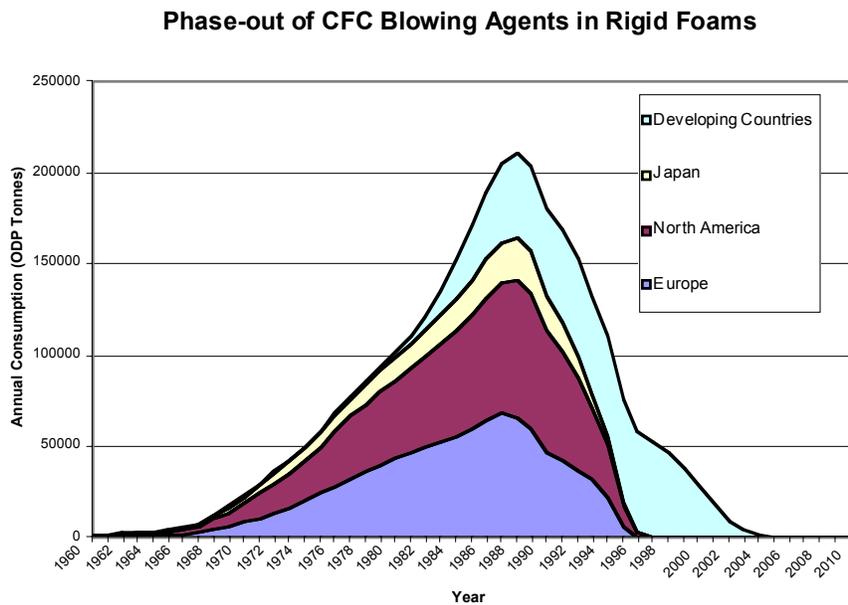
Figure 3-3: Regional variation of global CFC phase-out

In many cases, the initial replacements were HCFCs, which offered similar properties to the CFCs they replaced but with only 5-12% of the impact on the ozone layer. Some sectors such as the extruded polystyrene sheet sector and the European appliance manufacturers were able to make transitions directly to non-ozone depleting substances, thereby saving the need to make two transitions. In

most developed countries, HCFC phase-out in the foam sector will occur before 2010. However, use in developing countries is permitted until 2040, albeit with a freeze on consumption at 2015. Figure 3-4 illustrates the expected consumption trends for the global foam sector to 2010.

CFC/HCFC Blowing Agents in use globally in Rigid Foams
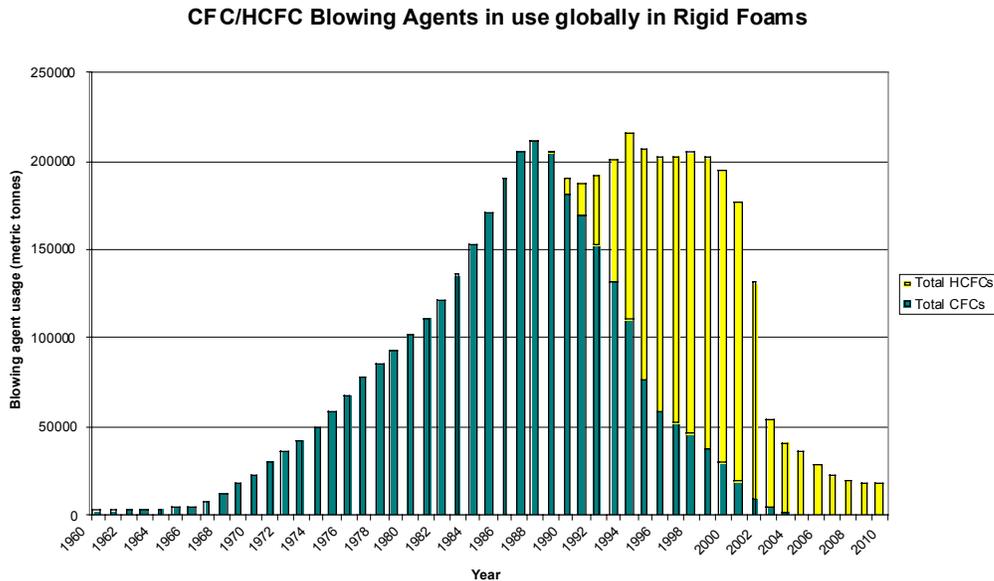
Figure 3-4: *Growth of CFC use in rigid foams and the subsequent demise following HCFC introduction*

3.2 Baseline emissions estimates from foams

Although the Montreal Protocol is fundamentally a consumption-based control, it is recognised that the rate of emission of CFCs and HCFCs from applications is the key factor in assessing the impact of these ozone-depleting substances on the stratospheric ozone layer. While many applications lead to immediate emission (e.g. aerosols), the nature of rigid insulation foams is such that, in many applications, the blowing agent remains in the foam for extended periods. Depending on the lifetime of the application, this can be upwards of 50 years in some cases. Accordingly, much of the foam manufactured using CFCs in the period 1960-1995 is likely to be still in use today. This provides a substantial opportunity for recovery of blowing agent at end-of-life. However, to assess this opportunity and to focus recovery activities in the most appropriate places, it is important to be able to model anticipated retention levels in differing product types.

In assessing emissions from foams, it is recognised that there are three prime phases in which emissions can occur. These are:

- Foam production and installation (first year losses)
- Installed foam during its use phase
- Decommissioning at end of life

Depending on the application and product type in question, these areas of emission (known as emission functions) can vary substantially. In view of the increasing importance being placed on quantifying emissions (particularly under the operation of the Kyoto Protocol), there has been increased interest over the last few years to develop appropriate emission functions for a variety of product types and end uses.

As part of an on-going study carried out for AFEAS over the past five years, the following emission functions for various foam applications have been derived and refined (see Table 3-2).

Table 3-2: *Emission functions derived for various foam types and applications*

Foam Type	First year release (%)	Release Rate (%/yr)	Time to Total Release[1] (yrs)	Lifetime of Foam (yrs)	Total remaining at decommissioning (%)
PU Integral Skin	95	2.5	2	15	0
PU Cont. Panel	5	0.5	190	50	70
PU Disc. Panel	6	0.5	188	50	69
PU Appliance	4	0.25	384	15	92
PU Com. Refrig.	6	0.25	376	15	90
PU Cont. Block	35	0.75	86	15	54
PU Disc. Block	40	0.75	80	15	49
PU Cont. Lam.	6	1	94	50	44
PU Spray	25	1.5	50	50	0
PU Reefers & Trans	6	0.5	188	15	86.5
PU OCF	100	N/A	0	50	0
PU Pipe in Pipe	6	0.25	376	50	81.5
Phen. Cont. Lam.	6	1	94	50	44
Phen. Disc Block	40	0.75	80	15	49
XPS Board	25	2.5	30	50	0
PE Board	90	5	2	50	0
PE Pipe	100	N/A	0	15	0

The applications where there are significant amounts of ozone depleting substances to recover at end-of-life are shaded yellow in Table 3-2. The retention within domestic appliances is particularly high because of the metal/plastic encapsulation of the foam. These retention levels have been verified by the appliance industry through cross checks on 25 year-old units blown with CFC-11. Using these basic emission functions and the historic usage patterns of CFCs and HCFCs within the various foam types and applications, it is possible to create a projected emission pattern of the type shown in Figure 3-5 below.

Emissions of Blowing Agent in Actual Tonnes
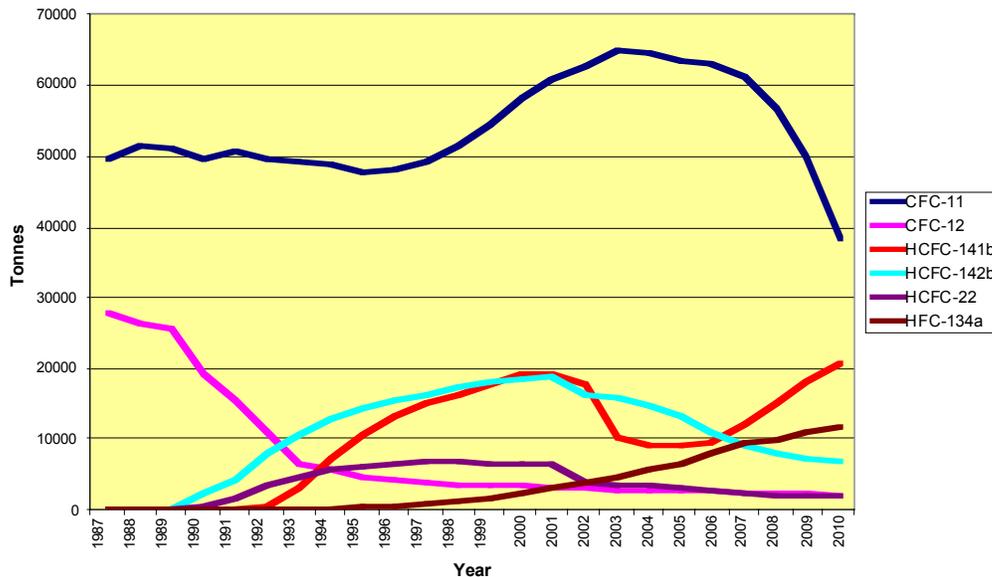
Figure 3-5: *Projected emissions estimates for various CFCs and HCFCs to 2010*

Figure 3-5 should, however, be used with caution because it assumes that, at the end of design life, release of the encapsulated CFC is instantaneous which, in reality, it certainly is not. There are two categories of reason why this is not the case:

- Incidental outcomes of non-intervention at the end of design life
- Specific initiatives to reduce emissions at the end of design life

In essence, these two categories summarise two alternative strategies best defined as 'leave well alone' and 'manage all end-of-life processes'. At their extremes, both of these routes can be highly effective in minimising emissions. In reality, however, even the processes of landfill and other apparently non-interventionist approaches have impacts on emissions because of poor handling and the damage resulting. Similarly, interventionist approaches such as mechanical recovery need to be highly engineered to avoid accelerating emissions unduly. These issues are addressed in more detail in the next section. Suffice it to say for the moment, that the emission profile shown in Figure x-5 represents a genuine 'worst case' scenario at end-of-life. Nonetheless, the graph provides a good indication of the potential scale of the emissions challenge over the next eight years. Even in 2010, there is still likely to be well over 1 million tonnes of CFC-11 remaining in rigid foams globally even assuming that most blowing agent in refrigerator foam in developed countries has been either dealt with or released by that time. The distribution of this CFC-11 is indicated in Figure 3-6 below:

Global CFC-11 projected in installed foams as at 2010
(approx 1.12M tonnes)
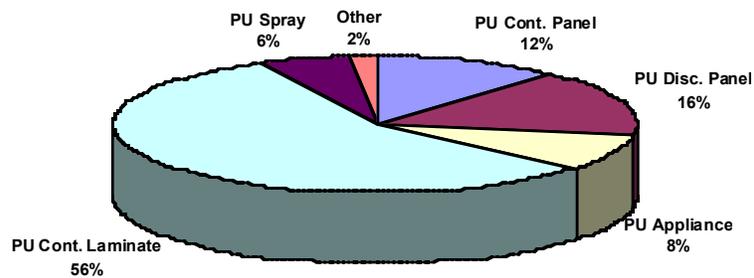
Figure 3-6: *Remaining CFC-11 in installed foams at 2010*

Although this is a very significant quantity, it is worth reflecting that, at their peak CFCs were being sold into the rigid foam sector at over 200,000 tonnes per annum. Accordingly, the projected CFCs remaining in 2010 represents around 5 years worth of peak supply.

An interesting further fact is that the burden of recovery, particularly in the appliance sector, will have switched from developed to developing countries. Figure 3-7 illustrates the likely split of CFC-11 banks in 2010. This split does not take into account any trade which may have taken place in second-hand refrigerators exported from developed to developing countries for re-use. The picture illustrates the importance of phasing out the use of CFC-11 in refrigerator plants in developing countries at the earliest possible opportunity. The current data set was compiled in 1998 on the basis of the best available information on transitioning at that time. Further work is now required to determine how these projected CFC-11 banks in 2010 might be altered by the latest projections for CFC phase-out.

Global CFC-11 projected in foams at 2010 by Regional Classification
(total 1.12 Mtonnes)

Developing Countries
32%

Developed Countries
68%
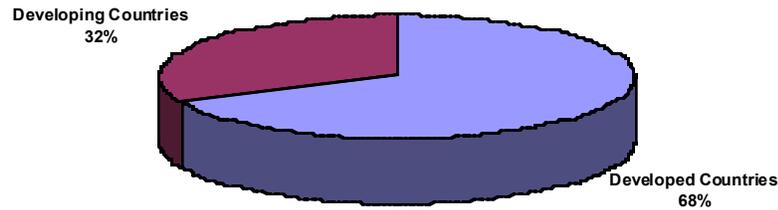
Figure 3-7: Remaining CFC-11 in foams by Regional Classification

3.3   Options at End of Design Life

Blowing agent recovery, while not mandated under the Montreal Protocol, has been recognised by many Parties as worth pursuing and several initiatives have been taken at national and regional level to take advantage of the excellent blowing agent retention of many rigid foam applications. However, the physical challenge of retrieving the installed foams from within structural building projects and other equally inaccessible locations has led to some severe questions about the practicality and cost effectiveness of such initiatives. In contrast, foams within domestic and small commercial refrigerators and freezers are considerably more accessible, particularly where units are already collected for recovery of refrigerant or for other material recycling reasons. Nonetheless, the potential for recovery of blowing agents from any foam source depends on the following factors:

- Quality of the foam cell structure and resulting diffusion rates
- Solubility of the blowing agent in the matrix
- Thickness of foam sections
- Types of facing materials
- Other materials adhered to the foam or facing materials

It is important to note that blowing agent recovery need not necessarily be undertaken at the end of a product's designed use, since secondary usage can be a serious option in some cases. In addition, any attempt to recover blowing agent,

even when mandated by regulation, will not be 100% effective. The following flow-chart (Figure 3-8) illustrates the 'real life' material flows for foamed products, including continued losses through abandonment and landfill:
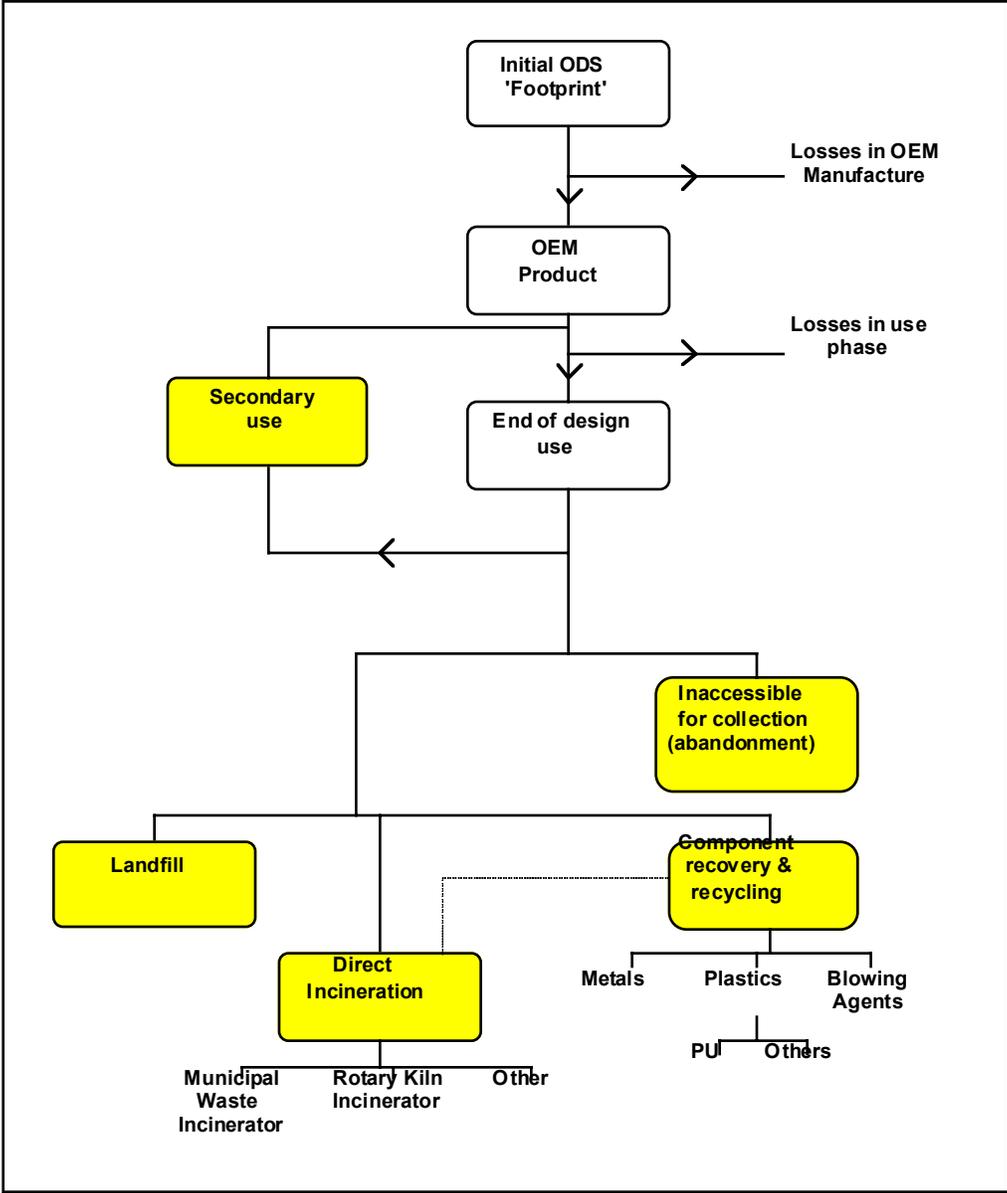
Figure 3-8: *Typical Lifecycle and Disposal Routes for Foam Products*

