MONTREAL PROTOCOL
ON SUBSTANCES THAT DEPLETE
THE OZONE LAYER

UNEP

Technology and Economic Assessment Panel

RESPONSE TO DECISION XVIII/12

REPORT OF THE TASK FORCE ON HCFC ISSUES
(WITH PARTICULAR FOCUS ON THE IMPACT OF THE CLEAN DEVELOPMENT MECHANISM)
AND
EMISSIONS REDUCTION BENEFITS ARISING FROM EARLIER
HCFC PHASE-OUT AND OTHER PRACTICAL MEASURES

August 2007

UNEP
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

REPORT OF THE TASK FORCE RESPONSE TO DECISION XVIII/12

August 2007

DISCLAIMER

The United Nations Environment Programme (UNEP), the Technology and Economic Assessment Panel (TEAP) co-chairs and members, the Technical Options Committees chairs, co-chairs and members, the TEAP Task Forces co-chairs and members, and the companies and organisations that employ them do not endorse the performance, worker safety, or environmental acceptability of any of the technical options discussed. Every industrial operation requires consideration of worker safety and proper disposal of contaminants and waste products. Moreover, as work continues - including additional toxicity evaluation - more information on health, environmental and safety effects of alternatives and replacements will become available for use in selecting among the options discussed in this document.

UNEP, the TEAP co-chairs and members, the Technical Options Committee, chairs, co-chairs and members, and the Technology and Economic Assessment Panel Task Forces co-chairs and members, in furnishing or distributing the information that follows, do not make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or utility; nor do they assume any liability of any kind whatsoever resulting from the use or reliance upon any information, material, or procedure contained herein.

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

Co-ordination:	Lambert Kuijpers; Paul Ashford and Radhey S. Agarwal
Composition:	Paul Ashford and Lambert Kuijpers
Reproduction:	UNON Nairobi
Date:	August 2007

ACKNOWLEDGEMENTS

The UNEP Technology and Economic Assessment Panel and the Task Force on Decision XVIII/12 co-chairs and members wish to express thanks to the Ozone Secretariat, to Implementing Agencies, as well as to a large number of individuals involved in Protocol issues, who contributed to this XVIII/12 report.

The opinions expressed are those of the Panel and its Task Force and do not necessarily reflect the reviews of any sponsoring or supporting organisation.

UNEP
TECHNOLOGY AND ECONOMIC
ASSESSMENT PANEL

REPORT OF THE TASK FORCE RESPONSE
TO DECISION XVIII/12
August 2007

Table of Contents

Executive Summary

Task and Organisation

This Report responds to the request of the Parties to the Montreal Protocol as set out in Decision XVIII-12 to *'further assess the measures listed in the report of the Ozone Secretariat workshop (July 2006) on the outputs of the IPCC/TEAP Special Report on Ozone and Climate'*. Parties requested that the TEAP give specific consideration to the following assessment parameters:

- Current and expected trends of ozone-depleting substance production and consumption, with a focus on HCFCs;
- The timing, feasibility and environmental benefits of such measures to Article 5 and non-Article 5 countries;
- The need to give full consideration to the influence of the Clean Development Mechanism on HCFC-22 as well as on the availability of alternatives.

In responding to the Decision, consultations occurred with a number of organisations including the United Nations Framework Convention on Climate Change (UNFCCC), the Inter-governmental Panel on Climate Change, the Executive Board of the Clean Development Mechanism of the Kyoto Protocol, and the secretariat of the Multilateral Fund of the Montreal Protocol.

In preparing for its response, TEAP formed a Task Force of 17 experts, 14 of which were drawn from within the TEAP and its TOCs, with the remaining three experts invited from external organisations. The secretariat of the Multilateral Fund attended the TEAP meeting which took place in March 2007 in Rome and provided important information on the outcomes of the recently completed HCFC-Surveys. The Ozone Secretariat facilitated contacts with the other institutions by letter and a series of informal dialogues ensued, conducted by the Task Force's co-ordinator.

Structure of the Report

The Report has a number of complementary and inter-linked components. The Task Force has endeavoured to make the treatment of each of these components sequential. The flow of the Report is therefore to establish background to the baseline first (and the variations that might exist) before introducing other compounding factors (e.g. the Clean Development Mechanism). The potential to influence this baseline is then discussed in the context of the '*practical measures*' proposed at the Ozone Secretariat's Workshop on the subject in Montreal (July 2006).

Figure ES-1 below provides a schematic of the structure:

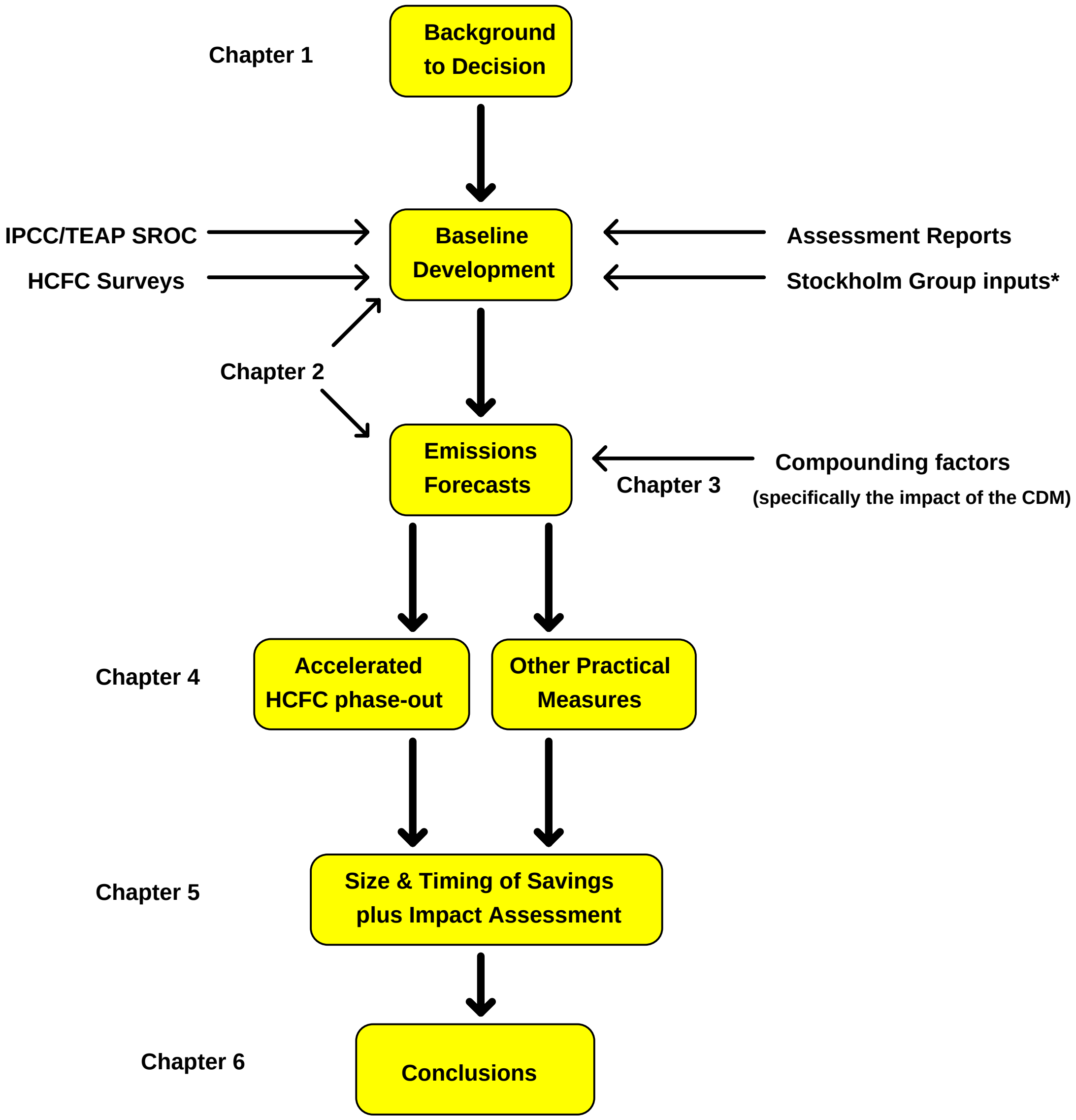


Figure ES-1 Structure of the Report responding to Decision XVIII/12

* The Stockholm Group is an informal gathering which has been meeting periodically to review the future of the Montreal Protocol

The Report is focused primarily on technically and economically feasible options to reduce emissions, although production and consumption are considered when it comes to reviewing capacity and availability of HCFCs and their alternatives. The analysis focuses on emissions in order to provide clear guidance on the timing of environmental benefits. This is important when considering uses in which annual consumption and annual emissions can be very much out of step. It also highlights that, some impacts already stored up in banks can only be managed by use-phase end-of-life measures and will be unaffected by future measures on production and consumption. The report does not estimate the cost of implementing the practical control measures.

Report Findings

- *Baseline Development and Business-as-Usual Emissions*

Chapter 2 of this Report outlines the methods and sources used to develop baseline emission estimates in terms of both ozone and climate impacts for the period to 2050. The Chapter provides explanations for choices made, as well as outlines of the treatment given to issues such as the development of feedstock demand. The following primary conclusions are drawn:

- Although at the lower end of the spectrum of growth scenarios between 2005 and 2015 (Growth Factor 1.78), the SROC consumption data provides the most substantive and complete treatment of demand trends at both sectoral and sub-sectoral level.

- While a number of baseline scenarios could be chosen for the use of HCFCs in developing countries after 2015, the preferred option follows precisely the provisions of the existing Montreal Protocol and assumes consistent demand throughout the period from 2015 to 2040 (as illustrated in Figure ES-2). Although this can be viewed as maximising the impact of *'practical measures'* evaluated in Chapter 4, this choice of baseline is justifiable and considered the most appropriate.