The flow-chart illustrates that there are five prime end-of-life scenarios for foams (shaded yellow). These are:

- Abandonment
- Secondary use
- Landfill
- Direct incineration (with energy recovery)
- Component recovery and recycling/destruction

3.3.1 Abandonment

Abandonment is a fact of life and will continue to be so, even within the most stringent regulatory framework. In general terms, there are two sources of the problem:

Accidental : – This arises when the foam in question is inaccessible or in cases where its presence is unknown and/or undetected

Deliberate : - This occurs when, for reasons of economy or social irresponsibility, the foam in question is disposed of in an uncontrolled fashion.

Quantifying the amount of foam abandoned in any application or region is extremely difficult because, by its very nature, it is uncontrolled. The only known method of gaining some insight into the practice is from the experience of local authorities called to clear up 'fly tips' and other impromptu collections of disposed waste. Even in these cases, it is seldom that the collection is either systematic or quantitative. Accordingly, it is typically necessary to make an assessment of abandoned foam products by inference from other data sources. However, this is inevitably an approximation because the precise amount of foam being decommissioned either accidentally or deliberately is never completely known.

While absolute values are difficult to specify, trends can be easier to spot. In some, but not all, societies, the tendency towards 'fly tipping' increases with the regulatory and, most importantly, financial burden placed on the individual disposing of the foam in question. Thus, if some sort of disposal tax is charged, there can be a reaction from the general public and individual corporations against incurring these costs resulting in the disposal of the foam in an uncontrolled manner. However, this is less the case in more disciplined and responsible societies such as Japan, where disposal taxation can be made to work.

To avoid such behavioural effects, the more widely used approach is to incorporate any element of disposal taxation into the purchase price of a replacement unit. This works particularly well if the tax can be sufficiently well targeted to apply only to

the products leading to a disposal problem. However, more typically it will not be possible to focus taxation measures so tightly and the tax may only act as a general disincentive to replace existing products. This can be environmentally counter-productive if less energy efficient products are currently in use.

As developed later, much of the current regulation governing disposal is driven not only by consideration of ODS recovery but also by more comprehensive resource recovery targets for recycling. In this case, more widespread taxation is justified.

3.3.2 Secondary Use

The ability to re-use a foam-based product depends on the way it is manufactured and installed in the first instance. The prime requirement for such a product is that it can be transposed from one application point to another without disrupting the integrity of the product itself. Historically, such characteristics have been the preserve of genuinely self-contained items such as refrigerators and, indeed, a significant trade in second-hand refrigerators has developed across regions of the world. Additionally, there is a significant trade within a country where units are sold on to poorer sections of the population. Nonetheless, the most common occurrence with refrigerators is their continuing use within a household after a new unit has been purchased.

Where units are traded between the Article 2 and Article 5(i) or CEIT countries, this practice has created a dilemma for regulators under the Montreal Protocol. On the one hand, the units provide access to improved standards of living for many residents in developing countries at affordable prices. In addition, the practice is a classic example of extending the use period of a product and avoiding premature obsolescence. On the other hand, the practice often extends the use of less energy efficient equipment and effectively exports a future disposal problem to a deve-loping country. This latter problem is of particular significance in the case of refrigerators using CFC refrigerants where rapid fugitive emission is more likely than with the foams themselves. In general, the Ozone Regulators in developing countries have come down against the practice of such trade and this position has now been supported by the prohibition of exports of used refrigerators from the European Union under the recent Regulation 2037/2000. The decision, however, remains a controversial one and even some environmental NGOs consider that it would be better to maintain the trade and install suitable recovery equipment for end-of-life management. The practicality and cost of so-doing remains the key barrier.

Another opportunity for life extension is the potential for re-use of building insulation elements. The growth of use of PU composite panels in Europe points strongly to the cost-effectiveness of this approach in the first instance with the added value of being able to dismantle these elements from the supporting structure

and re-using them at the end of the building's life. Obviously, such practice assumes that the effective lifecycle of the insulation element itself will be longer than the building in which it is used. With the performance standards of these elements increasing progressively and the duration of practical building utility decreasing, the assumption is becoming ever more applicable.

3.3.3 Landfill

Landfill has been the traditional destination of most of the foam products decommissioned over the last 30 years, including many products containing CFCs and HCFCs. Although the regulations surrounding the location and management of landfills has improved considerably over this period, there is still little measurement or control of specific materials entering into a given site in many countries. The exception in this respect is where materials are determined to be hazardous or special waste (e.g. asbestos based). In these cases, regulatory controls have increased substantially. For example, regulations in several European countries prohibit the landfill of combustible materials. This is already the case in the Netherlands, Sweden, Denmark and Switzerland. Austria and Germany will follow in 2004 and 2005 respectively. The new EU Directive will prohibit the placing in landfills of materials of high carbon content, which will include foams.

One of the options for monitoring the movement of CFC and HCFC-containing foams onto landfill sites would be to classify the material as hazardous or special waste. In some countries, this has been done and with significant effect. In other countries, thresholds have been set for foams to qualify as hazardous or special waste (typically at 5% by weight of CFCs). However, because the composition of foam waste is not easily determined, and is not instantaneously recognisable from its exterior appearance, such thresholds are hard to apply in practice.

In general, the attitude of a Party to the prospect of landfilling foams is largely dependent on their wider approach to landfilling as part of their waste strategy. In the United States, for example, there is such substantial capacity for landfill that it is unlikely that alternative strategies will be pursued unless the case for better control of CFC emissions from landfill is compelling. Nonetheless, there are bans on the landfilling of refrigerators in 13 states. To further understand the efectrs of the landfilling of foams, the American Home Appliance Manufacturers (AHAM) commissioned a study at the Danish Technical University (DTU) in 2000 to investigate the rate of emission of CFCs from shredded foams[3].

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[3] 'Determination of the fraction of blowing agent released from refrigerator/freezer foam after decommissioning the product' _Kjeldsen & Scheutz (2002)_

The study has produced two key conclusions that are relevant to this discussion:

- That blowing agent releases from the shredded foam are not high during the first six weeks after cutting
- That the rate of release is highly dependent on the particle size of the shredded element

A further conclusion from a separate study conducted by the DTU shows that there are anaerobic mechanisms whereby CFCs can be largely broken down by enzymes and bacteria. This has the effect of restricting the ultimate release of CFCs to the atmosphere

These are important conclusions when considering the future role of landfill activities in the management of CFC and HCFC containing foam. However, issues such as the identification of the breakdown products resulting from the anaerobic degradation of the halocarbons needs to be addressed before this method of approach can be endorsed fully.

Of course, in the case of refrigerator cabinets, there is an even stronger argument for the disposal of the cabinet in its manufactured form rather than in shredded or crushed form, since in its manufactured form the rate of release in disposal will be no different to its rate of release in use. On the basis that the major issue influencing the recovery of the ozone layer is not specifically the total chlorine loading emitted but the rate at which it is emitted, there is a school of thought which suggests that it is better not to disturb the CFCs in disposed foams unless and until cost-effective techniques are available to recover the blowing agent *without any risk of fugitive emission*.

3.3.4   *Direct Incineration (with energy recovery)*

Direct incineration of foams is distinguished from other incineration options by the fact that, in the case of direct incineration techniques, no attempt is made to separate the foam matrix from the blowing agent prior to incineration. There may be some accidental separation in some facilities as pre-shredding takes place prior to feeding into the incinerator.

In the context of the Montreal Protocol, the destruction of blowing agents in this diffuse form has been less well studied than for concentrated and re-concentrated streams of ODS. This has led to the TEAP Task Force on Destruction Technologies (TFDT) assigning a relatively cautious minimum Destruction and Removal Efficiency (DRE) of 95% for qualifying processes. Even with such a low threshold, only two processes have been shown to meet the requirements – namely Municipal Solid Waste Incineration and Rotary Kiln Incineration. These two stand out from the many other theoretical options because they have the ability to handle solid

waste streams. Reactor cracking facilities may also provide potential in future, but there is little available data as yet on this process.

Despite the caution of the TFDT, work in Europe as early as 1993 indicated that destruction of diffuse CFC-11 in a Municipal Waste Incinerator was 99.95 ± 0.04 % when processed in the temperature range of 800-1100 ºC. This compared with a destruction efficiency of 99.97 ± 0.03% for concentrated and re-concentrated sources.

More recent studies such as that carried out at the Karlsruhe Facility (Tamara) used construction foams containing significant quantities of fire retardant to demonstrate the granulated foams up to 3% by weight of waste feed (30% by volume) could be disposed of at a rate of 146 to 225 kg/hr. Destruction efficiencies for other ODS were observed to augment the original 1993 data on CFC-11. The results showed that the CFC-12 DRE exceeded 99.9% at 900 ºC, while both HCFC-22 and HCFC-142b achieved 99.99% levels at 850 ºC, reflecting the overall lower stability of the hydrogen containing ODS.
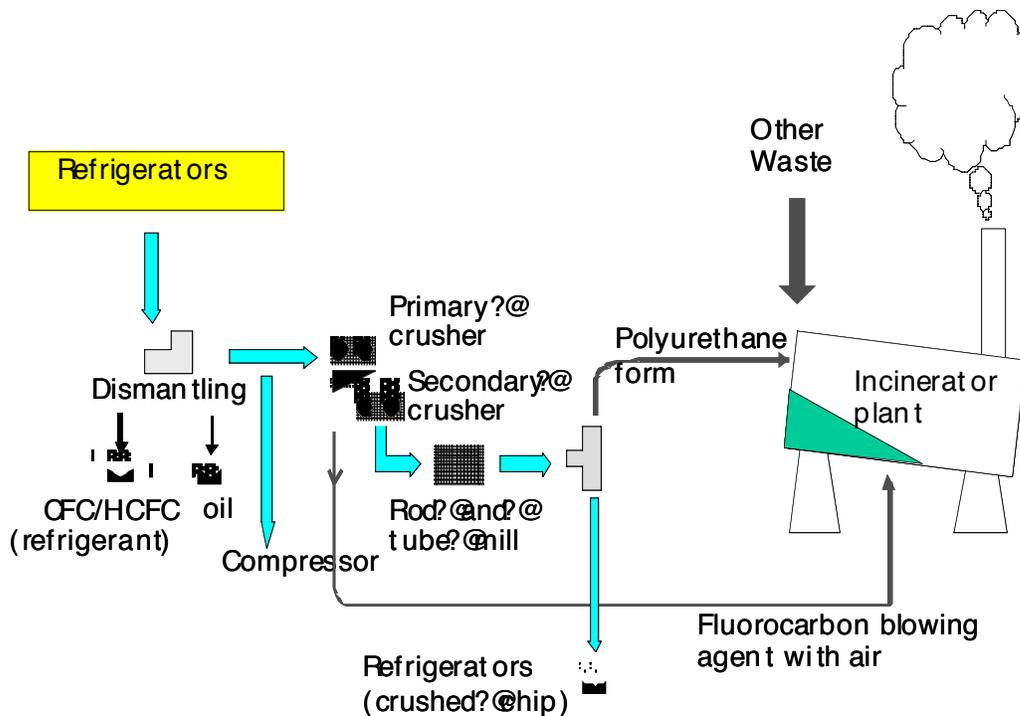
Figure 3-9: *Direct Incineration from shredded foam*

In Japan there is also considerable experience with rotary kiln incinerators, which are often used destroy foam outputs from closed shredding units without prior separation of blowing agent from the foam matrix. *Figure 3-9* illustrates the process. Test reports on trials carried out in March 2000 by Matsushita

(Panasonic) and Dowa Mining Company show destruction levels of better than 99.95%.

Direct incineration of complete refrigerators has been applied, both in the Netherlands and in Denmark.

Recent information suggests that one facility in the Netherlands has ceased processing refrigerators in this way because of the problems with slag build-up. Where the technique continues to be practiced (e.g. in Denmark), throughputs are kept at a low level.

In summary, therefore, direct incineration is seen as a viable method for the destruction of foams and is particularly effective where the foam can be separated from other components prior to incineration. Costs depend significantly on the available capacity for MSW incineration, but the technique can be highly competitive if the capacity is available.

3.3.5   *Component Recovery and Recycling/Destruction*

This method of handling foam waste has grown in technical integrity and environmental acceptability during the 1990s as the demand for high levels of material recycling has increased. This is particularly the case for domestic refrigerators where the concentration of metals and other plastics is of significance to national recycling targets. Indeed, in Japan, the current legislation demanding the component recovery from domestic appliances is driven by material recovery and recycling targets rather than by the management of ODS. Similar pressures are likely in Europe as the WEEE Directive is introduced within the next 2-3 years. A distinction between the regions is that, in contrast with Europe, ODS recovery from appliance foams in Japan remains voluntary. Nonetheless most responsible investments already include the facility to recover the blowing agents. It is likely that such recovery will become mandatory in Japan in the near future – at the very least for refrigerators and possibly even for building and construction waste. Such a step would be unique in the world, since most other regulators have viewed the economics of recovery from buildings as, at best, marginal. The current European Regulation (2037/2000) which is viewed as progressive in this area only calls for the mandatory recovery and disposal of ODS in domestic and commercial refrigerators, leaving the recovery of blowing agents from building products only required 'if practicable'. This phrase carries with it both technical and economic connotations and provides an opt-out for most European Member States at this time. However, the growth in use of pre-fabricated elements in building construction could potentially increase the practicability of blowing agent recovery (and possibly product re-use) over time. Accordingly, the mechanisms for collection and recovery of building waste will become increasingly visible in the next 5-10 years.

The history of mechanical recovery technology development has not been an unqualified success, with prototype units achieving recovery levels of less than 30% in the early 1990s. Viewed in isolation, it is self-evident that it would have been better to have left many refrigerators untouched rather than to accelerate the release of 70+% of the blowing agent in this way. Nonetheless the early equipment short-comings led to further developments and the state-of-the-art units of today can reach levels of recovery well in excess of 90% routinely. A typical plant design is shown below in Figure 3-10.
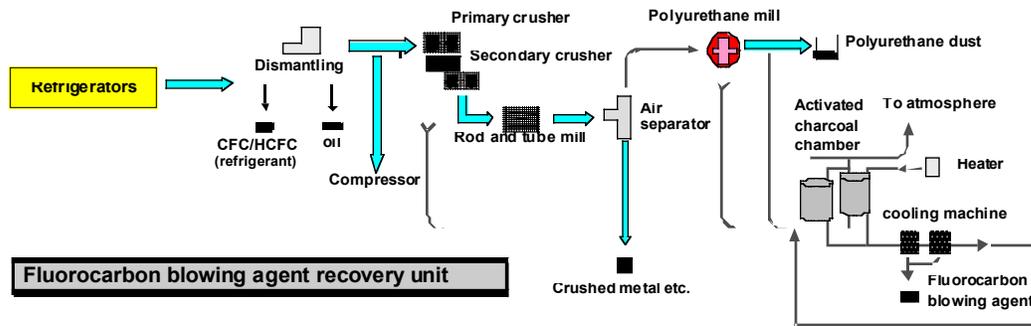
Figure 3-10: *A typical mechanical recovery plant*

Annex A is dedicated specifically to the definition of current good practice and the reader is encouraged to look there for further information.

After mechanical recovery of the ODS, the PU foam material can follow several recovery routes. If the foam is pure enough it can be recycled into e.g. pressboards, light weight insulating mortar or re-used as oil-binder. If the foam cannot be mechanically recycled it can be incinerated for energy recovery (e.g. in MSW, cement kilns, etc) or used in feedstock recycling technologies such as gasification or in blast furnaces together with other organic rich fractions.

3.4   **Maximising Prevention of Emissions**

As already hinted at in the previous section, one of the most environmentally sound proposals, at least in the short-term, would be to leave all decommissioned refrigerators and freezers 'untouched' at the end of their design life, either by submitting them all for re-use or by storing them long-term in their operational state (having de-gassed them for refrigerant first). The Figure 3-11 illustrates the baseline of emissions that could be expected from this course of action taking into consideration the three major developed country markets of North America, Europe and Japan.

CFC-11 Emissions - Appliances 'Leave Alone' option
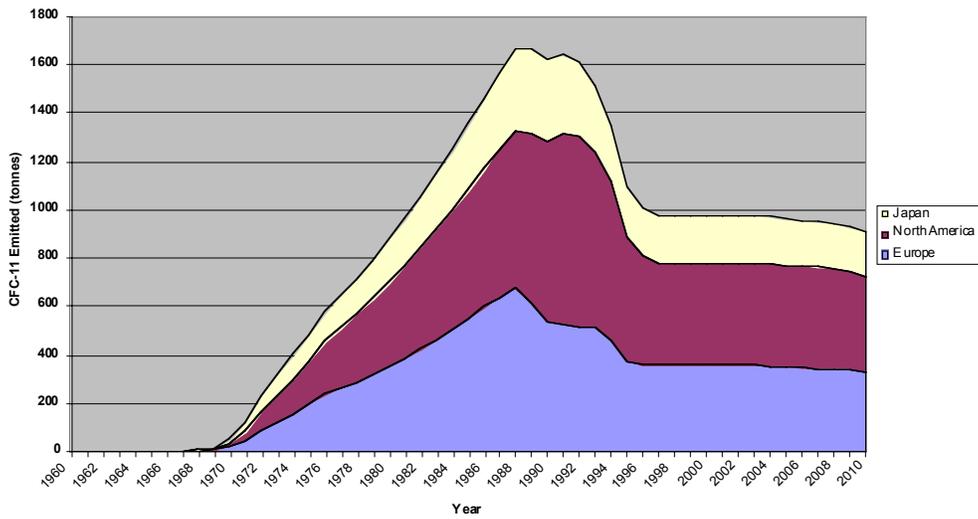
Figure 3-11: On-going emissions from 'leave alone' option

It can be seen that emissions of CFC-11 would be maintained below 1,000 tonnes per annum from here on, but that the rate of decrease of emissions would be slow and no ultimate reduction in emissions would result. This is in contrast with other measures that might slightly accelerate releases in the short-term, but reduce them in the medium to long-term. 100% mechanical recovery is a case in point, as shown in *Figure 3-12*.

CFC-11 Emissions - Appliances (100% Mechanical Recovery)
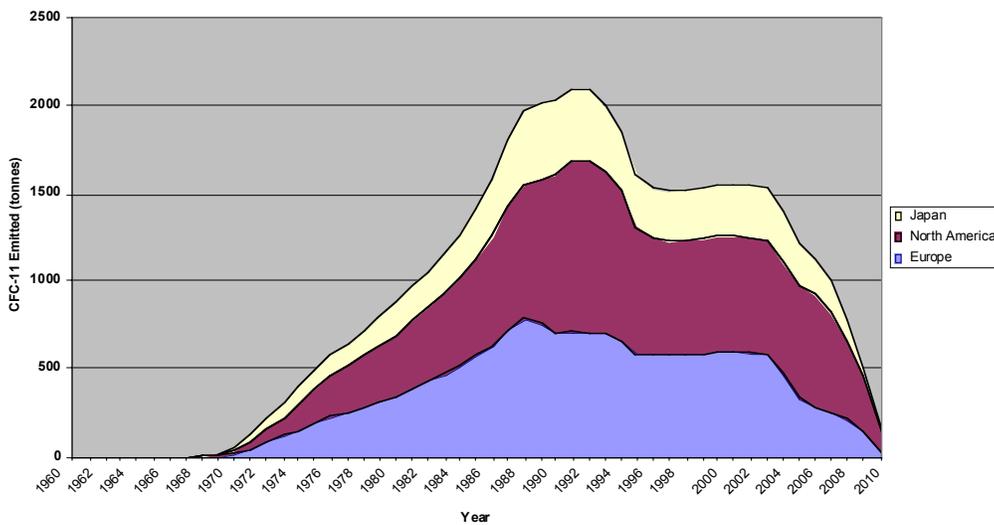
Figure 3-12: Emissions scenario for 100% mechanical recovery option

In this case, it can be seen that the emissions for the period 2000 to 2005 are increased to around 1,500 tonnes per annum, but the benefit is shown after 2005 when CFC-11 emissions reduce to levels well below 500 tonnes per annum with the balance of the blowing agent being destroyed by incineration of the re-concentrate.

The effectiveness of landfill as an emission reduction option depends heavily on the integrity of the foam being landfilled. In the case of a refrigerator, an in-tact cabinet will act in the same way as that considered in the 'leave-alone' option. In effect, the landfill site is being used as a giant storage space for low-level releases. At its worst, landfill can lead to the accelerated release of blowing agent through either accidental but severe damage to cabinets or by deliberate crushing and/or shredding of the units in order to save space. The work of the Danish Technical University[2] in this field is important because it revealed that emissions would be accelerated substantially in shredded foams having lower particle size distribution. For the purposes of this review, any consideration of releases from landfill sources has considered that the split between the five particle ranges[4] is distributed equally. This is undoubtedly an over-simplification and pessimists suggest that the particle size range could be heavily skewed to the smaller components.

For direct incineration processes, much depends on the assumptions made for the DRE in the foam in the incineration step itself. The figure of 95% adopted as a minimum by the TFDT makes direct incineration appear less attractive than it probably is. In addition, consideration has to be given to the way in which the foam is introduced into the incineration waste stream. Some sources suggest that the disposal levels of refrigerator foam through incinerators are quite high (e.g. up to 20% of total refrigerator disposal in the United States). However, if the refrige-rators are shredded in an open environment prior to incineration, the recovery and destruction rates could be quite low. Further work is necessary to provide better information in this area but, for the moment, this review assumes that direct incineration processes involve the emission of 5-10% of available blowing agent during processing (a probable best case scenario).

Having briefly compared the options, in isolation, we now have to acknowledge that every region of the world operates a mix of these end-of-life strategies and that these strategies are, in many cases, still under development. The revised flow-chart (*Figure 3-13*)shows the Task Force's best estimate of the current split of activity (i.e. in 2001) in the three main developed country regions. There is less information from developing country sources at this time, but efforts are on-going in high population areas such as Brazil and China to develop management strategies for

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[4] <4mm, 4-8mm, 8-16mm, 16-32mm & >32mm

refrigerators recently manufactured using CFCs and likely to be disposed of within the next 20 years.

The figure shows a flowchart titled with boxes. Starting from "Initial ODS 'Footprint'" at top, flowing down through "OEM Product" and "End of design use", with branches. Labels include:

- Losses in OEM Manufacture
- Losses in use phase
- Secondary use — Europe 20%, N. America 20%, Japan 20%
- Inaccessible for collection (abandonment) — Europe 5%, N. America 5%, Japan 15%
- Landfill — Europe 60%, N. America 55%, Japan 0%
- Component recovery & recycling — Europe 10%, N. America 0%, Japan 60%
- Direct Incineration — Europe 5%, N. America 20%, Japan 5%
- Metals, Plastics, Blowing Agents; PU, Others
- Municipal Waste Incinerators, Rotary Kiln Incinerators, Others

Figure 3-13: Split of management strategies by region in 2001

Figure 3-13 reflects the situation immediately prior to the introduction of the mandatory recovery requirement in the European Union and hence the split is expected to change dramatically in the next 2-3 years. However, one of the problems in making such a rapid transition is that, for some Member States, the concept of recovery of blowing agents is quite new, while for others it has been practised for some time. No formal standards exist for recovery processes at this

time and one of the purposes of Annex 'x' is to provide guidance for new investment in mechanical recovery processes, whether in Europe or elsewhere. It may be that similar documentation could be developed for other processes in time, including direct incineration and possibly even managed landfill – particularly if the early work at the Danish Technical University on the possible amelioration of CFCs by anaerobic degradation can be characterised and promoted in more depth.

As the strategies in various regions of the world further emerge, it will be possible to predict the likely peaks in emission with more accuracy. For the moment, it is clear that the worst-case approach of 100% emissions at the end of design life is far from appropriate, even with a low level of emission minimisation measures in place. Figure 3-14 shows the estimated combined emissions from CFC-11 in appliances from the three regions studied in detail. The effects of the measures in Europe and Japan can be clearly seen in the global assessment of 'actual/projected' emissions.
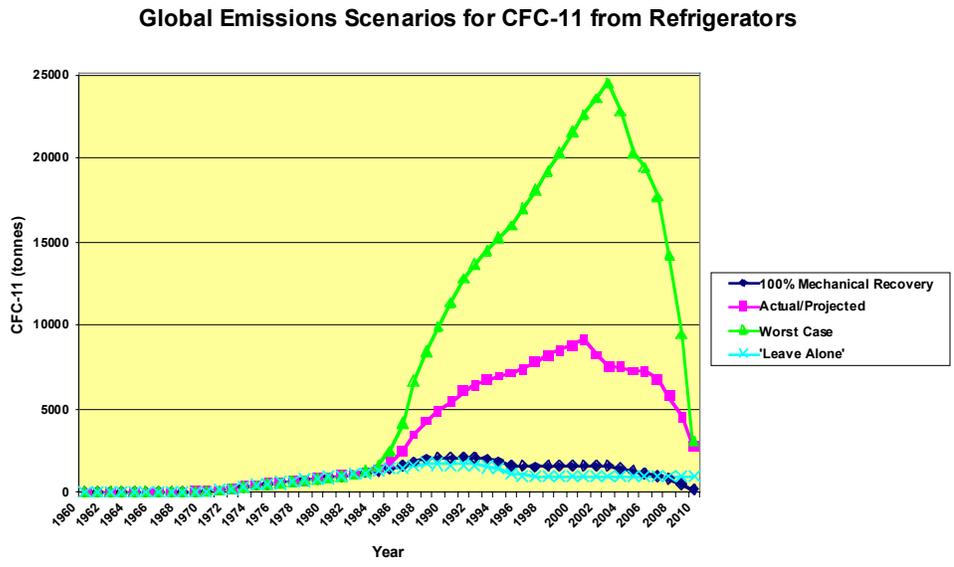
Figure 3-14: *Global emissions scenarios for CFC-11 from refrigerators*

3.5   Forecast Material Flows

The implication of introducing additional mechanical recovery and direct incineration requirements into key regional markets will be to increase the flow of both re-concentrated ODS and blowing agent containing foams to the existing incinerator stock. Although capacity considerations are considered more fully in the TFDT report, the forecast flows can clearly be depicted from the models already created. *Figure 3-15* illustrates the likely situation.

Global Recovery of CFC-11 from foam by Method
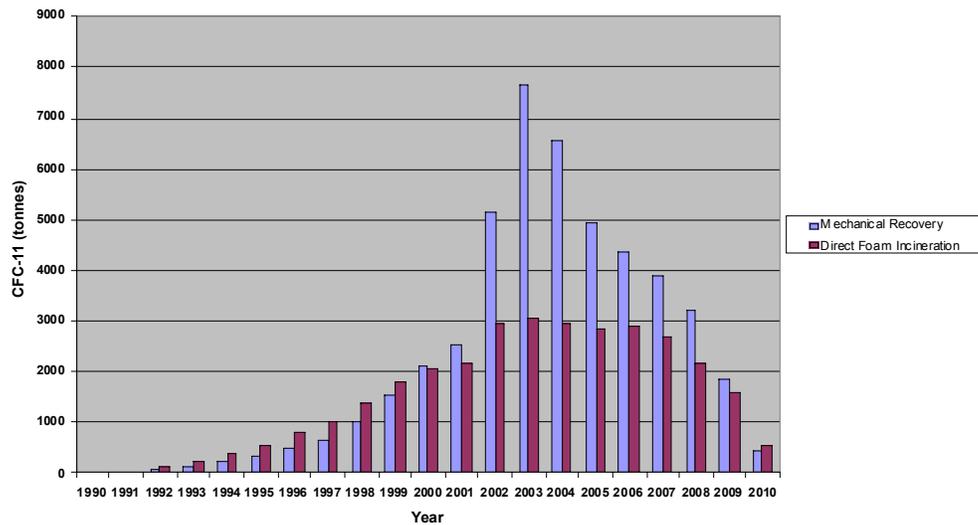
Figure 3-15: Expected global recovery of CFC-11 from foams by method

It should be noted that the bulk of this material is expected to come from the stock of domestic refrigeration units targeted by the existing legislation in both Europe and Japan. There will also be some flows from commercial refrigeration units in Europe, which are also included under Reg. 2037/2000. No significant allowance is made, however, for recovery and destruction from existing building stock. As noted previously, this is primarily on the basis of the cost and practicality of recovery. The drivers in Japan could change if wider regulations were introduced covering building insulation. However, the economic implications of such a move would need careful assessment prior to enactment.

Referring again to *Figure 3-15*, the direct foam incineration assessment may be over-stated because of the uncertainties surrounding the current practices in the United States. However, it is worth noting that 3,000 tonnes of CFC-11 would equate to ~850,000m^3 of foam processed per year. The flow of re-concentrated material from mechanical recovery alone is expected to reach 7,500-8,000 tonnes per annum at its peak in 2003. This is compared with the annual emissions for the same stock in *Figure 3-16*.