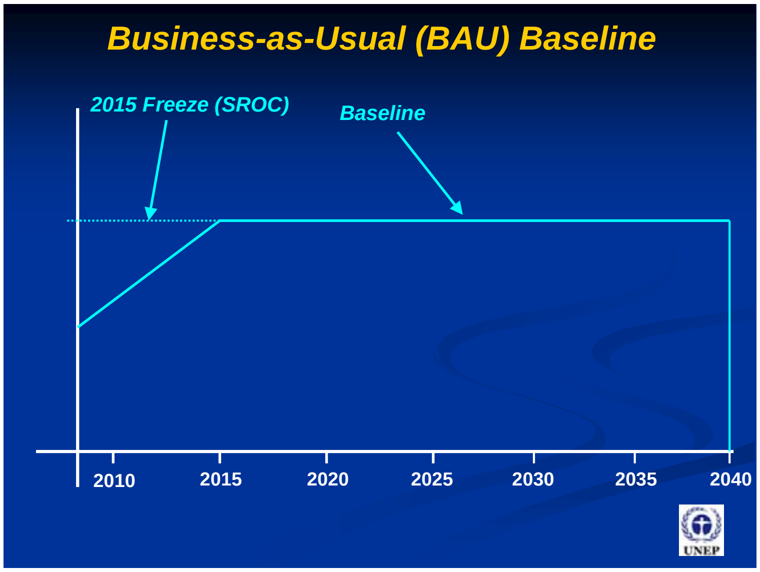


Figure ES-2 Business-as-Usual (BAU) Baseline based on 2040 'instantaneous' phase-out

- The existing provisions of the Montreal Protocol result in a year-on-year decrease in ozone-related emissions in the period to 2050, although a plateau is reached at just over 50,000 ODP tonnes per year in the period between 2025 and 2040 before the impact of the final phase-out takes effect. See Figure ES-3.

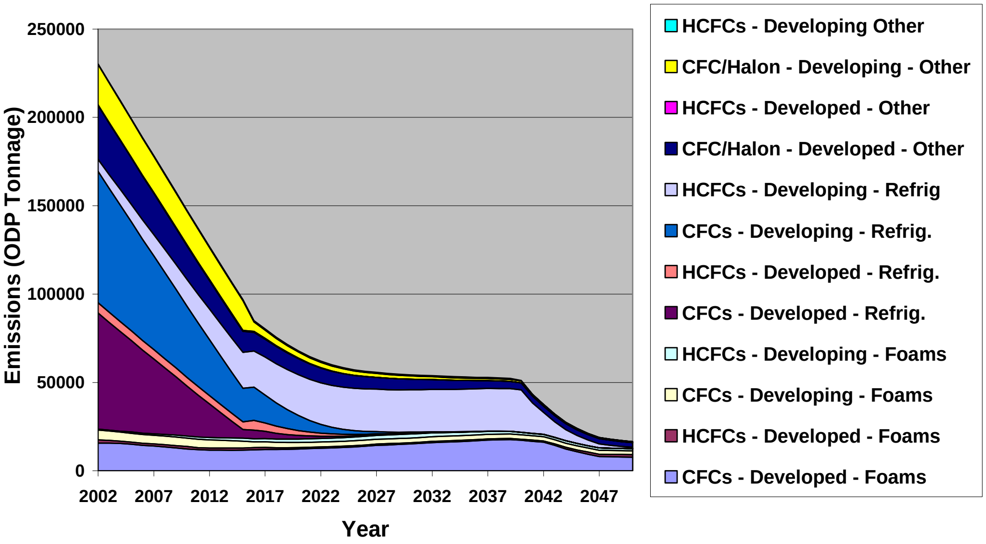


Figure ES-3 Emissions in ODP tonnes for all ODS applications (2002-2050)

- The ODS-related greenhouse gas emissions similarly plateau in 2025-2040 at an annual emission level of around 900 Mtonnes CO_2-eq which equates to around 3.5% of current annual global GHG emissions. This is shown in Figure ES-4.

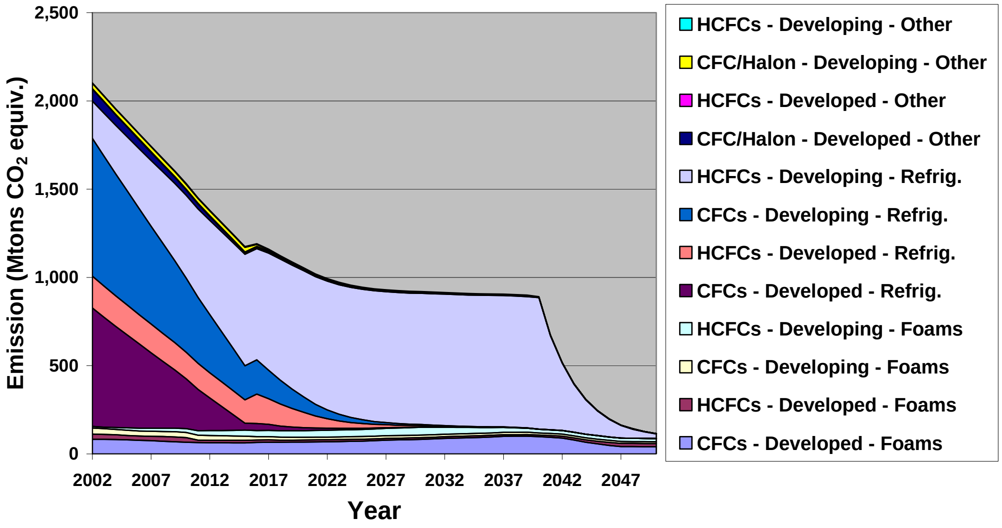


Figure ES-4 Emissions in Mtonnes CO_2-eq for all ODS applications (2002-2050)

- Emissions from the refrigeration and air conditioning sector are the single biggest component of the overall totals in both ozone and climate terms, representing 45% and 85% respectively during the plateau period.

- For the baseline scenario, where HFC-23 emissions are left unabated, trends in the use of HCFCs for feedstock cause a significant increase the emissions of ODS-related greenhouse gas emissions in the period from 2025-2039, as illustrated in Figure ES-5. As a result, these peak at approximately 1.35 billion tonnes in 2039 (i.e. around 5% of current global annual greenhouse gas emissions). In the same year, unabated HFC-23 emissions would be expected to account for just over 450 Mtonnes CO_2-eq which represents around 35% of the total ODS-related emission.

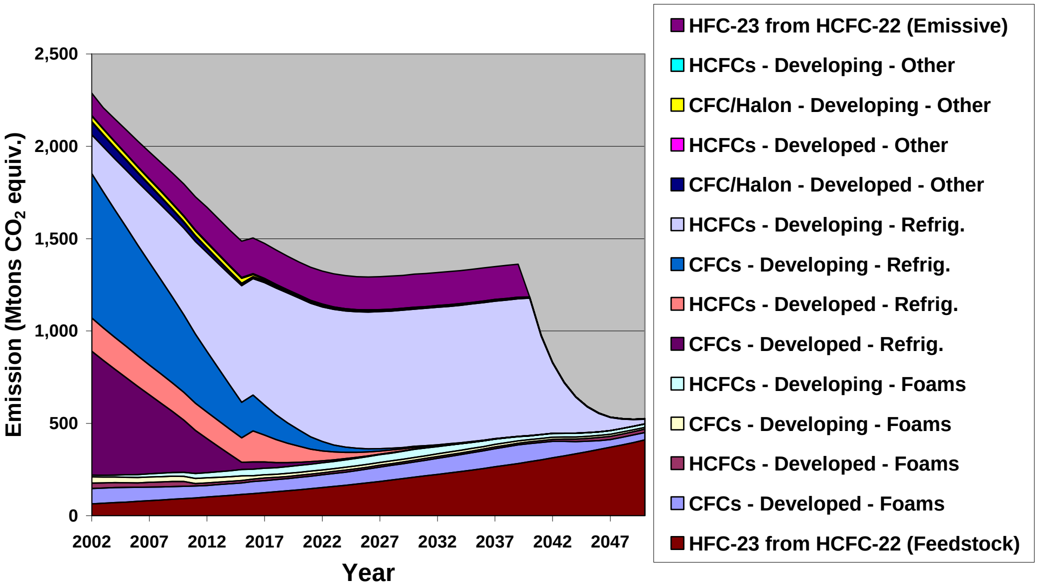


Figure ES-5 Impact of HFC-23 emissions on overall baseline forecast (2002-2050)

The climate benefits of an accelerated HCFC phase-out depend not only on the selection of the earlier freeze date and phase-out schedule, but also on the choice of technology to replace HCFCs in insulating foam and refrigeration and air conditioning sectors where indirect emissions from energy are significant. Parties and companies can use LCCP analysis to identify the options offering the greatest net climate benefits.

- *Inter-relationship with the Clean Development Mechanism*

Chapter 3 discusses in detail the current status of the Clean Development Mechanism (CDM) and its likely impacts. The chapter also discusses potential options for the removal of the impasse that exists on aspects of the on-going application of the CDM to HFC-23 abatement projects. From these discussions the following conclusions can be drawn.

- HCFC-22 production currently qualifying for CDM support is estimated at 260,000 tonnes, which represents 67-68% of developing country production. Although, these facilities have greater capacity (utilisation rate is currently

70%), increases in production will not qualify for further CDM support under the ‘existing’ facilities provision.

- Two sources of potential market distortion exist under the current arrangements. The first relates to the differing treatment of ‘new’ and ‘existing’ HCFC-22 facilities and the second relates to the fact that some facilities are not eligible for CDM support owing to their location.

- Monies flowing from the sale of Certified Emission Reductions (CERs) could be up to 10 times higher than the costs of mitigation and, under expected future carbon prices, will exceed the sales revenue for the HCFC-22 itself. See Figure ES-6.

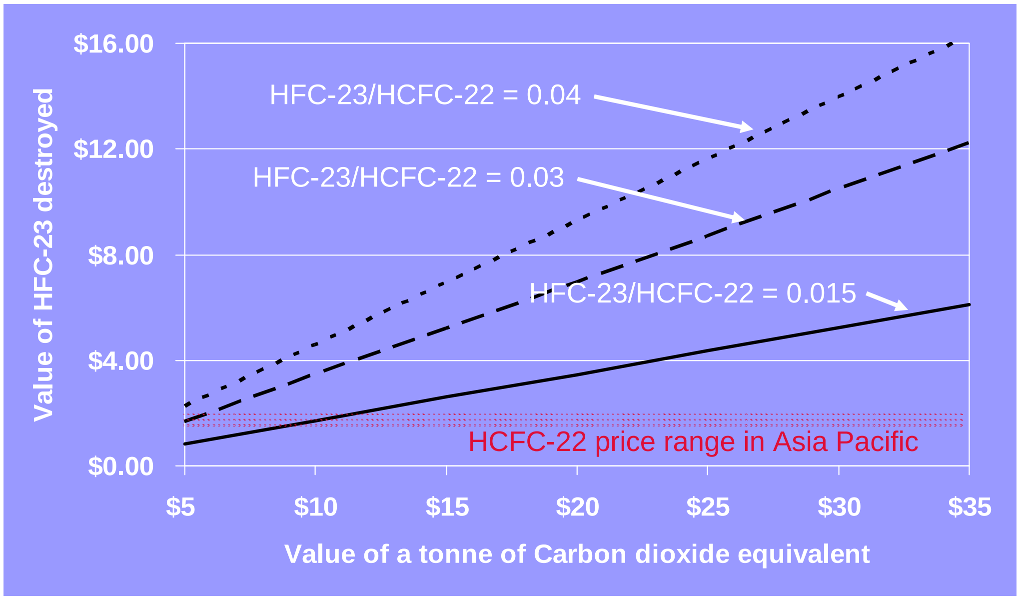


Figure ES-6 Value of CER credits per kg of HCFC-22 as the carbon price increases

- It is unlikely that the price of HCFC-22 would be depressed universally across the refrigeration sector, but individual producers could use their increased financial strength to implement tactical pricing strategies in localised markets to gain share. For ‘other’ HCFC-22 uses, demand is more elastic and the lowering of prices could improve the competitive position of downstream products (e.g. in foams). In extreme cases, it might even be possible that low HCFC-22 prices encourage the re-introduction of the chemical into foam applications in which it has already been replaced or as an aerosol propellant, where it has not been used widely before, or into other applications where environmentally superior technology is widely available.

- The CDM support currently offered to HCFC-22 facilities in developing countries could further accelerate the transfer of production from developed to developing countries, particularly if a provision for ‘new’ facilities is introduced. A method of ‘levelling the playing-field’ between ‘new’ and ‘existing’ plants may therefore be required

- An accelerated HCFC-22 phase-out is not expected to have any significant bearing on HFC-23 emissions in the first contracted period of the CDM and, in the absence also of any measures to control HCFC-22 production for feedstock use, the CDM itself is the only reliable mechanism available to prevent HFC-23 emissions in the short term.

- The Task Force has not identified any simple ways of solving the potential market distortions created by the CDM, since commitments are already in place for at least the next 7 years. One solution may lie in the development of an inter-governmental agreement of all developing countries hosting or planning to host HCFC-22 production facilities, in which national levies are applied to limit the financial gain of individual manufacturers. Under such a mechanism it could also be possible to include all ‘new’ facilities in order to maintain a level playing-field. Governments involved in any such future agreement could stipulate the uses financed by such levies, even including the possible use of such funds for ozone-related activities.

- *The Impact of an Accelerated HCFC Phase-out*

Chapter 4 evaluates three scenarios for the accelerated phase-out of HCFCs in developing countries. These are:

(1) Freeze at 2015 with linear phase-down of HCFC use from 2021-2030 (10 year advance);
(2) Freeze at 2015 with linear phase-down of HCFC use from 2016-2025 (15 year advance);

and

(3) Freeze at 2012 with instantaneous phase-out in 2040. (3 year advance in the freeze date).

- The scenario with a 15 year advance in phase-out of HCFCs (Scenario 2) delivers the most potential for ODS emissions abatement. For refrigeration alone, cumulative savings could be 468,000 ODP tonnes to 2050. The least effective ODS emissions abatement scenario arises from freezing at 2012 without an earlier phase-out date (Scenario 3), where cumulative savings over a comparative period are estimated to be about 75,000 ODP tonnes. However, this should not preclude the consideration of an earlier freeze, possibly in combination with other measures.

- ODS savings from accelerating HCFC phase-out measures increase when using higher baseline growth scenarios. With a Growth Factor of 2.5 between 2005 and 2015 (contrasted to SROC value of 1.78), ODS savings arising from a 15-year advance in the phase-out (Scenario 2) increase by 44%, as seen in Table ES-1.

Scenario	***Growth Factor as SROC***		***Growth Factor of 2.5***	
	ODP tonnes	*Mtonnes CO_2-eq*	*ODP tonnes*	*Mtonnes CO_2-eq*
Freeze at 2012	74,781	2,926	133,142	5,203
Linear from 2021	347,531	13,351	498,875	19,164
Linear from 2016	467,997	17,962	671,818	25,790

Table ES-1 Impact of high growth factors on refrigeration emission abatement (2002-2050)

- Cumulative savings in climate terms from ODS emissions reductions are potentially in excess of 18 billion tonnes CO_2-eq for the period to 2050 when phase-out is advanced by 15 years (Scenario 2). 3.5 billion tonnes CO_2-eq of this is attributable to avoided HFC-23 emissions, assuming that no HFC-23 mitigation strategy is otherwise in place (as is modelled by the baseline scenario).

- Since over 80% of the potential climate-related savings arise from the refrigeration sector, alternatives that result in lower GWP-weighted emissions (e.g. from a low GWP fluid or a less emissive design, or those that deliver sufficient efficiency improvements to offset their impacts) would be necessary to realise a significant proportion of this potential. Regulatory and/or fiscal incentives (e.g. the recent F-Gas regulation in the EU) can assist in creating an appropriate environment for such developments.

- Apart from the uncertainty over the pending availability of suitable low-GWP alternatives, the refrigeration sector carries with it a significant lag based on the servicing tail for existing equipment. This could act as a brake on plans to accelerate the HCFC phase-out unless equipment can be retrofitted or substantial quantities of HCFCs can be recovered, recycled and re-used. As a consequence, the proactive development and introduction of new alternatives needs to be encouraged, particularly if the climate benefits of accelerated HCFC phase-out are to be realised.

- The most appropriate control scenarios are likely to arise out of a consideration of the cumulative ODS emissions saved, the LCCP-based climate benefits that can be derived and the cost of transition. Since these characteristics vary sharply between use sectors, it is unlikely that one phase-down schedule would suit all circumstances. Accordingly, a sector-by-sector approach would be a viable alternative to the chemical-by-chemical approach suggested in some proposed Adjustments. A sector-by-sector approach would however require a further elaboration of the UNEP reporting structure.

- There are several specialist applications of HCFCs for which no technically or economically viable alternatives currently exist. This could impact both developed and developing countries as HCFC phase-out dates approach. Consideration will need to be given as to how such situations should be managed and whether continued use should be allowed in an otherwise accelerated framework through the application of an Essential Uses provision or other mechanism. The permissible criteria for the granting of such essential uses will need further consideration and could, in principle, extend to climate protection where alternatives would impose unacceptable additional climate burdens.

- Figure ES-7 shows the underlying impact of production for feedstock uses over time, particularly in the post-2040 period when production for emissive uses will have ceased. This substantial feedstock demand has the potential to differentiate future HCFC production controls from those previously adopted for CFCs.

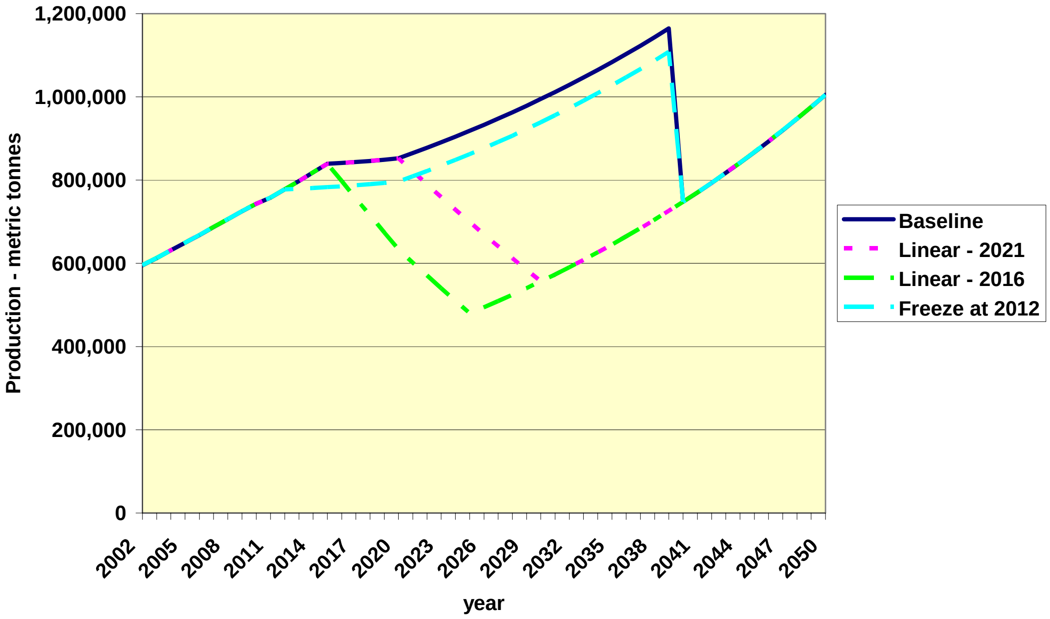


Figure ES-7 Impact on HCFC-22 production under the various scenarios

- The introduction of an earlier transition for HCFCs offers the potential to avoid rapid changes in HCFC production. With growth in feedstock demand for HCFCs continuing to 2050 and beyond, it is certainly possible to ensure at the global level that no additional intermediate capacity is needed to meet HCFC production for emissive uses (i.e. those controlled under the Montreal Protocol), even though changes in geographic demand may require some rationalisation, with the closure of some plants and the building of others.