CFC-11 recaptured/destroyed through Recovery Processes
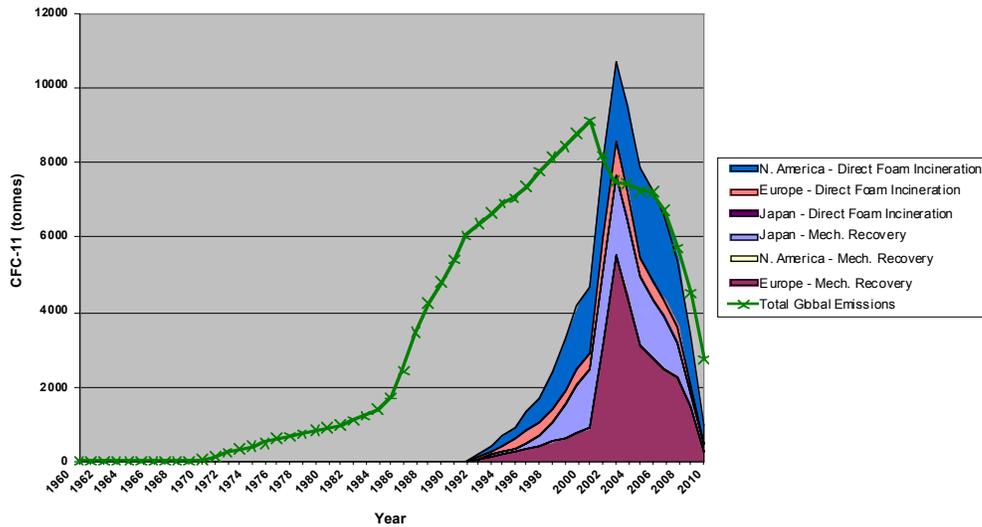
Figure 3-16: CFC-11 recaptured and/or destroyed through Recovery Processes

The absence of mechanical recovery processes in North America is striking in this graphic and there may need to be additional steps in this direction if significant further reductions in emissions are to be achieved. This presumes that techniques to better manage landfills are not forthcoming.

3.6   Conclusions

The following conclusions can be drawn from this review of blowing agent recovery options:

- Even without significant emission reduction measures, the actual and projected emissions from installed foam stock are considerably lower than assessed by assuming 100% emission at the end of design life (the worst case scenario)

- One of the best short-term options is to 'leave well alone' but this is recognised as impractical under normal waste management strategies

- Re-use of refrigerators has some advantages in terms of short-term emission reduction but this can transport the final disposal problem to areas of the world less equipped to manage it.

- Processes to recover foams must be engineered to a stringent minimum standard in order to avoid accelerating short-term releases. Open processes for the shredding and crushing of foams must be avoided.

- There is a need to better understand the current methods of disposal being practised in North America.

- Both direct incineration of foam granulate and full mechanical recovery processes are well proven. Incineration is capable of extremely high ODS destruction efficiency. Direct incineration of full refrigerator cabinets is commercially practised but there are current shortfalls in the capacities and numbers of Municipal Solid Waste Incinerators to handle significant numbers of refrigerators routinely.

- Once blowing agent extracted from foams is re-concentrated, it can be safely stored in order to overcome any short-term restrictions in destruction capacity.

- The technical and economic practicality of recovering blowing agents from foams other than those contained in appliances is yet to be fully established.

It would seem useful to revisit this issue periodically in order to review the effects of these and further strategy developments. Although a reduction of less than 5,000 tonnes in annual emissions of CFC-11 might seem modest against a 50,000 tonne baseline, it represents a saving in CO_2 equivalent emissions of in excess of 8-10 Mtons annually at a cost of $25-35 per tonne of CO_2. This is clearly well within the range of investments being made elsewhere to mitigate climate change.

4   Halons

4.1   Introduction

Halons are used nearly exclusively in fire protection, only minor amounts are used as refrigerants. Halons are halogenated hydrocarbons, first introduced into commercial use during the 1960s, which exhibit exceptional effectiveness in fire extinguishing and explosion prevention and suppression. They are clean, electrically non-conductive, and leave no residue. Halon 1301 has proven safe for human exposure at concentrations sufficient for fire extinguishing. This unrivalled combination of desirable properties led to the selection of these agents for many fire protection applications. Halon 1211, a vaporising liquid at room temperature, has been widely used in portable fire extinguishers, and to a lesser extent in fixed extinguishing systems for unoccupied areas. Halon 1301, a gas at room temperature, has seen widespread use in fixed systems throughout the industrial, commercial, marine, defence and aviation industries. Halon 2402, a low-boiling liquid, has primarily been used in the defence, industrial, marine, and aviation sectors in Russia and other countries of the former Soviet Union.

As controlled substances under the Montreal protocol, the production of halons in non-Article 5(1) countries has been banned as of January 1, 1994. Production is still allowed in article 5(1) Parties. Production in these countries is declining as well. The only remaining major manufacturer, China, will halt its halon 1211 production in 2006, the 1301 production will cease in 2010 under the Chinese Sector Plan for Halon.

The experience in the management of halon varies throughout the world. The report draws on this variety and points to appropriate annexes for context.

4.2   Use Patterns and Halon Management

Fire extinguishing systems are overall emissive uses: They exhibit their desired effects through discharges in case of a fire. Released gases cannot be recovered once the systems have been activated to extinguish a fire. On the other hand it is of outmost importance, that the halon quantities in extinguishing system are maintained at their design capacity, especially in fixed installations. The success of an extinguishing attempt depends on the concentration achieved at the location of the fire. Halon based fire protection systems are still installed worldwide and are carefully maintained. They are very important, as there are still applications, where no alternatives as safely of secure as halons exist (e.g. oil and gas industry, air transport, and military applications).

The 1994 halon phaseout was made possible by the fact, that these inventories can be seen as a "halon-bank" to be drawn from. Over time this "banked" halon has migrated from applications with less critical uses to more critical uses. These changing uses frees installed halons to be recycled and reused in other applications where acceptable alternatives have yet to be developed. This is accomplished by recovery and recycle. The extent of this shift has been reported by the Halons Technical Options Committee in their 1998 Assessment Report.

Management has been achieved through codes of practice developed with the fire protection industry or by regulation to ensure the safe and environmentally sound transfer of recovered halons. Halon banking programs have been established in most countries and halon emissions from normal operation have been cut drastically (see 1998 Report of the Halons Technical Options Committee for details). Just a few cases are documented here as examples.

4.2.1   Canada:

Environment Canada published the Environmental Code of Practice on Halons in 1996, which specifies the following requirements with respect of halon management in Canada:

- No release of halons except for fire fighting
- Mandatory reporting of halon release
- No new fire protection equipment containing halons
- Mandatory halon recovery
- Certification to service fire protection equipment
- No leak testing with halons
- No halon topping up of leaking fire protection equipment
- No non-refillable containers
- Mandatory labelling of fire protection equipment
- Mandatory plan to manage and eliminate halons

4.2.2   USA

Regulation of emissions are routed in the Clean Air Act amendments of 1990 and backed by Industry Codes of Practice designed to minimise emissions. These rules have been supplemented by regulations restricted venting of halon and require certification of service technicians.

4.2.3   Australia

State/Territory legislation requires the licensing of technicians working with ODS, as well as the trade, ownership and disposal of ODS and prohibits the venting of any ODS. The legislation in most States and Territories requires that halon fire protection systems are decommissioned and the proper disposed of halon. There are special exemptions for agreed "essential uses". An independent panel of experts assesses the essential nature of halon applications. State and Territory authorities use the panel's decisions to guide the continued use of halon within their juris-dictions. The panel originally focused on industry sectors and more recently on the few remaining agreed essential uses. These include light and commercial aviation, ocean going ships (for existing vessels only) and military applications.

4.2.4   Switzerland

Starting in 1992, Switzerland stopped all imports of halons and banned all new installations with the exception of critical installation in military vehicles, aircrafts or nuclear power plants. Furthermore, testing and training was banned at the same time. Existing installations can still be recharged until the end of the year 2002.

All systems have to be serviced by qualified companies every 3 years. In addition, all systems have to be registered and owners have to report discharges, decom-missioning and eventual destruction of the ODS.

4.2.5   European Union

The European Union has been relying on regulations of their member states until 2001. A mix of government regulations and industry codes of practice have been applied in the different countries. As of 1st October 2001, a new EU-regulation requires all but critical use systems to be decommissioned before the end 2003.

4.3   Life Cycle for Halon Systems

The "halon bank" represents a very valuable asset, as such, procedures have been developed to ensure safe collection and secure storage of recovered halons. Halon fire protection equipment, both fixed, total flooding installations and handheld or mobile extinguishers have to be serviced regularly to comply with local regulations.

Installers of clean-agent fire protection systems very often act as service providers as well. As such, during decommissioning of halon fire protection systems the halon is normally recovered and re-deployed for applications where acceptable alternatives are not yet available.

The fire protection industries in many countries have developed similar approaches to a *responsible management* of the remaining halon uses. These approaches encompass education of users about the ozone depleting nature of the extinguishing as and the need to minimise emissions during the life of the fire protection system but also of the obligation to recover and recycle/safely destroy surplus halon.

In the life cycle of halon systems losses of ODS can occur at several steps (see Figure 4-1). Several countries have implemented licensing systems (based on Codes of Practice) to maintain the quality of the servicing companies and help owners of systems to obtain qualified support for their systems.
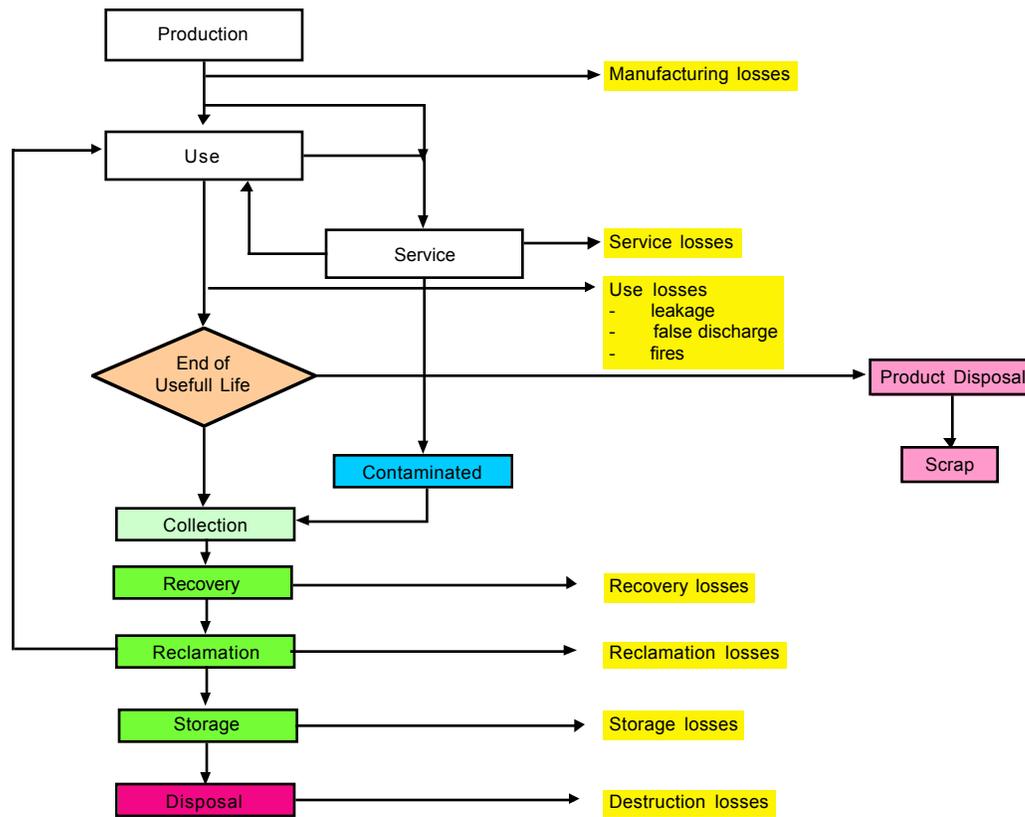
Figure 4-1: *Life cycle of halon installations*

4.4   Collection

4.4.1   *Fixed halon installations (halon 1301)*

Fixed halon extinguishing systems represent a major asset in the risk management portfolio of an enterprise. They are often well maintained and registered with servicing companies. As these companies very often act as extinguishant system manufacturers too, the collection and re-introduction of surplus halon into the use cycle is facilitated.

Halon 1301 is stored in pressurised cylinders with nitrogen added as an expellant. Pressurised cylinders can be dangerous devices if safe handling procedures are ignored. In the case of halon systems, additional facts have to be taken into account: To initiate a discharge, several systems exist for activation; including explosive actuation devices (squibs). The first step in collection of halons from fixed installations is the de-activation of the system. This should only be done by qualified service personnel, as the dangers of incidental activation of release mechanisms cannot be overestimated. Several severe incidents have been reported (see 1998 HTOC-report).

For detailed information on decommissioning of halon systems and the safe handling of cylinders see
https://www.denix.osd.mil/denix/Public/News/DLA/Halon/hal1.html

Collection of halons from decommissioned systems has been very successful over the past decade. As long as the extinguishing gas can be reclaimed and brought back into other, more critical applications it represents a value and is treated accordingly.

4.4.2   *Portable fire extinguishers(Halon 1211)*

Portable extinguishers are a widely dispersed use. They are found in factories and office spaces, on board ships and aircraft but there is also a widespread domestic use. Depending on country specific regulations the cylinders have to inspected and tested for pressure-security on regular intervals. However, the connection between manufacturer and users may be much looser than in the case of fixed extinguishing systems.

Collection of handheld extinguishers has proven to be rather difficult. Whereas large organisations or companies have developed fairly successful internal programs for collecting extinguishers either for use on critical facilities or for subsequent destruction, such programs involving the general public have been much less successful. In the USA for example, a program driven by an NGO (Friends of the Earth) has yielded disappointing results. Australia on the other side has been fairly successful with its collection program in the early 90s. It appears to be of crucial importance to establish adequate collection and storage programs and to provide adequate funding at the same time (see also TEAP Report 2001, Response to Decision XII/7)

4.5 Recovery and Reclamation

Recovery and reclamation activities for halons should only be done by instructed and qualified personnel. Care has to be taken to avoid accidents and to reduce losses of ODS to the absolute minimum.

4.5.1 Halon 1301 from fixed Systems

Recovery and reclamation for halon are often done in a single step. As halon 1301 cylinders are pressurised with nitrogen this has to be separated out in the process. The pressure can be relieved before decanting takes place, or as part of the decanting process depending on the recovery process used. The gas mixtures have to be cooled down to allow the halon to condense fully. Then the nitrogen can be blown off and the pressure is reduced. The remaining halon gas can now be cleaned by putting it through several filters that remove water, oil and other impurities. Cross contamination can be removed by secondary distillation. The resulting gas is now, depending on the thoroughness of the process, brought back to the required specifications. It is then stored under low pressure in large containers.

4.5.2 Halon 1211 from portable extinguishers

Halon 1211 extinguishers may contain nitrogen as a pressurising agent, although this is not always the case as the vapour pressure is such as to allow operation without external overpressure. It can be decanted using standardised equipment and is subsequently stored in containers.

4.6 Storage

Halon is a gas at ambient temperature. For efficient storage it is condensed to a liquid phase (approx. 42 bar). It should be pure with no overpressure gasses present. Total flooding system containers are not suitable for long-term storage because they contain nitrogen (or another overpressure gas) which need not be stored. Valves are prone to leakage and accidental breaks may produce severe damage to people and installations.

Long term storage requires emission controls. Control measures include routine weighing to verify the weight balance of the container; leak monitoring using halon sensors, fixed ground level sensors, liquid level detection. All these methods should include regular visual inspections to monitor the physical condition of the containers. Equipment and empty containers must be available to transfer product from any leaking container

Accurate inventory controls are essential to ensure the integrity of the monitoring regime.

4.7   Halon Inventories

For the past several years the HTOC has used a computer program to estimate the size of the halon "bank" and the annual transfer of halon from less critical to more critical applications. The computer program uses historic production data and estimated recovery and emission factors for halons. It is based on a steady state flow of halon fire protection equipment reaching the end of its useful life, when the halon is then recovered, recycled and reused for more critical and essential uses.

In the following table, estimated cumulative production, emissions and remaining inventories for halon 1301 are compiled for 5 regions of the world.

There is evidence that supplies of halon have been set aside and not declared by industry and users. As time passes these stocks are drawn down for use. This undeclared use tends to mask the actual usage of halon.

Table 4-1: *Global Halon 1301 inventory (in actual tonnes)*

	Europe Australia	Japan	North America	CEIT	Art 5(1)	Total
Cumulative Production	30'661	20'444	51'102	8'199	35'259	145'665
Cumulative Emissions	21'071	10'152	35'861	5'312	27'817	100'213
Actual Inventory	9'590	10'289	15'241	2'887	7'442	45'449

However, two events have recently taken place that have drastically changed this pattern. Firstly, the US Military established its own halon bank and has built a reserve adequate for the expected life of critical equipment. This decision has resulted in a much larger than expected flow of halon from existing installations into a single bank. Secondly, the newly adopted EC-regulation that mandates the decommissioning of all but critical halon system before the end of 2003 has resulted in a collapse of the market for recovered and recycled halons in Europe.

Taking these limitations into consideration, the HTOC plans to redesign the model and hopes to present new future projections of the halon inventory in its 2002 assessment report. However, the data for 2000 appear still to be valid.

Table 4-2: *Global Halon 1211 inventory (in actual tonnes)*

	Europe Australia	Japan	North America	CEIT	Art 5(1)	Total
Cumulative Production	68'969	9'853	59'117	10'893	137'305	286'137
Cumulative Emissions	44'095	5'731	37796	8'752	80'118	176'492
Actual Inventory	24'874	4'121	21321	2'141	57'187	109'644

The total inventory of installed and stored halon in the world was estimated at roughly 780'000 ODP tonnes. The ODP of halon 1301 is 10 and for halon 1211 is 3.

As explained earlier, the regulations in the European Union require early decommissioning of halon systems and the destruction of surplus halons. This policy will certainly lead to a reduction of the inventory in Europe.

As of now, there is no quantitative information available on the effect of the implementation of the measure.

5   Aerosols and MDIs

5.1   Non MDI Aerosols

Limited quantities of CFC containing aerosols are still produced in Article 5(1) parties; these aerosols are usually either industrial specialities or non-MDI pharmaceutical products. Like all aerosols these are totally emissive products and therefore of little relevance to the TFCSR.

5.2   MDIs: Introductory notes

A unique situation exists with MDIs, which require Pharmaceutical-grade CFCs, which are produced under Good Manufacturing Practices with sufficient purity so that they are acceptable to health regulatory authorities for use in human inhalation products. These regulations vary between countries. At the present time, four CFC production facilities all situated in the European Union, produce and supply CFC-11 and CFC-12 to pharmaceutical firms that manufacture CFC MDIs. Another unit in the USA produces CFC-114, but does not produce CFC-11 or CFC-12. These facilities also export to Article 5(1) countries to meet their basic domestic needs including pharmaceutical use. Some facilities located in Article 5(1) countries also produce pharmaceutical-grade CFCs which are used in these countries.

The largest manufacturer of pharmaceutical-grade CFCs announced the closure of its factory in Netherlands by 2005. This factory is currently the only supplier of pharmaceutical grade CFC-11and CFC-12 to the U.S. It is highly unlikely that the U.S. will have finished its transition out of CFC MDIs by 2005. Theoretically the U.S. can follow three different approaches, none of which are exclusive of the others, to avoid running out of medication for its asthma and COPD patients:

*   Seek alternate suppliers that meet FDA standards for pharmaceutical grade CFCs, as there are others in producers in Europe and in Article 5(1) Parties.
*   Seek FDA approval for the finished products (MDIs) and import them.
*   Seek to set up enough storage of pharmaceutical- grade CFCs either in the USA or at the EU or a combination of both.

5.3   Supply of pharmaceutical- grade CFCs

Currently, production of pharmaceutical-grade CFCs occurs on a campaign basis (meaning that a CFC production plant operates during a defined time period to produce a specific quantity of pharmaceutical-grade CFCs for future use, after which the facility is switched over to produce another product(s) or shut-down until further production of the desired CFCs is required).

If there were an unexpected failure, delay or quality problem in any of these factories (particularly in the largest facility) there could be supply problems. As a protection against unexpected events MDI manufacturers around the world currently keep CFC reserves, sometimes this represents up to one year of production needs .

One particular concern at the beginning of the reformulation process was the possibility that there could be a few drugs that could prove impossible to reformulate as non-CFC MDIs, and therefore require CFCs for a few years while alternative medications were developed and approved. It will be important to see whether those countries, which are more advanced in the transition, face unexpected difficulties in reformulating all their MDIs. If this is not the case, then the concern for a long-term storage (more than three or four years) is considerably reduced.

5.4   Storage requirements

If some storage were needed to assure supply of pharmaceutical-grade CFCs in the U.S., its size will depend on the cumulative requirements expected beyond 2005. Predicting the actual consumption of pharmaceutical CFCs after 2005 in the U.S. is difficult as it depends of approval of new drugs (including non-MDI alternatives) by FDA and their acceptance by the users. In its 2001 report TEAP recognised that*: "While the quantities of CFCs requested by non-Article 5(1) Parties for the manufacture of CFC MDIs has been reduced substantially over the past five years, it has proven to be extremely difficult to predict future requirements for CFCs."*

 However, it seems likely that by 2005 the U.S. requirements for pharmaceutical-grade CFC should be less than 1000 metric tones. It is even harder to estimate for how long CFCs will be required in the USA after 2005 and at which rate their use will decline. It is not unreasonable to assume that up to 3000 metric tones of CFCs could be the total needed to meet the cumulative USA requirements beyond 2005 to produce CFC MDIs, but there is also a risk that this figure could be too high. As USA MDI producers held an inventory of close to 2000 metric tones at the end of 2001, a storage of this size should not pose great operative problems. It is important to stress that any excess CFC will have to be destroyed and the cost of destruction may need to be borne by the MDI manufacturer that requested its production.

5.5   Recommendations

In its 2001 Report ATOC evaluated the merits of "Just-in-time supply" – defined as the supply of the quantity of CFC required by a MDI manufacturer to assure continuous production of CFC MDIs – against "Final Campaign Production". This

approach requires that at a given point in time a stock is built up to meet the total projected CFC requirements for all future production of CFC MDIs. ATOC recommended that Parties may wish to consider the following

Continue just-in-time supply for as long as possible;
Any Final Campaign Production should be done preferably as late as possible into the transition;

Should a Final Campaign be needed in the future, and recognising that this could not be implemented quickly, the Parties may wish to consider changes to the legal framework of the Montreal Protocol to facilitate Final Campaign Production.

These legal issues that would need to be resolved if the Final Campaign Production option was chosen arise from the fact that this option not only involves the Essential Use Exemption process of the Montreal Protocol, which allows multiple year requests, but also the current European Union system of granting Production Licenses. In this case, the European Union would have to allow a CFC producer to manufacture in a given year (2005) the total amount requested for several years in the future.

5.6   Experience with long term storage

Although the satisfactory storage of pharmaceutical-grade CFCs for extended periods, e.g. 3-5 years under controlled conditions appears possible, it is not clear that some product would not be lost.

Stockpiles of CFCs are currently being held by a number of pharmaceutical companies, and some of these companies have been using some stockpiled material. The material from the stockpiles for use has generally met specification and been suitable for use. However, there have been a number of exceptions to this, which longer-term storage may only exacerbate. Problems include

Odour – This is one of the most persistent storage problems for pharmaceutical CFCs, particularly for CFC-12, which can develop a strong odour on storage. This makes it unsuitable for use in MDIs. There have been instances where substantial quantities of CFC 12 have 'gone off' in this way. It is sometimes possible to remove such odour by 'polishing' it out with adsorbents, but the approach is not reliable, and material 'reworked' in this way may not be acceptable in countries with exacting pharmaceutical standards.

Related impurities – CFCs are chemically stable, and are unlikely to undergo significant chemical change on storage. In recent years, analytical methods

(Gas Chromatography) have been developed to a very high level and are currently 'state of the art'. There have been previous instances of CFC stockpiles effectively becoming out of specification on impurity content during storage. This has been attributed to the improvements in analytical techniques over the duration of the storage period and not to any change in the material.

5.7   Disposal of unused MDIs

In the specific case of pharmaceutical aerosols, some MDI units may not be consumed prior to their expiration dates. It is common practice that such expired products will be collected and recovered by pharmaceutical companies. Technically it is possible to recover the propellants contained in these MDIs, but if CFCs produced under the Essential Use Allowances were used to manufacture these MDIs they cannot be recycled, but must be destroyed

6   Solvents

6.1   Introduction

Generally, most OD solvents are eventually emitted in both Article 5(1) and other countries. A small quantity is destroyed, either deliberately or concomitantly with the destruction of other products.

In some cases, the solvent can be recycled a number of times, but there is always an overall loss of anything from 5 per cent up to 50 per cent at each recycling stage. There are 16 identified solvents sub-sectors and the possibilities of recovery and recycling are different in each one. Furthermore, the economies of scale are very important. The biggest problem is with the Small and Medium User (SMU), where recovery and recycling are frequently almost impossible and certainly uneconomical.

The recovery of solvents is often very costly. It therefore requires something more than economic incentives to "sell" the idea. There have been a few "carrots" and some "sticks" used to do this. These may be subsidies, larger allocations, free recycling or sanctions against users who do not comply. This is often poorly received by industry as all the methods involve some degree of bureaucracy. It requires both incentives and sanctions to apply successful measures but because each sub-sector uses the solvents in different ways, there can be no general rule applicable to all. It therefore requires human skills to show each kind of user how he can best co-operate.

6.2   The Recovery and Collection of Used Solvents

Very large users (say, more than 25 tonnes of recoverable solvents per year) will probably have in-house collection and recycling and consequently have their own means and methods. Smaller users (say, down to about 5 tonnes per year of carbon tetrachloride or 1,1,1-trichloroethane or 1 tonne per year of CFC-113) will generally collect the used solvent in 200 litre drums for transport to an external recycler. Some recyclers insist on minimal quantities per batch, which may vary from one to four drums, so this should be considered. Drums used for storing solvents prior to recycling should be in good condition and stored in cool conditions where an accidental leak or spill can be contained.

It is of prime importance to have separate drums for each type and blend of used solvent. *Any mixture of used solvents cannot be economically recycled and must be destroyed.*

6.3   **The Destruction of Used Solvents**

Small quantities of pure solvents or solvent blends are not destroyed: it is much more usual to recycle them.

Solvents contaminated with, for example, radioactive waste or severely toxic and persistent chemicals are destroyed according to the nature of the contaminant, rather than that of the solvent.

Most often, it is products contaminated with solvents that are destroyed. For example, after recycling (distillation) or use in a vapour-phase cleaning machine, the "bottoms" (the residue left at the bottom of the still or the machine) consists of, e.g., oil, grease, wax or resins, often mixed with solids, such as earth or sand. If it is a clean, light oil from a degreasing operation, the quantity of residual solvent may be very small, less than two per cent. On the other hand, heavy greases, waxes and resins may need as much as 50 per cent solvents content to keep the bottoms liquid enough to handle.

These bottoms are mostly combustible, sometimes flammable, and are often added to fuel oil used for calcining cement, up to one or two percent. There are two problems with such destruction: the generation of toxic and corrosive gases from the pyrolysis of the solvent and any heavy metal content, frequently found in still bottoms. This implies that the kiln flue must be fitted with electrostatic precipitators and scrubbers to capture the noxious compounds, so that they may be treated as hazardous waste. To burn still bottoms without these precautions may be dangerous.

Unfortunately, it is much more usual to put the still bottoms into old oil drums and landfill them. Within a short time, the steel will rust and perforate or the drum will be crushed by the weight of vehicles and the contents will escape. The volatile solvents will eventually percolate to the surface, where they will be emitted.

6.4   **The Recycling of Used Solvents**

As a rule, used solvents can be recycled by distillation. This requires expert knowledge because recycled solvents may not be as pure as virgin ones and may therefore be more limited for critical applications. Good recyclers always analyse each distilled batch to ensure that it meets minimal specifications for a given application. The analysis should include composition, residual volatile and non-volatile impurities, stabiliser content etc. The recycled solvent can then be categorised as suitable for given applications. For example, poor quality recycled solvents will be useful for gross cleaning of, say, engine blocks from earth-moving machinery, whereas the best quality can be reserved for more critical applications.

Some critical applications may require only extra-pure virgin solvents, e.g., laboratory analyses.

A distinction should be made between azeotropic and zeotropic blends during recovery.

6.4.1 Azeotropic blends

An azeotropic blend is a mixture of solvents whose vapour phase has the same composition as the liquid phase. An example is a blend of CFC-113 with about 6.1 per cent of methanol, often used for defluxing. Theoretically, the distillate will have the same composition as the original solvent, provided there is no water present. However, such blends frequently contain small quantities of water which will reduce the methanol content of the distillate, because a secondary azeotrope of water and methanol would remain in the still bottoms: this would mean that the recycler would need to add more methanol if the distillate were to be reused for defluxing. Small quantities of stabilisers, such as nitromethane, are present in the original solvent and the quantity in the distillate may be insufficient to ensure an adequate working life, requiring replenishment.

6.4.2 Zeotropic blends

A zeotropic blend is a mixture of solvents, which fractionates during distillation. Some of the fractions may be azeotropes and others single components. One example is a mixture of 35% ethanol in CFC-113, also used for defluxing. During distillation, the first fraction is an azeotropic blend of CFC-113 with 3.9 percent ethanol and the second fraction is pure ethanol. In practice, only the first fraction is recycled because it is not economical to recover the ethanol, which is highly flammable, unless costly, special stills are used. If only the first fraction is distilled, the bottoms must be considered as flammable.

6.4.3 Purity of the distillate

Low-cost stills consist of a boiling sump and a condenser. The vapour is generated close to the heat source in the sump and bubbles rise through the liquid, where they burst on reaching the surface of the liquid. The bursting bubbles project contaminated liquid into the vapour zone and there is an exchange of solvent between this liquid and the vapour. Some of the contaminant will reach the condenser and enter in the distillate. More sophisticated stills may reduce the quantity of contaminant in the distillate, sometimes to near-zero, by the use of various reflux techniques. Some such stills can also distill and separate all the fractions of zeotropes. The purity of the distillate is a function of the still design.

It should be noted that reflux stills are less energy-efficient (i.e., the quantity of distillate recovered per kWh of energy used is lower), potentially contributing to climate change where the primary energy source is derived from fossil fuels.

6.5   Choice of External Recycler

Some recycling companies have "high-tech" facilities with correctly equipped analytical laboratories. They also ensure that environmental and health and safety regulations are respected. Their distillates, meeting given specifications, are usually sold at prices between 75 and 95 percent of that of virgin solvents, often with minimal profit margins.

Other companies have a simple alembic, no laboratory and do not respect the regulations. The quality of their distillates is often very mediocre, with little or no stabilisation. Although they may be cheaper to buy, these solvents may be more costly to use, even for gross degreasing, because excess acids may damage the equipment or the parts being cleaned. This kind of recycler is more profitable.

A major contribution to the cost of recycling is the transport of used solvents and distillate. Some recyclers make regular collection and delivery rounds, say, once per month to each district, to minimise these costs (and the consequent emission of greenhouse gases).

It is recommended that solvents users choose carefully their recycler, where a choice is possible, preferably with a visit to the facility, to ensure that the quality of the recycled solvent meets their requirements and that the price of the recycled solvent is proportional to the quality.

6.6   Major Sub-sectors

6.6.1   Electronics defluxing

This is usually done either by vapour-phase cleaning with CFC-113 or cold cleaning with 1,1,1-trichloroethane, though there are no sharp distinctions. The major problem of recovery and recycling is that the still bottoms are essentially wood rosin, some fluxing chemicals and by-products, including toxic heavy metal salts and a large percentage of solvent to maintain the residues liquid.

Because of the complex geometry of the parts, the drag-out of solvent or its vapour in the workshop may be considerable. Active carbon filters in the exhaust ventilation system may theoretically recover this, but it is not economically viable unless the emissions are several tens of tonnes of single solvents per year.

Cold cleaning produces larger quantities of solvent for recycling because the process does not incorporate inbuilt purification, as does vapour-phase cleaning.

6.6.2   Precision cleaning

By definition, much precision cleaning cannot be done with recycled solvents. However, the used solvents are usually of excellent quality for recycling. This paradox can often be overcome by using recycled solvent for the earlier, less critical processes in the production line, reserving the virgin solvent for the final stages.