- As an additional consequence, the case for a Basic Domestic Needs provision is offset by the fact that several HCFCs will be continue to be needed for feedstock uses. Nonetheless, BDN provisions may still be valuable to ensure that levels of supply and demand are reviewed, particularly for non-feedstock HCFCs such as HCFC-141b. They may also be required to facilitate the transfer of HCFCs between Article 5 countries.

- *<u>The Potential Contribution of Other Practical Measures</u>*

Chapter 4 also evaluates the impact on emissions savings of the other practical measures identified in the July 2006 Workshop, both in terms of their magnitude and timing. The following conclusions are drawn:

- The potential impact on emissions savings of the other practical measures in aggregate is equal to or greater than the ozone and climate protection of an accelerated HCFC phase-out alone. However, the 'linear 2021' (10-year advance) and the 'linear 2016' (15-year advance) remain the single biggest individual components of the scenarios in which they feature, as seen in Figures ES-8 and ES-9. Therefore, the option to both accelerate the HCFC phase-out and implement all technically feasible practical measures would yield greater benefits than either action alone.

- The most advanced accelerated HCFC phase-out schedule combined with all other practical measures provides cumulative ozone-related savings of nearly 1.25 million ODP tonnes (see Figure ES-8) and in excess of 30 billion tonnes CO_2-eq of potential climate protection (see Figure ES-9).

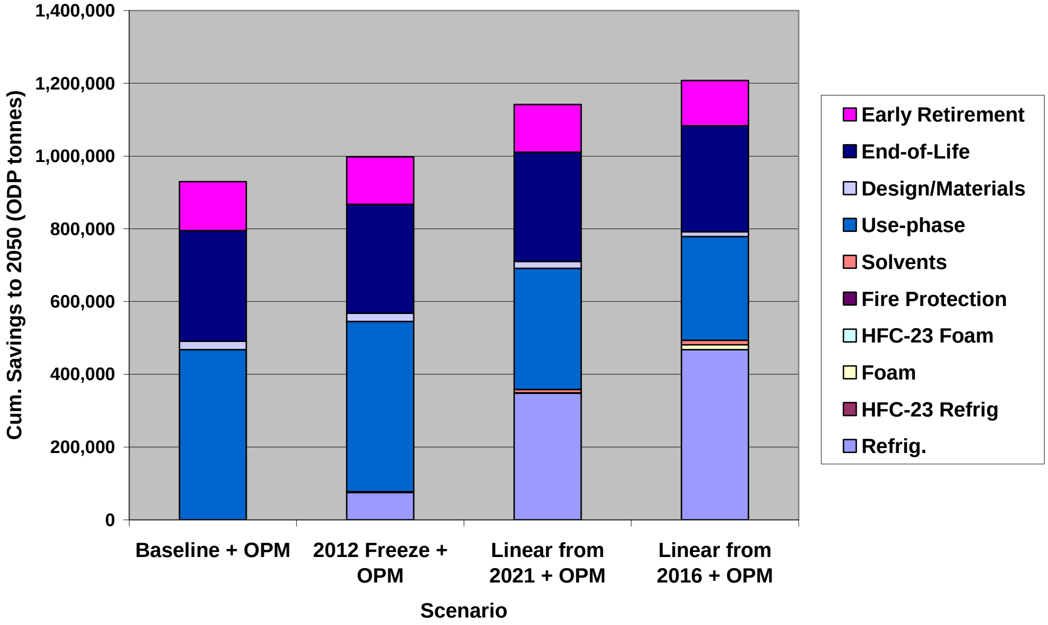


Figure ES-8 Cumulative savings of different scenarios for all measures in ODP tonnes

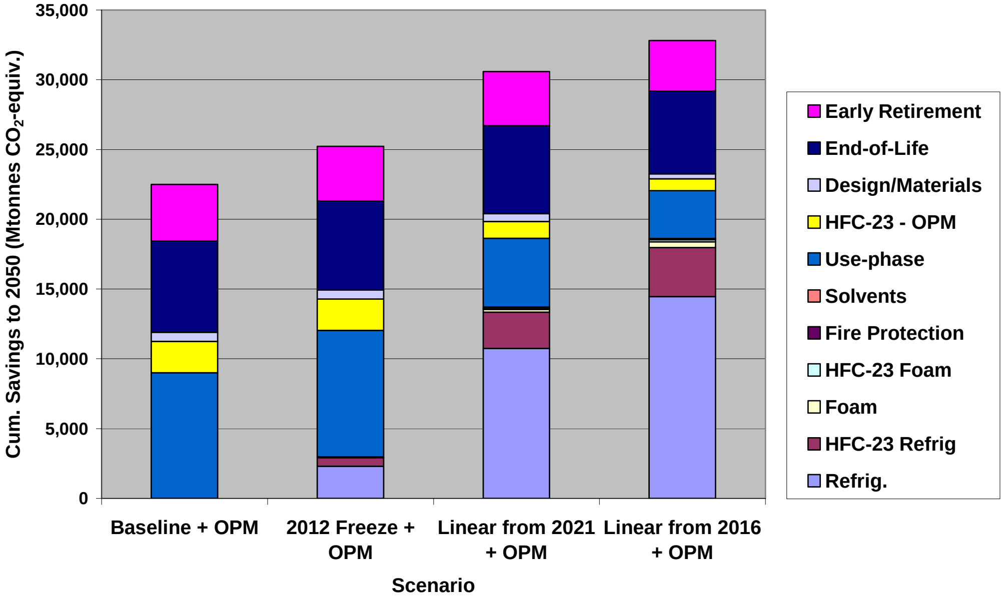


Figure ES-9 Cumulative savings of different scenarios for all measures (Mtonnes CO_2-eq)

- There is good correlation with the SROC mitigation scenario analysis although this report provides important new additional information on the further development of savings over time.

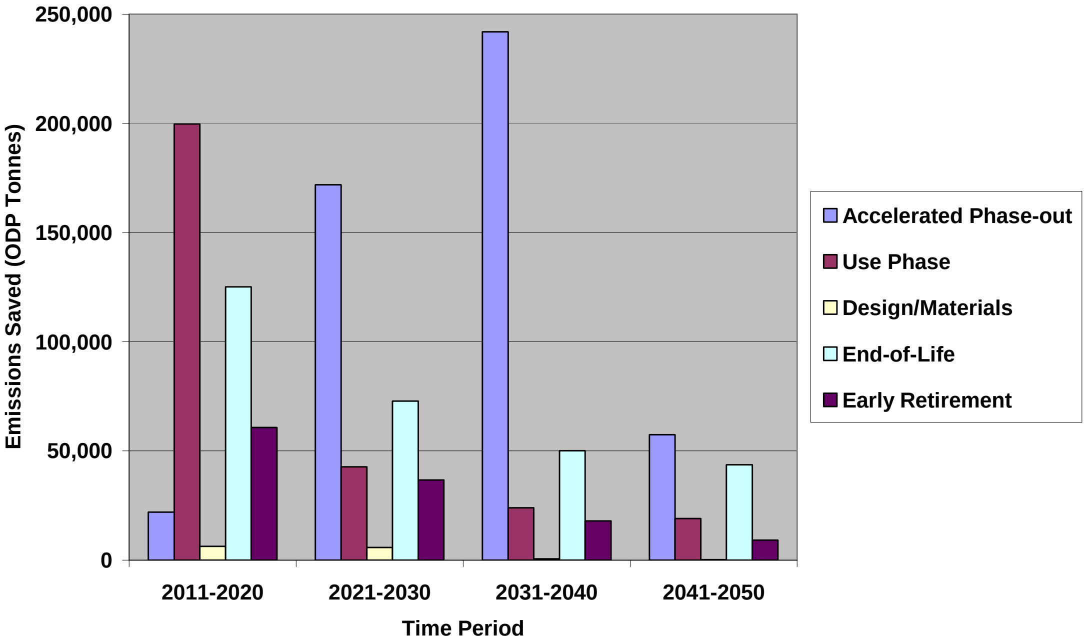


Figure ES-10 Timing of savings from all measures in ODP tonnes – 'linear 2016'

- There are important use-phase benefits to be gained in the decade from 2011-2020, as illustrated in Figure ES-10. The major components of these savings are found in leakage reduction within the commercial refrigeration sector (80,000-90,000 ODP tonnes depending on scenario) and in the management of halon banks (~90,000 ODP tonnes)

- End-of-life measures are consistent and significant contributors to savings in terms of both ozone and climate, with cumulative savings of around 300,000 ODP tonnes and about 6 billion tonnes CO_2-eq. Early retirement of equipment can provide an additional 130,000 ODP tonnes and 3.5-4 billion tonnes CO_2-eq not accounting for energy efficiency benefits that might also accrue. Conversely, design measures and material selection changes do not contribute substantially to emissions savings. See Figures ES-10 and ES-11.