There is one application within this sub-sector that requires special mention: the grinding and polishing of optical components. This process uses a heavy wax to hold the components onto the jigs and 1,1,1-trichloroethane is often used for both removing the wax and any residues from the diamond pastes and slurries. Recycled solvents are good for the dewaxing and cleaning, but may leave "drying spots" or other residues. This may be overcome by having a second, small, vapour degreaser with virgin solvent by the main machine, with a transfer of the parts from the main machine to just the vapour zone of the second machine to ensure spot-free optics.

6.6.3   Metal cleaning

It is usually possible to use recycled solvents for all forms of metal cleaning, whether vapour phase or cold cleaning. The general remarks otherwise applicable to defluxing are also applicable to this sub-sector.

Some metal cleaning is done by hand-wiping. It is unlikely that there will be any significant recovery possible, although recycled solvents are usable for this, in most cases.

6.6.4   Dry cleaning

Dry cleaning may use well-recycled carbon tetrachloride, CFC-113 or 1,1,1-trichlo-roethane. Some additives specific to this sub-sector may be needed. The still bottoms from the machines would be insufficient in volume to justify recovery from small enterprises, unless the solvents recyclers specifically collected them on a routine round and "averaged" them with similar small amounts from a plurality of shops.

6.6.5   Adhesives and coatings

These applications are usually totally emissive and the users do not purchase the solvents as such. Whether the product manufacturers can use recycled solvents or not can only be judged by themselves. Very large users may use extraction systems with active carbon filters to reduce emissions. The filters would require regeneration with superheated steam either *in situ* or at a plant of a specialist third party,

depending on the type of installation. However, the condensate from this regene-ration could be recycled only if all the products used in the plant were composed with the same solvent. Otherwise, they would need to be destroyed.

6.6.6   Oxygen systems and heat exchangers

This is a specialist form of metal cleaning, where the solvent is pumped along metal tubing, which is then dried with hot air or gas. Oxygen systems need to be cleaned of any trace of organic products to eliminate the risk of explosion. Only virgin solvents are admissible for the final rinse, although recycled solvents may be usable, subject to specifications for the first clean. The solvent can be recovered for recycling for other applications. This is a lossy operation and emissions are great. For heat exchangers, the operation is similar although less critical but care must be taken for compatibility if recycled solvents are used for aluminium or light alloy exchangers.

6.6.7   Aerosol spraying of solvents

This is usually a totally emissive sub-sector with no possibility for recovery or recycling. Because the can fillers cannot judge what their products will be used for, their professional ethics would dictate their using only virgin solvents.

7   Methyl Bromide

7.1   General scope of use

Methyl bromide is used as a fumigant against a wide spectrum of pests, including pathogens (fungi, bacteria and soil-borne viruses), insects, mites, nematodes and rodents. These pests may be in soil, in durable or perishable commodities or in structures and transportation vehicles.

It has features that make it a versatile and convenient material for several specia-lised applications. As a fumigant, it is quite penetrative, thus reaching pests in soil, commodities and structures often at a considerable distance from the application point and inaccessible to many other control measures (e.g. contact insecticides, fungicides and nematicides of low volatility). Also, it is active against most pests at low concentrations, though there is a broad range of susceptibility. Exposures for commodity and space treatments typically range from an hour up to 2 days with concentrations ranging from 10 to 150 g m^{-3} and, for soils, some days with application rates of 20 to 100 g m^{-2}. Exposure periods and concentrations used typically are varied within these ranges depending on system under treatment, target pest, and quarantine, contractual and other specifications and regulations. Further details of its scope of application and reasons for preferred use can be found in the MBTOC Assessment Reports.

7.2   Supply and storage of methyl bromide

Methyl bromide has a boiling point of 4°C. It is normally supplied and transported as a liquid in pressurised steel cylinders or cans. Typically the cylinders used range in size from 10 kg to 200 kg capacity. There is also trade in larger cylinders of up to 18 t capacity and in small disposable steel cans, typically of 0.4 - 1 kg capacity. In general, use of these small cans is restricted to some Article 5(1) countries, and has been discontinued in developed countries.

Methyl bromide is usually applied directly from the cans or cylinders in which it is transported, though it may also be decanted from large cylinders from which it is then directly applied. Decanting is not permitted in some countries.

Fumigant grade methyl bromide is typically stored indefinitely in the containers in which it is normally supplied and transported. As pure methyl bromide, it is stable indefinitely, though the cylinders and cans require protection from excessive moisture in storage. Moisture can cause rusting, rendering the cans or cylinders unsafe. In severe cases this can lead to rupture or leakage of the fumigant. Impure methyl bromide containing moisture on charging the cylinders may turn brownish in

storage with formation of HBr and di-methyl ether with corrosion risk from the HBr.[5]

It is not uncommon to encounter cylinders of methyl bromide that have been held for several years close to the end of the methyl bromide supply chain. However, this is likely to be only a small fraction of the methyl bromide annual consumption. Most methyl bromide is consumed within a year or so of manufacture. At present, there is no 'bank' of unused methyl bromide, though there is potential for some stockpiling as phaseout approaches. This is constrained by lack of supply, since Protocol control measures on production and consumption limit the material now available for stockpiling.

7.3   Use processes

7.3.1   Manual application to soils

Two types of process are used for manual application to soils – direct application and the 'hot gas' process. In the 'hot gas' method, liquid MB from cylinders under pressure is vaporised in a vaporising device (heat exchanger) and then introduced under a plastic cover laid over the soil area to be treated, to retain the gas during the exposure period.

Worldwide, outside USA, this is the principal method of application and almost exclusively the only method used in fumigating soil in greenhouses (glass and plastic houses). In many countries, this method is widely used also for outdoor fumigations. In some situations, field fumigation is carried out with mulched strips (strip fumigation) of 0.80 - 1.20m wide, instead of completely sheeting the treated area.

When applied from small steel cans of less than 1 kg capacity, the methyl bromide is not normally vaporised, but discharged directly as a liquid from the can under its own pressure using a special dispenser. This can be done so as to release methyl bromide under the plastic cover without damage to the cover.

Methyl bromide may be supplied as a mixture containing 2% chloropicrin (added as a warning agent) when used for manual application.

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[5] Note: Principal risk from leakage is toxicity

7.3.2 Mechanised injection to soils

In this method, MB from cylinders is applied by injecting the fumigant to a depth of around 20 cm into the soil (shallow injection). The treated area is simultaneously covered by plastic sheeting to restrict gas loss. The process is normally carried out as a broad-acre fumigation where one sheet is glued to the previous one. However, some application is done under strips of plastic, with the edges of the strips buried by the machinery in the soil.

Another system of mechanised injection is deep placement (approx. 80 cm) of the fumigant without covering the area with plastic sheets, though the soil surface may be compacted to attempt to restrict gas loss. The deep injection of MB is carried out mainly prior to planting and replanting in deciduous orchards, vineyards and other plantations, mainly in U.S.A.

Mechanised injection is carried out with outdoor fumigation only, and is the dominant method in U.S.A. It is also used in some European countries, Israel, Australia and South Africa.

A variety of mixtures of MB and chloropicrin are increasingly used in this type of fumigation. Use of such mixtures is allows continued fumigation practice while reducing consumption of MB to meed Protocol requirements. Mixtures of up to 75% chloropicrin are in use.

7.3.3 Application to commodities, structures and transport

Methyl bromide is typically applied by the 'hot gas' process. The methyl bromide, as a liquid from the supply cylinder, is passed through a heated vaporiser (heat exchanger) which vaporises the fumigant before it is applied through suitably perforated distribution pipes, laid out in such a way as to facilitate good distribution. In best practice, the mixing of the fumigant is further assisted by forced recirculation or with a fan within the fumigation enclosure.

More rarely, methyl bromide applied directly from the cylinder through a narrow bore application line (or series of lines) culminating in an atomising jet or series of jets which are designed to enhance the speed of vaporisation of the fumigant. The rate at which the liquid fumigant becomes a vapour is largely dependent on the ambient air temperature. These lines and jets are laid out either on top of the commodity, or throughout the structure to try to ensure an even distribution of fumigant

For commodity treatments, the enclosures vary from gastight purpose built fumigation chambers (portable and fixed) to very poorly sealed bagged stacks. In between these extremes, are ship's holds (sometimes very gas tight, but not

always), freight containers (often not very gas tight), and well sealed, sheeted bagged stacks (can be very gas tight). The level of sealing has an important effect on the retention of the gas during the fumigation, as thus the proportion of the methyl bromide applied that is subsequently available for recapture.

In the case of treatment of structures, the gastightness varies from aircraft (sometimes very gastight), ship's holds, modern food factories and mills (can be very gastight) to older buildings such as many flour mills (often not very gastight and, in many cases, expensive to make more than partially gastight).

In most countries, commodity and structural treatments are carried out with 100% methyl bromide formulations, superseding the formulation that contained 2% chloropicrin as a warning agent.

7.4   Estimates of quantities of methyl bromide recoverable after use

Estimates of the proportion of the applied methyl bromide released into the atmosphere from fumigation vary widely. Part of this variation is a true variation reflecting the wide variety of soils, commodities and structures treated with methyl bromide, and part is a variation in opinion amongst experts as to the most appropriate figures to use to best reflect the average proportion emitted. Good data on the fraction of methyl bromide emitted by particular treatments is very scarce or absent.

During any fumigation operation there are three distinct opportunities for methyl bromide to be emitted to the atmosphere:

- by inadvertent leakage during the actual fumigation treatment.
- during venting of the fumigation space immediately after fumigation or removal of the cover sheets when a deliberate discharge to the atmosphere take place.
- following treatment, when the treated soil, commodity or structure slowly emits any sorbed methyl bromide.

Practically, the scope for recovery of methyl bromide after fumigations is likely to be restricted to treatments carried out in enclosures i.e. space fumigations of commodities, structures and transport. At this time no system for recovery of methyl bromide from soil fumigation has been commercialised and there appears to be no system at an advanced developmental stage. Furthermore, since the phaseout of methyl bromide for soil uses in non-Article 5(1) is imminent (2005), such systems are unlikely to be developed.

Best practice for commodities, transport and structural uses require treatments to be carried out in well sealed systems, limiting leakage and thus maximising the fraction of the methyl bromide initially applied that is theoretically available for recapture. Leakage rates from well sealed rigid enclosures are typically <10% d^{-1} and optimally <5% d^{-1}. This leakage limits the total methyl bromide available for recapture (exposures range from 2-48 hours in general for commodity and structural treatments - the exposure period being commodity and situation dependent).

The availability of methyl bromide for recapture is also limited by the reactivity of the methyl bromide with the treated commodity, associated packaging and dunnage and with the fabric of the fumigation enclosure. It is not unusual to lose most of the methyl bromide applied (>80%) from reaction in some of the more reactive commodities that may be fumigated (e.g. oilseed meals)[6].

A further constraint on recapture is the reversible sorption of methyl bromide on treated commodities. Methyl bromide is taken up by physical sorption including adsorption and dissolution in fats and also by reversible chemical bonding. This sorption reduces the free space concentration resulting from a dosage of methyl bromide. Because desorption can be slow and rate limited by diffusion, recapture of a high percentage of the methyl bromide remaining after a fumigation can be a slow process. Removal of methyl bromide down to workspace and health maximum limits in air, typically 5 ppm v/v or less, may take 3 or more days from treated grains or timber.

For 1998 usage patterns, MBTOC (1998) estimated the proportions of applied MB eventually emitted to the atmosphere to be 31 - 88%, 85 - 95%, 69 – 79% and 90 - 95% of applied dosage for soil, perishable commodities, durable commodities and structural treatments respectively. These figures, weighted for proportion of use and particular treatments, correspond to a range of 43 - 87% overall emission from agricultural and related uses, with a best estimate of overall emissions of 73%. Since 1998, the proportion of methyl bromide used in soil applications has fallen, in response to control measures under the Protocol for non-Article 5(1) countries, while both the proportion and absolute tonnage used in perishables and QPS on durables has risen.

With current control schedules and lack of systems for recapture from soil applications, the scope for recovery of methyl bromide is limited to space fumigations in Article 5 countries, and those space fumigations exempt from phaseout in non-Article 5(1) countries. MBTOC (1998, p. 308) gave a range of estimated emissions from these applications as 51-95% of applied material. This suggests a potential

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[6] Other fumigants may be more appropriate, but methyl bromide may be used from tradition or because of specification by buyers

recovery overall of around 86%, range 81-91%, applied (weighted mean of figures given for space fumigations (durables, structural and perishables) given in MBTOC (1998, Table 9.1).

The potential recoverable estimate of 86% includes methyl bromide lost by leakage during the fumigation period and all of the desorbable fumigant. In practice some leakage is inevitable and the time required for total desorption may be excessive. On the basis that 15% (10% loss from leakage, 6% residual material and other inefficiencies) of the potentially recoverable material is not recoverable in practice, it is estimated that 70% of applied material can be recovered from the space fumigations referred to above.

In 1998, total space treatments in Article 5(1) countries were estimated to be approximately 5,290 tonnes, while QPS uses in non-A5 have been estimated at about 7,998 – 11190 tonnes, giving a total of 13,288 – 16480 tonnes. On the basis of 70% recapturable methyl bromide, this corresponds to an emission of approximately 9.300 – 11.535 tonnes that could be reduced or prevented.

7.5   Collection and reclamation of methyl bromide for reuse

The use process for methyl bromide is such that collection of methyl bromide in concentrated form is unlikely to occur. Methyl bromide is intentionally discharged directly from supply containers into air and is not normally used as a concentrated fluid contained within a system. However, it is feasible, technically, to recapture methyl bromide from the dilute streams resulting after a fumigation is complete and then to reclaim the pure material.

At this time the cost of reclamation of methyl bromide for reuse is substantial compared with the cost of new material, and reclamation is in use in only a very few, specialised plants. The systems have been installed to meet local environmental standards, not for ozone-protection reasons.

Two processes have been demonstrated commercially – sorption on a zeolite, and direct condensation. Both require substantial capital investment. Additionally, it is possible to desorb and reclaim methyl bromide after recapture on activated carbon. These processes are described further in MBTOC (1998).

An issue with these processes, and any other aimed at recycling MB, is whether the recovered MB is sufficiently pure to be able to be reused as "pure MB" to comply with the specifications for fumigant use, particularly established quarantine schedules. Also it may not meet the labelling requirements of individual countries, including approval by the original manufacturer.

Some fixed fumigation installations have provision of transferring remaining methyl bromide in dilute form to another chamber, with top up with methyl bromide from concentrate (i.e. cylinders) to reach target fumigant concentrations. Scope for this type of reuse is limited principally to the few fixed facilities that conduct many fumigations in succession.

As a result of lack of supply of recycled material, it is most unlikely that the interim needs of Article 5(1) countries for MB can be met even in part by 'banks' of recycled material. At this time, trade in recycled methyl bromide is not an issue of concern, again due to the lack of recycled material.

7.6   Destruction technologies

Destruction of unused methyl bromide. Presumably technologies suited to destruction of CFCs and volatile halons are also suited to destruction of unused methyl bromide, itself correctly described as halon 1001. To the knowledge of TEAP, this has not been tested specifically. There is also potential to use unwanted methyl bromide in non-A5 countries for domestic needs of A5 or for QPS purposes in non-A5.

Destruction of methyl bromide after use. Three systems are in commercial use for destruction of methyl bromide in dilute form after fumigations are complete.

Recapture on activated charcoal followed by incineration or catalytic destruction. A process recently developed in the USA uses activated carbon to capture MB followed by thermal destruction. The intention of developers has been to provide a supply and disposal service by transporting the MB-laden carbon to a central processing site where it would be reprocessed or destroyed (Knapp *et al*. 1998, Leesch *et al*. 2000). A small commercial unit is in operation at Dallas/Fort Worth airport capturing MB from quarantine operations (McAllister and Knapp 1999) and a larger unit is now operating at a commercial berry fruit exporter's site in Watsonville, California (Knapp (2001). Both plants reduce the MB concentration in the fumigation chambers down to a level of 500 ppm before venting the remainder. Once each plant has processed sufficient MB to fully load the activated carbon beds, they are shipped to Pennsylvania to be incinerated. Preliminary data suggested that in excess of 95% of the MB being vented could be removed. After allowing for MB lost by adsorption into the commodities being fumigated, the Watsonville plant has achieved a recovery of 80% of the original dose applied.