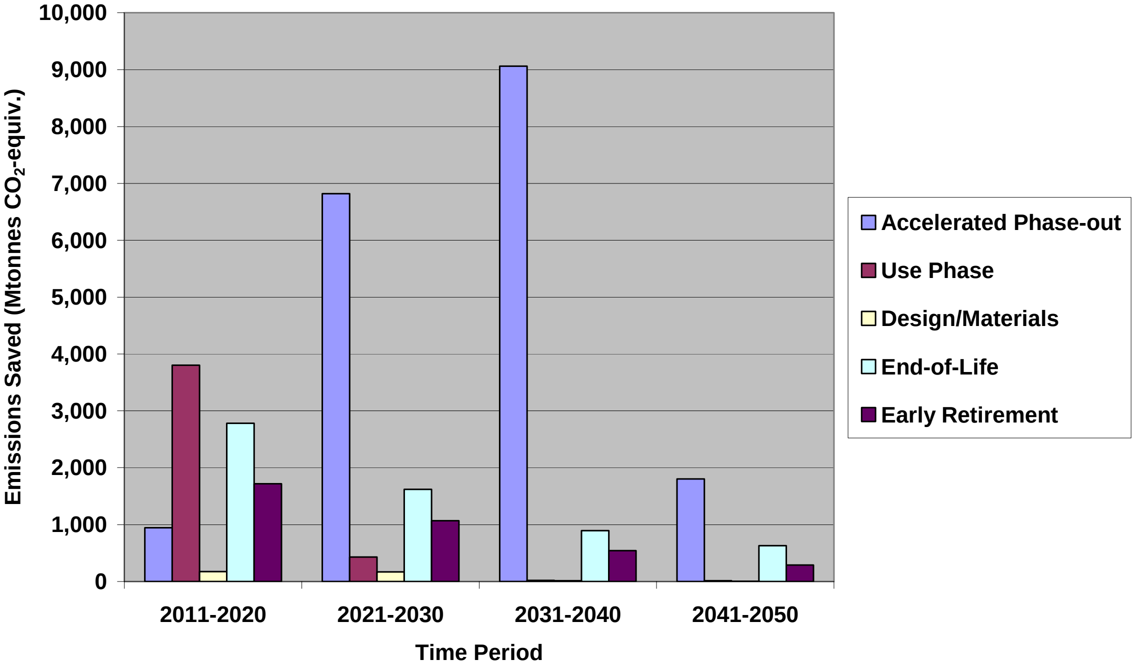


Figure ES-11 Timing of savings from all measures in Mtonnes CO_2-eq – linear 2016

- Decisions on the suite of measures to be adopted can only be optimised at regional level. The relative cost-effectiveness of each measure is a vital component of the decision-making process, but is not considered in this report.

- Evaluations using the approach previously adopted by the Science Assessment Panel to assess the influence of factors on ozone recovery (return to 1980 levels of EESC) show that accelerated HCFC phase-out can advance ozone recovery by up to 3.3 years based on a mid-latitude assessment. When the contribution of all other practical measures is added, the recovery of the ozone layer can be brought forward by as much as 7.1 years.

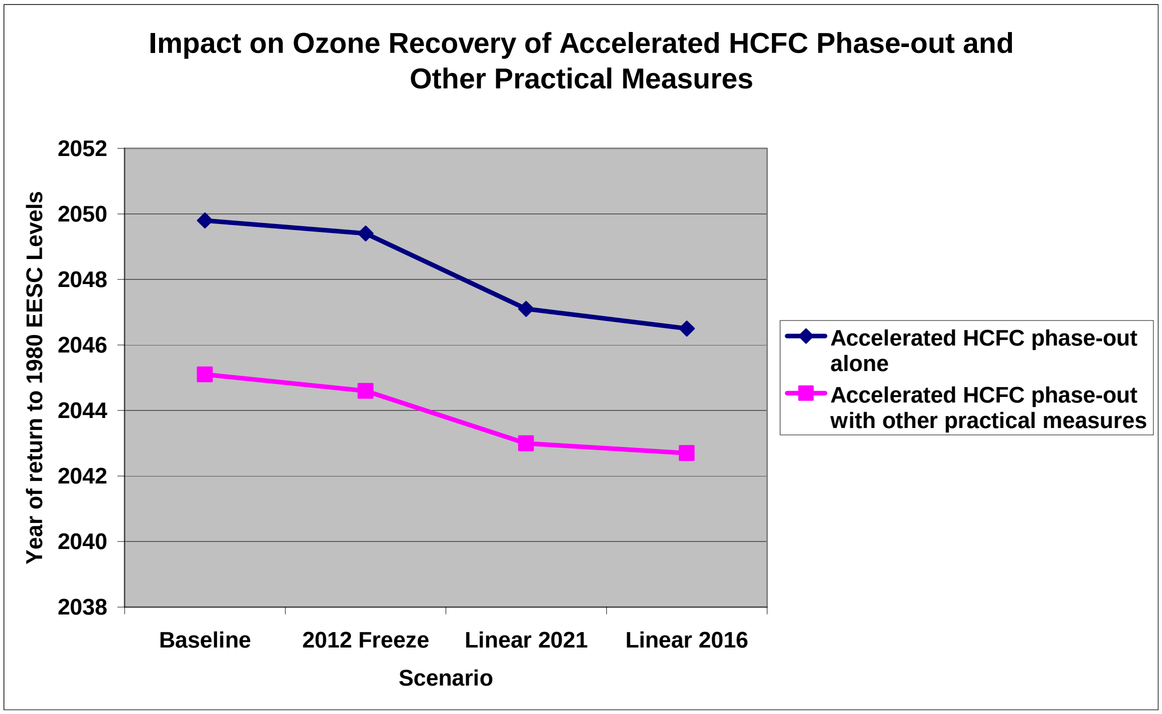


Figure ES-12 Impact on Ozone Recovery of Practical Measures assessed in this Report

Summary Conclusion

The analysis of potential emissions savings that can be made by the *'practical measures'* identified at the July 2006 Ozone Secretariat Workshop has re-confirmed the value and importance of addressing such measures in a systematic manner. All types of measure have a potential role to play, particularly in stimulating early emissions savings, but it is clear that the single biggest contributor to cumulative emissions savings both in terms of ozone and climate is an accelerated HCFC phase-out. Since this has already been achieved in a number of sectors and regions, it is clear that technology exists to facilitate a wider phase-out. However, to gain maximum climate benefit from such a transition, further efforts are needed to promote the development and deployment of alternatives delivering lower climate impact, particularly in complex sectors such as commercial refrigeration.

Recognising that early planning for transition can increase efficiency and minimise costs, there is a strong case for setting policy and regulatory frameworks as soon as possible. Additional regional incentives might include the limitation of exports of HCFC-containing products to those regions that have already phased-out and the introduction of supportive funding mechanisms. These mechanisms could also be extended to the implementation of the other *'practical measures'*, where co-financing may be available from the voluntary market in recognition of the climate benefit accruing.

The Clean Development Mechanism will continue to play a key role in ensuring that HFC-23 emissions from HCFC-22 production do not contribute unnecessarily to greenhouse gas emissions. The worst of all cases would be for HFC-23 emissions to go unmitigated. The inclusion of new plants under the CDM will therefore be necessary in all HCFC phase-out scenarios, especially if HCFC-22 manufacture for feedstock use continues. It will also be necessary to avoid CDM revenues remaining with the HCFC-22 producers to prevent on-going market distortions. Therefore, co-operation between countries hosting HCFC-22 production would be very valuable in ensuring a level playing field. The revenues, so captured, could provide important sources of government funding for worthwhile environmental objectives, which might also include ozone-related objectives.

1 Introduction

1.1 History of the Special Report on Ozone and Climate and its Supplement

The IPCC Special Report on Ozone and Climate (SROC) was developed in response to requests by the Parties to the *United Nations Framework Convention on Climate Change* (UNFCCC)[1] and Parties to the *Montreal Protocol on Substances that Deplete the Ozone Layer*[2] for policy-relevant, scientific, and technical information regarding alternatives to ozone-depleting substances (ODSs) that may affect the global climate system.

The original Terms of Reference for the SROC did not prescribe the assessment of the impacts of on-going ODS consumption or the impacts of on-going ODS emissions from banks. However, in the early stages of the development of the Report, it became obvious that these were integral parts of the assessment. Developing countries would still have the capability to consider one type of ODS as an alternative to another type of ODS (e.g. HCFCs as an alternative to CFCs) and it was realised that the emissions of banked ODS in the refrigeration and foam sectors would also have a significant impact on the climate as well as on the ozone layer.

The coverage of these aspects of ODS consumption and emission was reported to both the UNFCCC and the Parties to the Montreal Protocol, even though the main focus of the SROC was maintained on the climate effects of these trends and did not make any attempt to assess the ozone-related impacts. This objective became the subject of a further Conference Room Paper (CRP) tabled at the Twenty-fifth meeting of the Open-ended Working Group (Montreal, 27-30 June, 2005) by the EC, Norway, New Zealand, and UK, which, amongst other elements, was to '*…elaborate clearly the ozone depletion implications of the issues raised in the Special Report*'. A Supplementary Report (the "ODS Supplement") was subsequently presented to the Seventeenth Meeting of the Parties in November 2005.

The following sections highlight the key messages contained in the SROC and its ODS Supplement.

1.1.1 Key messages of the IPCC/TEAP Special Report on Ozone and Climate

The SROC draws conclusions in three key areas:

- The inter-action between ozone protection and climate change;
- Production, banks and emissions of ODSs and their substitutes; and
- Options for ODS phase-out and reducing greenhouse gas emissions.