One of the critical features of this process is the environmental impact (truck fuel, energy use) of transporting equipment containing the activated carbon beds saturated with MB over some distance to the reprocessing or destruction plant. While it may be feasible to consider this technology in the continental USA and

other areas where quarantine treatments are concentrated, it is unlikely to be cost effective in other parts of the world.

There is present research in Japan on the catalytic decomposition of MB. Promising recent results from using new Mn/Cu-zeolites indicate that satisfactory levels of destruction can be obtained at lower temperatures than previously achieved and the production of CO will be minimised. This research is still at an early stage of development.

New research from Japan has been reported in which MB that has been previously captured on activated carbon or zeolite is introduced to a reactor heated to 400 – 500 ^{o}C and decomposed with CaO to inorganic salts (Yahata, Tsuchiya and Toba (2001)). A bench scale apparatus has been described that gave MB concentration reductions of 99.99%.

Recapture on activated charcoal followed by destruction by chemical reagent. Recovery and destruction systems are now being sold based on MB capture from fumigation operations using activated carbon followed by direct destruction of the sorbed MB by treatment of the carbon with aqueous sodium thiosulphate solution (Nordiko 2001). Commercial units have been installed in the ports of Hobart and Melbourne in Australia. Some recovery/destruction units are designed to be clip-on units for fixed or container-based fumigation installations and are completely self-contained. The spent carbon can be regenerated for reuse by rinsing with water and drying with air at 40°C.

Detailed recovery data for this process has not been published but is said to be high.

Mixing with ozone. A plant using ozone to destroy methyl bromide was installed in 1996 at a fumigation facility in California, USA. The facility is used for import and export fumigation of a variety of commodities. Ozone is added to the discharge and air washes from the vacuum fumigation chambers to destroy the most of the MB present. Activated carbon is used to scrub any residual traces of MB from the discharge air stream. Results from two monitored trials indicated that in excess of 90% of MB used was destroyed.

In addition to the destruction technologies noted above, there have been several attempts to remove methyl bromide from fumigation enclosures post-treatment using reactive liquid scrubbing, usually amines such as mono-ethanolamine. These are discussed further in MBTOC (1995, 1998).

7.7 References

Knapp G. (2001) Commercial methyl bromide recapture. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, Nov. 5 – 9, 2001. Paper 116

Knapp G. F., McAllister D. L. and Leesch G. J. (1998) Methyl bromide recovery. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Orlando, Dec. 7 – 9, 1998. Paper 58.

Leesch J. G., Knapp G. F. and Mackey B. E. (2000). Methyl bromide adsorption on activated carbon to control emissions from commodity fumigations. Journal of Stored Product Research, 36, 65-74.

MBTOC (1995) 1994 Report of the Methyl Bromide Technical Options Committee. 1995 Assessment. (J. Banks, co-ordinator). UNEP, Nairobi.

MBTOC (1998) Report of the Methyl Bromide Technical Options Committee. 1998 Assessment of Alternatives to Methyl Bromide. (T. Batchelor, co-ordinator). UNEP, Nairobi.

McAllister D. L. and Knapp G. F. (1999) A commercial recapture system for methyl bromide at Dallas/Ft. Worth International Airport. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, Nov. 1 – 4, 1999. Paper 56.

Nordiko (2001) Nordiko Quarantine Systems. http://www.nordiko.com.au/

Yahata T., Tsuchiya Y. and Toba M. (2001) Development of emissions reducing method and apparatus for volatile organic halides. Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. San Diego, Nov. 5 – 9, 2001. Paper 119.

8 Transportation Regulation

8.1 Dangerous Goods Regulation

The United Nations Transportation of Dangerous Good Model Regulations were prepared as guidance for the development of national regulations. The Model Regulations regulate the classification, documentation, safety marks, means of containment, training, emergency response, and reporting requirements for safety transport and accidental release of dangerous goods. According to the Model Regulations, an ODS is classified as a dangerous good (or a commodity), Class 2.2, compressed gas, non-flammable and non-toxic material. Shipment of the material requires a shipping document, not a waste manifest.

There are three major categories of ODS,

- low pressure CFCs,
- high pressure CFCs and halons and
- toxic substances such as methyl Chloroform and Methyl Bromide).

Low pressure CFCs that are liquids at room temperature (e.g., R-11, R-113 and R-123) are not specifically controlled by the Model Regulations. Such ODS may be stored and handled in regular drums with adequate labelling as per normal commercial practices, similar to the containers and labelling procedures used when purchasing the virgin or reclaimed product. They may be transported without any specific manifesting requirements.

High pressure CFCs and halons that are compressed gases at room temperature (e.g., R-12, R-22, R-114, R-500, R-502, and halons 1211 and 1301) are considered as dangerous goods under the Model Regulations. Specifically, they are considered either Class 2.2 compressed gases (non-flammable, non-toxic) The toxic substances are classed under 2.3 for MeBr and or Class 6.1 for toxic substances.

The Model Regulations describe the specific requirements for cylinders that may be used to contain the ODS. Cylinders to be used for containing, storing, and transporting CFCs and halons that are compressed gases must meet the appropriate pressure rating. The pressure rating for most CFCs is typically 260-400 pounds per square inch (psi), and the pressure rating for R-13 is 1800 psi. R-13 is a refrigerant that is used for very low temperature in special applications.

8.2 Labelling

The safe transportation of goods requires that Dangerous Goods be identified. A standard label must be placed on each individual container and on external

packaging to indicate the contents. For class 2.2 materials the label is a green diamond shape marked with a gas cylinder graphic and the numbers 2.2.

8.3   **Shipping documents**

The Dangerous Goods transport documents should include a certification or declaration that the consignment is acceptable for transport and that the goods are properly packaged, marked and labelled. Emergency response information is also to be provided. This can be in the form of a material data sheet, notation in the transport document or contact telephone number depending on the national regulations applicable.

The International Civil Aviation Organisation and the International Maritime Organisation require specialised information sets to accompany any shipment of dangerous goods.

9   The Basel Convention

9.1   History and Basic Principles

The Basel Convention was adopted in 1989 as an international initiative to implement and control the treatment and disposal of hazardous wastes. The Convention was organised to attempt to minimise transboundary movement and the generation of hazardous wastes. As of March 2002, 150 Parties from five world regions have ratified the Convention.[7] The Parties agreed to manage the transport and disposal of specified chemicals in an environmentally sound manner, as decreed by the Convention.

There are 3 overarching principles for operating under the Basel Convention:

1.   Minimise hazardous waste generation
2.   Treat and dispose of waste in its country of origin
3.   Minimise transboundary hazardous waste shipments, but if necessary move waste to a place it can be disposed of in a manner consistent with environmentally sound management (ESM) principles.

In addition to disposing of materials in a way that is protective of the environment, the treaty requires basic safety documentation such as manifests and approvals from disposal facilities in advance of waste arriving for disposal.

9.2   Control of ODS under the Basel Convention

Under the Basel Convention, chlorofluorocarbons and halons are not contained in Annex VIII (list of hazardous wastes) and there are no technical guidelines for the environmentally sound management of wastes consisting of or containing ODS. Since ODS are not definitively controlled by the Basel Convention, the individual parties have determined independently whether certain ODS are to be considered hazardous materials. In the case of transboundary movement of ODS for reuse and recycle, the chemicals are not controlled under the Convention. However, in the case of exportation for disposal, parties located in select regions, such as Europe, have chosen to identify refrigerants and other ODS as hazardous materials and thus places them under regulation by the Convention. European controls exist under the EC Waste Shipment Regulation (Council Regulation (EEC) No 259/93) and under

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[7] The Parties include 34 countries from the region of Africa; 37 from Asia and Pacific; 28 from Western Europe and Others; 21 from Central and Eastern Europe; and 29 from Latin America and Caribbean.

the OECD Decision C(2001)107. In both texts, chlorofluorocarbons (AC 150) and halons (AC 160) are controlled as hazardous wastes. The export of these wastes from the EU to non-OECD countries is prohibited.

Future ODS destruction options under the Basel Convention could include the following steps.

a)   All wastes consisting of or containing ODS may be ecotoxic and therefore could be identified under category Y 45 of Annex I of the Basel Convention (Organohalogen compounds other than substances referred to in this Annex). Therefore all wastes consisting of or containing ODS could be listed in Annex VIII of the Basel Convention which would lead to the world-wide control of transboundary movements of these wastes. An application to this effect could be made to the Technical Working Group of the Basel Convention. Some experts have argued that gases may not be included in Annex I of the Basel Convention. However, gases are not excluded from the scope of the Basel Convention and ODS may change physical state under different pressure and temperature.

b)   Technical guidelines for the environmentally sound management of wastes consisting of or containing ODS could be developed similar to the technical guidelines for the environmentally sound management of wastes consisting of, containing, or contaminated with POPs.

c)   A working relationship between the bodies of the Montreal Protocol and the bodies of the Basel Convention could be established to provide for a meaningful division of labour in order to avoid duplication of efforts.

9.3   Actions by the Basel Secretariat to Harmonise with the Montreal Protocol

At the Technical Working Group of the Basel Convention, Nineteenth Session in Geneva, 14-15 January 2002, Item 8 of the provisional agenda took up the issue of co-operation with the Montreal Protocol. It noted that the Montreal Protocol Technology and Economics Assessment Panel formed two Task Forces; on Destruction Technologies and on Storage, Collection and Reclamation; and that the chairs of the task forces requested the secretariat of the Basel Convention, through the Ozone secretariat, nominate an expert to serve on each of the two Task Forces. The Technical Working Group reported in its report that "Currently, in co-operation with the Chairman of the Technical Working Group, the secretariat is consulting with a number of Parties regarding the nomination of two experts to assist in each of the Task Forces set up by the TEAP". The Basel report goes on to say:

"Preliminary consultations undertaken by the secretariat with Parties provides for the following views:

(a) Annex VIII to the Basel Convention does not include halons because there is no consensus that halons in general possess Basel Convention hazardous characteristics. Annex IX to the Basel Convention does not include halons because there is no consensus that halons in general are not Basel wastes. At a practical level, the transfrontier movement and disposal of waste halons is adequately covered by the Montreal Protocol and there is no need to duplicate the Montreal Protocol provisions with the Basel Convention provisions. Therefore, it is not appropriate to develop guidelines on halons in the context of the Basel Convention. However, it should be stated that the Basel Convention has prepared technical guidelines on non-hazardous wastes, such as tyres when Parties found such guidelines to be helpful.

(b) The development of guidelines on halons would be appropriate and useful. However, this should only be done if Gases are added to Annexes I and III of the Basel Convention. Halons would not be considered hazardous wastes."

The report also provides for the following actions.

"The Technical Working Group may wish to:

(a) Take note of the ongoing cooperation with the Montreal Protocol on substances that deplete the ozone layer;
(b) Provide any guidance to the secretariat on the development of cooperation with the Montreal Protocol;
(c) Also provide any guidance to the secretariat in regard to its response to the Ozone secretariat concerning the appropriateness and usefulness of considering the development of technical guidelines on halons."

APPENDIX A: Standards for the Reclamation of Blowing Agents from Refrigerator Foams

Purpose and Scope

In providing this Annex, the Task Force is not seeking to endorse the mechanical recovery approach over that of direct incineration or other disposal technique. Its prime purpose is, in recognition of the fact that mechanical recovery is by far the most common method in use for the recovery of blowing agent at this time, to set out issues which should be considered in seeking to set standards which can be considered as 'environmentally acceptable' and, as far as possible, encourage the adoption of best practice in this important and growing field.

In addition, it is recognised that many technologies are still under development and/or refinement, making the application of best practice guidelines premature in some cases. This is particularly the case in Japan, where the recovery of blowing agents is voluntary and plants are still constructed primarily to maximise material recycling levels. In such cases, the adoption of the more rigorous elements of these guidelines, particularly as they relate to the on-going verification of performance, is not likely to take place in the immediate future.

Many such mechanical recovery plants combine the extraction and recovery of refrigerant with that of the collection and recovery of blowing agent. This Annex only relates to the blowing agent segment of performance. However, it should be noted that several of the existing standards referred to in this text cover both elements of recovery.

The Basic Process

Although mechanical recovery equipment can vary substantially in its detailed design, the basic principles tend to be common. The following flow-chart of a Japanese plant is fairly typical:
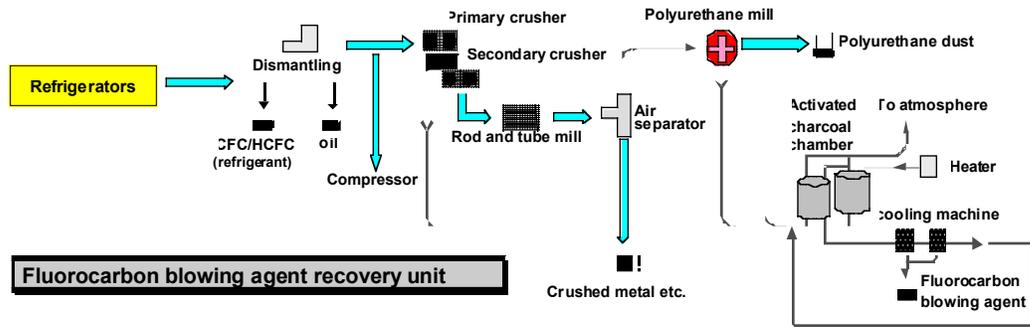
Figure 1: *Typical Mechanical Recovery Plant*

Potential Sources of Emission

Mindful that fugitive emissions from the equipment itself can be the largest single source of losses, the other key area of blowing agent loss are:

- In foams remaining attached to metallic materials following the shredding process
- In foams remaining attached to plastic materials following the shredding process
- In air exhausted from the plant after passage through an appropriate absorber
- In waste water outputs from the equipment
- As residual blowing agent in the polyurethane matrix emerging from the process.

Before dealing with the management of fugitive emissions, this annex will deal with each of these identified sources of emission in turn.

Foams remaining attached to Metallic Materials

The process of shredding the refrigerator 'box' can vary substantially from one equipment design to the other. However, the general forces involved and the relatively low compressive strength of the foam insulation are usually sufficient to ensure that the major bulk of the foam is removed from the metal surfaces. A few existing draft standards make reference to this area of loss (see Table 1) but only TA Luft and the draft DIN standard put a value to a maximum permissible loss which is expressed as a percentage of the total weight of metal. In these respective cases, 0.5% and 1% are noted as the proposed maxima.

At first sight, because of the substantially different specific densities a quantity of foam expressed as a percentage of metal by weight seems excessive. However, as seen in the summary of losses later in this Annex (Figure 2), the fact that we are

dealing with a total foam metric rather than a blowing agent metric leads to lower blowing agent losses by this route than would otherwise have been anticipated. Nevertheless, opportunities to reduce it should be taken since Figure 2 indicates that the current contribution from this source, based on a 0.5% limit, can be as much as one third of the total.

The method of measuring the percentage loss is assumed to be by simple weight loss measurements following solvent extraction or high temperature treatment. However, there are no specific methods of test yet identified.

Foams remaining attached to Plastic Materials

The inner liners of most domestic refrigerators have been designed from plastic materials for many years. Typical choices include ABS and high impact polystyrene (HIPS). During the shredding process, most plants separate out ferrous and non-ferrous metal from the shredded outputs leaving the plastic materials remaining. However, this stream tends to be less pure than others since it often contains synthetic rubber items such as door trims etc.

For these reasons, it initially seems less valuable to try to set a limit on foam outputs in this stream, particularly since there is no obvious method of identifying the attached foam other than by physical removal by hand and subsequent weighing. However, this is the method proposed and currently practised in Germany, allowing the setting of maximum permissible percentage losses in the draft TA Luft standard of 0.5%.

Blowing Agents in Air Exhaust Flows

Although designs may vary, most currently commercial units use re-generable carbon absorption units to extract the blowing agents from the air stream. Most suppliers guarantee a maximum concentration in the airflow on the outlet side of the carbon absorber. A typical value for such a guarantee is 50mg/m^3 and it is noted that most of the references in existing and draft European standards refer to concentrations (see table 1), often driven by local air quality regulations rather than by wider Montreal Protocol considerations.

It is the view of the Task Force that this source of loss should always be considered in mass balance terms because of the likely variations in air flow rate from plant to plant. Accordingly, reference to blowing agent loss per hour or blowing agent loss per unit processed is essential. Of course, the two are linked by the number of units processed per hour and, in reality, it will always be possible to deduce the key parameter of losses per unit. Currently, most standards and draft standards in Europe define this parameter in terms of blowing agent lost in grams per hour. The range of allowable losses is substantial from 0.5g/hour in the case of

the LAGA guidelines to 75g/hour in the case of the draft DIN standard. However, most proposals lie below 10g/hour. Figure 2 illustrates the significance of losses in comparison with other sources arising from the adoption of a 5g/hour limit based on a throughput of 60 units/hour. It shows that the losses under these assumptions represent less than 1% of the total losses of typical mechanical recovery. Accordingly, the guideline of 5g/hour may be considered to be unnecessarily stringent by some.

Of more specific importance is the design of the adsorption system. In a re-generable carbon system, it is normal for one bed to be in adsorption mode while the other is in desorption mode. Once a carbon bed is saturated, there is a risk of 'breakthrough', where considerably higher concentrations of blowing agent reach the outlet stream. When this happens, it is essential to have an alternative pathway for the air to flow. This can be done by building into the system a re-circulating loop but is more typically achieved by having a third carbon adsorption bed available for such emergencies. The value of this approach is that the productivity of the process is not interrupted. One of the vital aspects of any such design is that there is an appropriate alarm to indicate immediately when 'breakthrough' has occurred.

Blowing Agents in Waste Water Outputs

The immediate question arising under this heading is 'what sources of water exist in the process?'. Experience shows that levels of water of around 1litre per unit are typically recovered from refrigerators put through a mechanical recovery plant. The source of this water is often from the storage conditions of the unit prior to processing but some water may also be present in the foam and in other parts of the equipment. In some processes, the bulk of the wastewater is taken out at the air separation stage and water remaining in the polyurethane matrix at this stage is captured later in the blowing agent catchment vessel. It is assumed that any destruction technology used for the blowing agent itself will then deal with the contaminated water.

As for the water extracted at the air separation stage, it is found in the case of CFC-11 that the immiscibility of the two components is such that they can be easily separated and that the remaining CFC-11 in the water phase is less than 100 g/litre. Of course, such low solubilities cannot be assumed for all blowing agents and care should be taken to ensure that all wastewater handled at the air separation stage is regularly tested for content after any separation processes have been completed.

One factor which may influence this overview is the method by which desorption of carbon beds is achieved. Some methods are reported to use steam to flush through the carbon adsorbers and, in this case, wastewater management will need to be carefully considered to avoid significant further losses through this route.

No standard or draft standard so far considered has included any formal limitation on blowing agent losses in water. However, it is the view of the Task Force that the absence of such a provision violates the integrity of a mass balance approach and needs to be included. As in the case of airflow, it is proposed that such a maximum permissible loss should be expressed in either grams per hour or grams per unit. However, it seems rational to set a guideline in line with the likely performance of a typical plant in order to avoid the permission of unnecessary losses. At this stage, 1g/hour seems a rational starting point.

Residual blowing agent in the Polyurethane matrix

Most mechanical recovery plants focus on the importance of extracting as much blowing agent from the polyurethane matrix as possible. Figure 2 illustrates that this focus is well founded, as blowing agent retention in the polyurethane matrix continues to be the most concentrated area of loss. The challenge of extracting blowing agent is complicated in polyurethane matrices by the fact that blowing agents are often soluble in the matrix. This means that grinding and other processes need to be applied to accelerate the release of blowing agent and this is common practice by various methods.

Current standards and draft standards focus on a maximum residual weight of blowing agent remaining in the matrix after extraction - usually as a percentage. The current maximum permitted range is from 0.1% to 0.5%. It is the considered view of the Task Force that the sensitivity of the overall recovery performance to this parameter is such that a limit of 0.5% is probably too great bearing in mind the state of technology as it current exists. A guideline of 0.2% is therefore believed to be a more appropriate figure (as reflected in Figure 2), particularly in view of the fact that <0.1% is currently considered the best practice. There are two reasons why 0.1% is not proposed as the definitive performance level. These are:

*   There is some concern that existing methods of test may not be accurate below the 0.1% level.
*   The cost/abatement curve associated with higher recovery levels needs to be considered on a plant-by-plant basis. The Task Force are aware that, in many parts of the world, financial considerations could dissuade recovery in other-wise viable sectors.

There is a view among some equipment manufacturers and potential operators that the limit of 0.2% should not apply to PU dust being taken forward for incineration or similar destruction technique. This position is supported by the Task Force provided that clear evidence can be provided of material control between the output of the mechanical recovery equipment and the final destruction point. In order to avoid risk of significant inadvertent losses from potentially hot PU dust with high

exposed surface area it is proposed that, even under these circumstances, the maximum level of retained blowing agent should not exceed 0.5% by weight.

In respect of test methods for measuring residual blowing agent in foam, the Task Force is aware of three[8] current methods. All are based on head-space analysis of blowing agent extracted by the use of solvent. The main differences appear to be in the size and form of the sample introduced and the choice of solvent. A 'round robin' of test procedures might be useful to compare methods in order to make any further recommendations on test selection.

With respect to cost/abatement considerations, some process operators have noted that the extraction of blowing agent from the polyurethane matrix is not a rate-determining step for the plant and, accordingly, there is limited incremental cost in moving to the higher recovery standard. However, the Task Force considers that it is too early to extend this observation across the wider range of mechanical recovery equipment potentially covered by this Annex.

Fugitive Losses

The issue of fugitive losses was raised at the outset of this review and deferred until this point. It is self-evident that leaks within the mechanical recovery equipment could swamp the effects of other losses covered so far in this Annex. However, it is believed to be totally feasible to design and monitor plant in such a way as to ensure that leaks do not occur and, if they do, that they are detected and responded to promptly. It is inappropriate, however, for guidance such as this to make any prescription on how this should be achieved. Notwithstanding this, the Task Force believes that the onus should be clearly on the mechanical recovery equipment manufacturers and operators to demonstrate compliance with the basic principles outlined below:

- That the plant should be comprehensively monitored by suitable gas detectors

- That the detectors should be set to detect emissions at a concentration which assures the minimum loss of blowing agent in the event of a leak.

- That, where appropriate, the plant should be shut down on the detection of a leak.

- Where shutdown is not appropriate, written instructions should be kept available to ensure that operators know precisely how to act in the event of a leak.

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[8] One test method has been developed by Butterworth in the UK, another is as currently practised in Germany and the third is an internal method agreed by the producers of PU foams and raw materials.

In the absence of non-standard excursions, it is expected that baseline fugitive losses can be maintained below 5g/hour or 125mg/unit. This level is reflected in Figure 1. Some mechanical recovery equipment manufacturers are suggesting that a zero leakage unit can be engineered. However, the Task Force feels it inappropriate to reflect this target in its expectation for plant performance at this time, although commending it as an objective provided that it can be achieved cost-effectively.

Overall Assessment of Losses

The various potentials for loss reviewed in the last section can be accumulated together as shown in Figure 2.
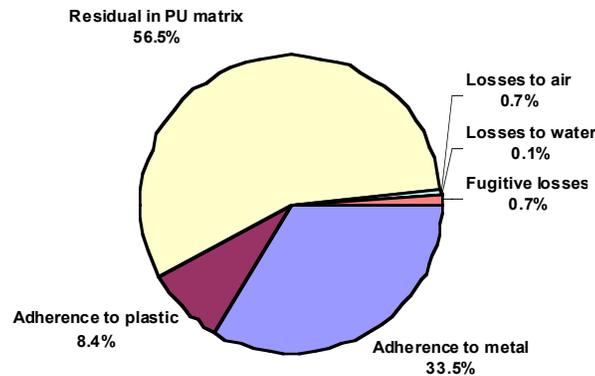

Figure 2: Potential Sources of Blowing Agent Loss during Mechanical Recovery (total 10-11 g/unit)

This assessment leads immediately to the conclusion that the anticipated loss per unit is typically 10-11 grams/unit. The next question is, of course, whether this level of loss is permissible in macro terms.

Significant work has been conducted by the German refrigeration industry during the last five years on establishing the average amount of foam injected into their units. The existing RAL standard defines three types of unit. These are:

Type 1:   Domestic refrigerators
           typical for domestic use with a load capacity of up to 180 litres

Type 2:   Domestic Fridge-Freezers
           typical for domestic use with a load capacity of 180 – 350 litres

Type 3:   Domestic Chest Freezers
            typical for domestic use with a load capacity of up to 500 litres

Using these basic 'types' and the product mix sold in the market, the German industry has been able to estimate an average of 300-340g of blowing agent across the range of units sold. Using 320g as the basis for the calculation, it can be seen that a loss of 11 grams represents 3.4% of the original charge. However, taking into account emission functions identified in previous TEAP publications (0.25% per year), and assuming a 20-year life, the recoverable blowing agent becomes 304g and the 11g loss equivalent to 3.6%. However, while recognising that any loss is regrettable, it is viewed that such losses would be acceptable as the ongoing basis of a minimum standard.

Monitoring and Reporting of Performance

The Task Force believes that it is not possible to frame any guidelines in this field on the basis of overall percentage recovery because the inputs to the process are not well enough defined. There are three problem areas:

- The density of foam varies within the cabinet, making representative samples difficult to select

- The product mix of refrigerator units (i.e. CFC, HCFC, HFC, HC blown) will be unknown if mandatory labelling has not been in place historically.

- The product mix will depart from CFC predominance over time and proportions of HCFC, HFC & HC will increase in line with Montreal Protocol initiatives.

Having said this, work carried out in the development of the RAL Quality Assurance Standard RAL-GZ 728 has shown that with large enough sample sizes (600 Type 1; 250 Type 2; and 150 Type 3) it is possible to smooth out these variations.

As a macro cross-check of on-going performance of mechanical recovery equipment, it would be possible to use the RAL 1000 unit recovery test, conducted every 3-6 months, and the results recorded for reporting purposes only. Not only would this serve as an internal check against any equipment problems that may be developing but would also serve to provide regulators with information about the overall effectiveness of their recovery schemes. Additionally, it would show long-term trends of the type suggested under item (iii) in this section. It should be stressed that no pass/fail criterion should be implied by this suggestion. In many cases, manufacturers would not wish to be bound in such a way because of all of the uncertainties outlined above.

Other Safety and Environmental Considerations

In preparing this review of issues to be considered in setting guidelines for mechanical recovery equipment, the Task Force would wish to draw attention to the fact that this Annex does not represent any type of design guide for such plants. Issues such as plant safety and energy efficiency are not explicitly dealt with in any detail.

However, the Task Force would wish to draw the attention of interested parties to the fact that equipment of this type will be increasingly dealing with product mixes based on hydrocarbon blown foams. Accordingly, they need to be designed in the light of the potential handling of typically low concentrations of cyclo-pentane, iso- & n-pentanes and even iso-butane.

On the energy efficiency side, equipment designers need to be mindful that one of the arguments against this form of recovery is that the energy consumed in the process heavily offsets the environmental gain. This is a strong argument for direct incineration, although this too has its constraints. Equipment manufacturers therefore need to strive for the lowest energy consumptions wherever possible and in its recommended that average energy consumption data per unit be established and published on all appropriate literature relating to the equipment being purchased.

Conclusions

It is the view of the Task Force that there are current performance guidelines, based on limiting losses at various points of the plant, that can be applied to new capacity being installed today. These do not fully represent best practice at this stage but provide an adequate screening of existing equipment performance to avoid the perpetuation of poorer quality designs.

The following table (Table 1) illustrates the view of the Task Force concerning these current recommendations for new capacity installed within the next five years and the potential target for future capacity thereafter.

Table 1: *Recommendations*

Parameter	Current Recommendation	Future Target
Adherence to metal	<0.5% by weight	<0.25% by weight
Adherence to plastic	<0.5% by weight	<0.25% by weight
Residual blowing agent in PU	<0.2%	<0.1%
Losses to Process Air	125 mg/unit	125 mg/unit
Losses to Waste Water	25mg/unit	25mg/unit
Fugitive Emissions	125 mg/unit	100 mg/unit

Additional requirements include minimisation of fugitive losses through proper monitoring and management of non-standard events. These conclusions will doubtless remain under review. However, the purpose of this Annex is to provide sufficient guidance to allow regulators and investors to agree on minimum performance criteria for the current investment cycle.

Table 2: Comparison of different European Quality Standards (and drafts) relating to Fridge destruction

a) EXISTING STANDARDS:

	CFC Volumes in Step 2 (Insulation)	CFC Volumes in Step 1 (Cooling Circuit)	Mandatory test method to determine CFC values in Steps 1 & 2	Residual R12 in Cooling Oil	Residue R11 in degassed PUR Foam	Residual Concentrations of CFC in the Atmosphere	Mass-flow of CFC in the Atmosphere	Adherence PUR on Metal waste fractions	Adherence PUR on Plastic waste fractions	Other points
RAL GZ728 (08/2001)	283 grams R11/unit	115 grams R12/unit	1000 units /mandatory mix 60% small(type1); 25% medium (type2; 15% large (type 3) - (Step 1 must do '100 unit test') (Step 2 must do additional 100 unit test)	<0.1 weight %	<0.2 weight %	no details (as a rule <20 mg/m3)	<5 grams CFC/hour (continuous measurement)	metal fraction should be as uncontaminated as possible	plastics fraction should be as uncontaminated as possible	Comprehensive monitoring of all material flows mandated Annual check on this
Federal Environment Ministry Guidance (01/1998)	283 grams R11/unit	115 grams R12/unit	1000 unit/ mandatory mix 60/25/15%	no details	<0.1 weight % feasible; <0.5 weight % not to be exceeded	no details	no details	no details	no details	
LAGA - Guidelines (09/2000)	283 grams R11/unit	115 grams R12/unit	1000 unit/ mandatory mix 60/25/15%	<0.1 weight %	as above	no details	<0.5 grams CFC/hour	no details	no details	
Austrian minimum requirements	283 grams R11/unit	115 grams R12/unit	1000 units/ mandatory mix 60/25/15%	<0.1 weight %	<0.2 weight %	<150 mg/m3 (yearly measurement)	no details	no details	no details	

(b) STANDARDS UNDER DEVELOPMENT/IN DISCUSSION

	CFC Volumes in Step 2 (Insulation	CFC Volumes in Step 1 (Cooling Circuit	Mandatory test method to determine CFC values in Steps 1 & 2	Residual R12 in Cooling Oil	Residue R11 in degassed PUR Foam	Residual Concentrations of CFC in the Atmosphere	Mass-flow of CFC in the Atmosphere	Adherence PUR on Metal waste fractions	Adherence PUR on Plastic waste fractions
TA Luft (German Regulation Draft 09/20001)	no details	100 unit test from RAL	no details	<0.2 weight % total halogen content	<0.2 weight %	<20 mg/m3	<10 grams CFC/hour	<0.5 weight %	<0.5 weight %
DIN 8975-12	no details	no details	no details	<0.2 weight % total halogen content	<0.5 weight %	<150mg/m3 (no continuous measurement)	no details (but with this mass concentration this should be <75 grams CFC/hour	<1 weight %	no details

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