---

[1] Decision 12/CP.8, FCCC/CP/2002/7/Add.1, page 30 Eighth Conference of the Parties to the UNFCCC, New Delhi, India, 23 October – 1 November 2002

[2] Decision XIV/10, UNEP/OzL. Pro 14/9, page 42. Fourteenth Meeting of the Parties to the Montreal Protocol, Rome, Italy, 25-29 November 2002

Inter-action between ozone protection and climate change

The Special Report highlights the fact that emissions of CFCs have dominated the contribution of halocarbons to direct radiative forcing (RF).

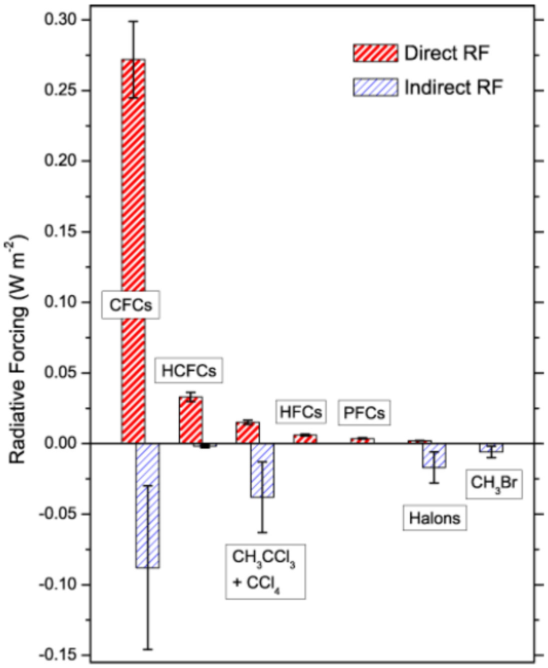


Figure SPM-2. Direct and indirect radiative forcing (RF) due to changes in halocarbons from 1750 to 2000.[9] Error bars denote ±2 standard deviation uncertainties. [Based on Table 1.1]

Warming attributed to ODSs and cooling associated with ozone depletion (an example of an indirect RF effect) are two distinct climate forcing mechanisms that do not simply offset one another. This continues to be an important scientific finding when considering the impact of future actions to assist ozone layer recovery, while minimising additional climate change and will be mentioned regularly throughout this Report.

Even when taking account of the two effects, the on-going CFC phase-out would still represent the single biggest contribution to climate change mitigation from among the halocarbons.

Production, Banks and Emissions

The SROC focuses on the period until 2015 and cites actual values as at 2002 and projected values for 2015. The projections are made using two scenarios – a Business-as-Usual (BAU) Scenario and a Mitigation Scenario. The latter covers the implications of a series of measures, which are summarised within the next section. The fact that production and consumption data could not be reliably predicted beyond 2015 dictated that the analysis did not extend beyond 2015, which was a limiting factor within the SROC.

The following charts summarise the findings:

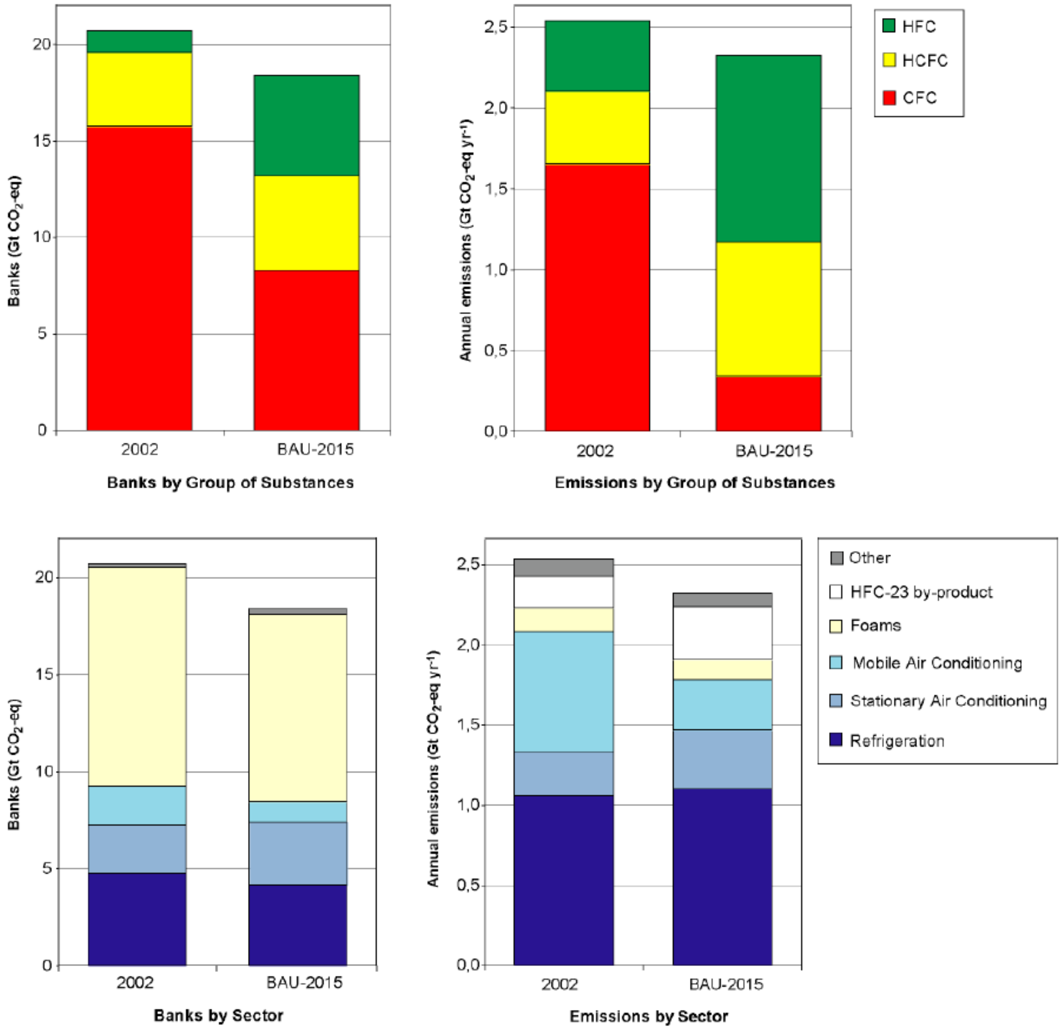


Figure SPM-4. Historic data for 2002 and Business-As-Usual (BAU) projections for 2015 of greenhouse gas CO_2-equivalent banks (left) and direct annual emissions (right), related to the use of CFCs, HCFCs and HFCs. Breakdown per group of greenhouse gases (top), and per emission sector (bottom). 'Other' includes Medical Aerosols, Fire Protection, Non-Medical Aerosols and Solvents. [11.3 and 11.5]

Emissions in the post-2015 period are not considered except in the case of foams, where the long-lived nature of the products (and related banks) necessitates a BAU emissions assessment up to 2100.

Key observations include the following:

- By 2002, the emissions of CFCs from pre-existing banks of ODS exceeded those arising from new production/consumption;
- In all circumstances, the GWP-weighted emissions from the refrigeration and air-conditioning sectors dominate the other sources; and
- In 2015, the largest banks remain in foams (mostly CFCs) but the majority of emissions are projected to arise from other halocarbons used as ODS substitutes.

One of the remaining uncertainties in this analysis is the lack of comprehensive information on historic use-patterns. This becomes particularly significant when comparing banks and emissions derived from ‘bottom-up’ production/consumption estimates with those derived from atmospheric measurements. The situation is compounded by the fact that not all historic uses of ODS were covered within the scope of the SROC, since many do not use HFCs or PFCs as substitutes. The Task Force on Emission Discrepancies (TFED) addressed these matters further in 2006 and provided confirmation that the comparative data was in agreement. However, further expansions in data reporting are required to fully characterise the ODS use-patterns around the world.

Options for ODS phase-out and reducing greenhouse gas emissions

The Mitigation Scenario was derived from sectoral assessments of opportunities for emission reductions, with the major opportunities being identified as:

- improved containment of substances;
- reduced charge of substances in equipment;
- end-of-life recovery and recycling or destruction of substances;
- increased use of alternative substances with a reduced or negligible global warming potential; and
- greater use of not-in-kind technologies.

In choosing emission reduction strategies to mitigate climate impacts, care needs to be taken to ensure that reductions in direct emissions of greenhouse gases are not offset by hidden decreases in energy efficiency. Accordingly, a holistic lifecycle approach is required for a comparative analysis using the principles of life cycle assessment (LCA), applied to climate-specific issues. Life Cycle Climate Performance (LCCP) incorporates these principles, and was used extensively for the assessment of ODS alternatives.

The sectoral contributions to total emission reduction under the Mitigation Scenario are as follows:

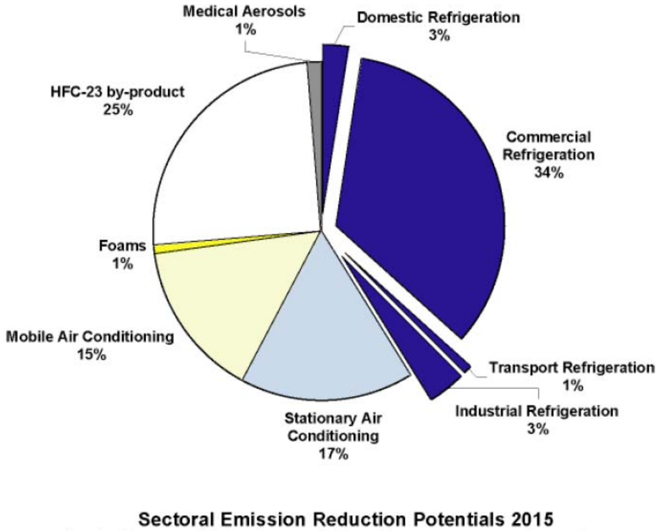


Figure SPM-5. Sectoral reduction potentials for direct emissions of CFCs, HCFCs, and HFCs in 2015 as compared to the BAU projections. The overall reduction potential is about half (1.2 GtCO$_2$-eq yr^{-1}) of the BAU direct GHG emissions.

Identifiable emission reduction options under the Mitigation Scenario represent about half of the emissions under the BAU Scenario at 2015 when measured in climate terms. However, additional savings could accrue after 2015, particularly in the long-lived foam sector.

1.1.2 Key Messages from the ODS Supplement to the SROC

As noted earlier, the purpose of the ODS Supplement was to present the conclusions of the SROC in terms of ODS emissions and banks, in ODP tonnes and other metrics traditionally used by the Montreal Protocol, as shown in the following charts:

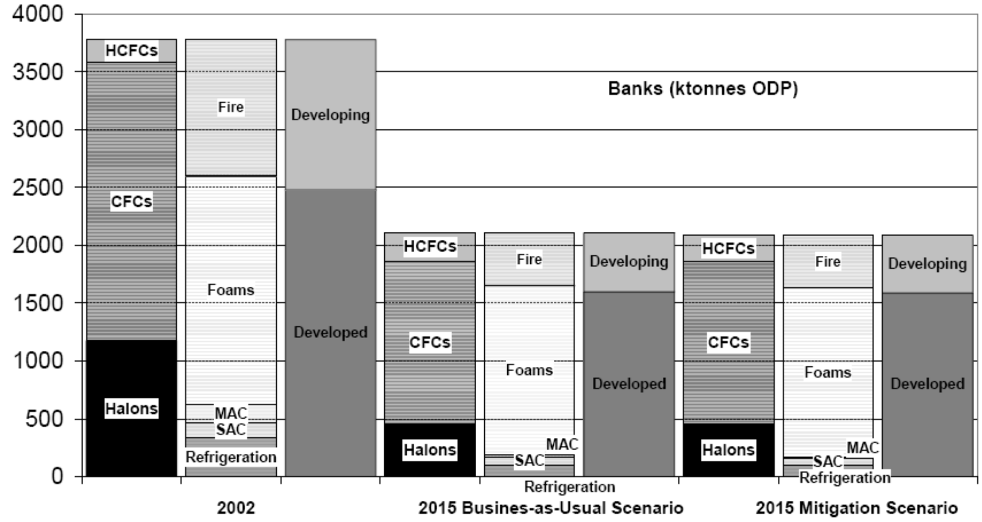


Figure 3-1 Banks of halocarbons expressed in ktonnes ODP. Breakdown per group of substances, per emission sector en per region (non-Article 5(1)/Article 5(1) countries), for 2002, 2015 Business-as-Usual Scenario, and 2015 Mitigation Scenario.

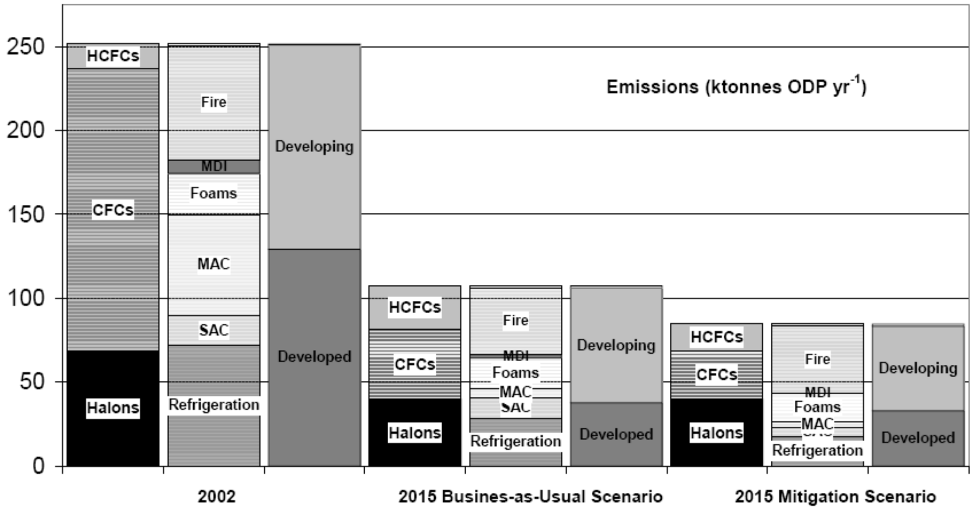


Figure 3-2 Emissions of halocarbons expressed in ktonnes yr^{-1} ODP. Breakdown per group of substances, per emission sector en per region (non-Article 5(1)/Article 5(1) countries), for 2002, 2015 Business-as-Usual Scenario, and 2015 Mitigation Scenario.

From these charts, it was clear that the impact of the Mitigation Scenario on ozone recovery was less significant than for climate protection as noted in the SROC - partially because measures to reduce the emissions of non-ODS substitutes were excluded from the analysis. Regarding a return of Equivalent Effective Stratospheric Chlorine (EESC) to pre-1980 levels, the following summarised points can be extracted:

- The Science Assessment Panel (WMO, 2003) previously estimated that recovery of the ozone layer could occur at around 2044 based on BAU assessments, which had lower bank estimates than the SROC;
- Adoption of the SROC bank sizes, coupled with revised servicing assumptions would extend BAU recovery to 2046-2048; and
- Improvements in bank management procedures could accelerate ozone recovery, but the extent of the improvement is unlikely to be more than 2 years.

The ODS Supplement also noted that emission avoidance via not-in-kind alternatives or emission reduction measures are likely to be more cost-effective in the early stages of the lifecycle, with end-of-life measures being the most challenging technically and economically. Nevertheless, actions taken at end-of-life have high potential to further accelerate ozone layer recovery because of their magnitude.

Since the finalisation of the ODS Supplement Report in 2005, the Science Assessment Panel has published its 2006 Assessment Report in which (based on SROC bank assumptions) it predicts slower ozone layer recovery (up to 2065), reflecting the fact that bank emissions in mid-latitudes will take longer to have impact on the stratosphere over the Antarctic than previously predicted. This finding has once again focused the interest of the Montreal Protocol community on bank management issues.

1.2 Decision XVII/19 and the OEWG Workshop

The analyses in both the SROC and the ODS Supplement made it clear that emission reduction options were “many and varied” and that the future Decisions of the Parties to the Montreal Protocol could have significant benefits not only on the recovery of the ozone layer but also on avoiding the future emissions of greenhouse gases, which would have climate change consequences. Following the presentation of the ODS Supplement at its Seventeenth Meeting, the Parties decided (in Decision XVII/19) to continue the analysis by inviting Parties to submit their suggestions for *‘practical measures’* to the Secretariat; this ahead of the convening of a one-day Workshop in conjunction with the 26th Open-ended Working Group of the Parties to the Montreal Protocol held in Montreal. The purpose of the Workshop was to produce an agreed-upon list of these *practical measures* for onward consideration. Authors of the ODS Supplement worked with the Ozone Secretariat to group the proposals and facilitate this Workshop, which took place on Friday 7 July 2006 and was subsequently reported by the Ozone Secretariat[3].

---

[3] UNEP/OzL.Pro/Workshop 2/2

The text of Decision XVII/19 highlighted that the *'practical measures'* should be *'relating to ozone depletion'* but should also contain information on *'other environmental benefits, including those relating to climate change'* that would result from these measures.

One of the aspects of the Decision was that all *'practical measures'* should *'arise from the report'*. This proved difficult to interpret in practice because some very *practical measures* for ozone (e.g. earlier phase-out of HCFCs) were not always explicitly addressed in the original SROC and its ODS Supplement. Nonetheless, sufficient cross-references were available to ensure the consideration of all suggestions received from Government experts and were ultimately adopted as *'practical measures'* in either their original form or as an amalgamation with other similar proposals.

The fact that the timing of savings was not considered as part of the listing from the Workshop made it difficult to assess the inter-relationship between measures, with the possibility that there could be double counting of benefits in some instances. An additional, but intentional restriction on the scope of the Workshop was that no prioritisation should be under-taken. The outputs were therefore delivered to the Eighteenth Meeting of the Parties to the Protocol in New Delhi[4]as a single list, which would require further analysis before offering additional guidance to Parties.

1.3 Development of Decision XVIII/12

At the New Delhi Meeting of the Parties, several Parties sought to develop a Decision that would further analyse the *'practical measures'* arising from the Workshop, with particular focus on the impact of measures relating to HCFCs. In parallel some Parties proposed an evaluation of the impact of the Clean Development Mechanism (CDM) on the supply and demand of HCFCs. During the discussions, it became clear that it would be very difficult to conduct two parallel studies on different elements of the HCFC 'jigsaw' without considering the inter-actions between them. It was therefore decided to combine the two elements into one over-arching Decision, which became Decision XVIII/12. The text of the Decision is as follows:

- *Recalling Decision XVII/19 which requested the Ozone Secretariat to organise an experts workshop on the Intergovernmental Panel on Climate Change/Technology and Economic Assessment Panel special report in the margins of the twenty-sixth meeting of the Open-ended Working Group in 2006,*
- *Noting with appreciation Parties' submissions for the list of practical measures as well as the preparations of the Technology and Economic Assessment Panel for the workshop,*
- *Noting with appreciation the report of the workshop provided by the Ozone Secretariat,*
- *Noting with appreciation the summary of Scientific Assessment of Ozone Depletion 2006 , and its options on additional measures to accelerate the recovery, but further noting with concern better scientific understanding now suggests a 10 to 15 year later return of chlorine levels to pre-1980 values in the atmosphere,*

---

[4] 30th October – 3rd November 2006

- *Noting with appreciation the report of the Technology and Economic Assessment Panel Task Force on Emission Discrepancies,*
- *Mindful that Parties not operating under paragraph 1 of Article 5 of the Montreal Protocol should phase out consumption of hydrochlorofluorocarbons by 2030 and freeze production by 2004 and that the Parties operating under paragraph 1 of Article 5 should phase out consumption of hydrochlorofluorocarbons by 2040 and freeze production by 2016,*
- *Aware of the potential implications of Clean Development Mechanism projects in hydrochlorofluorocarbon-22 production facilities,*
- *Acknowledging, therefore, that further work needs to be done to reach the targets of the Vienna Convention and the Montreal Protocol for recovery of the ozone layer,*

1. *To request the Technology and Economic Assessment Panel to further assess the measures listed in the report of Ozone Secretariat workshop on the Intergovernmental Panel on Climate Change/Technology and Economic Assessment Panel special report, in the light of current and expected trends of ozone-depleting substance production and consumption and with a focus on hydrochlorofluorocarbons, taking into account timing, feasibility and environmental benefits in Parties operating under Article 5 and Parties not operating under Article 5 of the Protocol;*
2. *To request the Technology and Economic Assessment Panel to provide information on current and future demand for, and supply of, hydrochlorofluorocarbons, giving full consideration to the influence of the Clean Development Mechanism on hydrochlorofluorocarbon-22 production, as well as on the availability of alternatives to hydrochlorofluorocarbons;*
3. *To request the Ozone Secretariat to facilitate consultations, as appropriate, by the Technology and Economic Assessment Panel with relevant organizations, namely, the United Nations Framework Convention on Climate Change Secretariat, the Intergovernmental Panel on Climate Change, the Executive Board of Clean Development Mechanism of the Kyoto Protocol, and the secretariat of the Multilateral Fund, to enable the Technology and Economic Assessment Panel to draw on the work already carried out under these organizations, including any work relating to hydrochlorofluorocarbon-22, and consider, in cooperation with the Scientific Assessment Panel, the implications of these findings for the recovery of the ozone layer;*
4. *To request the Technology and Economic Assessment Panel to report its findings on the issues mentioned in paragraphs 1 and 2 above to the Open-ended Working Group at its twenty-seventh meeting for consideration, with a view to providing a final report to the Nineteenth Meeting of the Parties.*

The scope of the Decision and its challenging time-scale for completion, particularly in the light of the work already underway on the 2006 Assessment cycle, meant that the information reported to the 27th meeting of the Open-ended Working Group was delivered as a PowerPoint™ slide presentation and focused on preliminary findings only. This Report presents the systematic consideration of all of the issues raised within the Decision. In setting out its Report, the Task Force has considered the impact of the Clean Development Mechanism (paragraph 2) as part of its assessment of the baseline HCFC demand[5] and ahead of consideration of the other *'practical measures'* highlighted by the Workshop.

---

[5] The term 'demand' is used throughout this Report to mean the market activities which generate the requirement to purchase a substance. Accordingly, 'demand' can, in part, be met by recycled materials which differentiates the term from 'consumption' as defined under the Montreal Protocol.

1.4 Task Force Membership and Consultation

At its 2007 meeting in Rome (27-30 March 2007), the TEAP discussed and agreed the composition of the Task Force to respond to Decision XVIII/12. In view of the scope and complexity of the Decision a range of experts were identified from both inside and outside of the current TEAP membership. The following table presents a list of Task Force members by country.

Category/Role	***Name***	***Country***
Co-chairs	Radhey S. Agarwal	India
	Paul Ashford	United Kingdom
Co-ordinator	Lambert Kuijpers	Netherlands
TEAP Members	Stephen O. Andersen	United States of America
	Biao Jiang	China
	José Pons	Venezuela
	Miguel Quintero	Colombia
	Helen Tope	Australia
	Dan Verdonik	United States of America
	Masaaki Yamabe	Japan
	Shiqiu Zhang	China
TOC Members	Denis Clodic	France
	Sukumar Devotta	India
	Roberto Peixoto	Brazil
Other Invited Experts	Dave Godwin	United States of America
	Jean Lupinacci	United States of America
	Guus Velders	Netherlands

In addition to the wide representation on the Task Force itself, the Decision (paragraph 3) invited the TEAP to consult via the Ozone Secretariat with a number of other important stakeholders. These included, but were not limited to, the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, the Intergovernmental Panel on Climate Change (IPCC), the Executive Board of Clean Development Mechanism (EBCDM) of the Kyoto Protocol, and the Secretariat of the Multilateral Fund (UNMLFS).

The Task Force worked with the Ozone Secretariat to prepare letters to the Executive Board of the CDM as well as to other stakeholders. In broad terms, the IPCC has deferred to the UNFCCC in matters covered by the scope of Decision XVIII/12 and has been kept informed by the Task Force on matters covered within an on-going, informal dialogue with the UNFCCC secretariat.

The Chief Officer of the MFS attended the part of the TEAP meeting in Rome for the discussion of Decision XVIII/12, during which the Chief Officer presented the results of the work carried out under the ‘HCFC surveys’ project by one Implementing Agency and by a bilateral project. These results have been fully considered as inputs to the baseline demand considerations if this report.

The EBCDM provided a reply by letter in which it confirmed its interest in the outputs of the TEAP Task Force’s response to Decision XVIII/12 and reiterated many of the challenges currently faced by the Executive Board on HFC-23 projects. Part of the on-going, informal dialogue with the UNFCCC Secretariat has involved the exchange of information on current CDM procedures and the current status of approvals granted to facilities under this Mechanism.

2 Establishing the Baseline for Consumption and Emissions

2.1 Sources of Data

Paragraph 2 of Decision XVIII/12 invites the TEAP to:

> *….provide information on current and future demand for, and supply of, hydrochlorofluorocarbons, giving full consideration to the influence of the Clean Development Mechanism on hydrochlorofluorocarbon-22 production, as well as on the availability of alternatives to hydrochlorofluorocarbons;*

Chapters 2 and 3 of this Report address this request, with Chapter 2 focusing on the demand drivers (for both emissive uses and feedstock), the current production platform and the likely future development of capacity. Chapter 3 focuses specifically on the Clean Development Mechanism and its likely impact on HCFC-22 production and consumption.

The Task Force has evaluated a number of sources of data in preparation for this Report. These include:

- IPCC/TEAP Special Report on Ozone and Climate (SROC)
- Country-specific HCFC surveys from the Implementing Agencies
- World Bank inputs to the Stockholm Group deliberations
- UNEP reported production and consumption to 2005
- The 2006 Assessment Reports of the Assessment Panels

One of the complications of comparing such datasets is that their scope and time scale can often be very different, making the available data difficult to reconcile. For example, the UNEP data will only provide a cross-check for the assessment of historic and current data since it does not make projections. The following table seeks to 'align' these datasets for HCFCs to make comparison possible:

Data Source	***Sub-Set***	***2002***	***2004/5***	***2015***	***Growth Factor***[6] ***(2005-2015)***	***Comment***
SROC	*Global*	496,000	-	551,000	-	
	Developed	268,000	-	47,000	-	
	Developing	217,000	275,000[7]	489,000	1.78	
UNEP Reporting	*Global*	492,255	508,436	-	-	Consumption
World Bank	*Global*		460,000	-	-	
	Developed		180,000	-	-	
	Developing		280,000	786,000	2.81	
HCFC-Surveys	*China*	117,600	143,000	298,000	2.08	
	Latin America	-	34,793	75,104	2.16	5 countries
	Middle East	-	336	692	2.06	Lebanon only
	S/SE Asia	-	17,117	41,654	2.43	3 countries

Table 2.1 – Demand estimates for emissive uses of HCFCs - 2002-2015 (metric tonnes)

---

[6] The term 'Growth Factor' is used throughout this Report to mean the ratio of the demand in 2015 and the demand in 2004/5.

[7] Linear interpolation between 2002 and 2015

It can be seen from Table 2.1 that the estimated growth factor used for the SROC (1.78) is lower than predicted by other forecasts. In contrast, the growth factor of 2.81 anticipated by the World Bank study (and used by the Stockholm Group) is significantly higher than those identified in the HCFC-surveys. Specific reasons for this are discussed in later sections of this chapter.

Although composite growth factors are an appropriate approach for a macro-analysis and can be used to support a generic sensitivity analysis at sector or fluorocarbon level (see Section 4.3.2.1), complications arise when using such generic growth factors for the (sub)-sector-specific analysis required in Section 4.4. This point is considered further in Section 2.1.1. Conversely, although the HCFC-surveys provide good (sub)-sector-specific information, the geographic coverage is not sufficiently broad to support the global assessment required under Decision XVIII/12.

In conclusion, the only data available to the Task Force that meet both the breadth and depth of the requirement for this Report are those that have been already used to support the SROC. For this reason the SROC demand data until 2015 form the backbone of the analysis carried out in this Report. One implication of this data source selection is that estimates of the impact of emission reduction measures are likely to be conservative. Where appropriate, further sensitivity analyses help to put these potential under-estimates into context. The following section gives further information about the SROC dataset.

2.1.1 IPCC/TEAP Special Report on Ozone and Climate (SROC)

Although the SROC provides the most usable data available for the projection of demand by sector to 2015, they are not, in themselves, comprehensive. As noted briefly in Section 1.1.1, the SROC only covers those sectors, that have adopted, or are considering, HFCs or PFCs as possible ODS substitutes. This means that some previous ODS applications (e.g. consumer product aerosols) are not included within the scope. In practice, this is not a major concern, since the focus of this Report is on those applications still using ODSs at present and on those that are likely to use HCFCs or their alternatives in future. Where all ODSs are already phased-out and HFCs/PFCs are not involved as alternatives (such as with consumer product aerosols), there would seem little likelihood of switching back to ODS, unless the economics of ODS use were to shift dramatically. This might conceivably happen if the mitigation of HFC-23 emissions from HCFC-22 production continue to be compensated under the existing CDM provisions. This possible eventuality is reviewed in more depth within Chapter 3.

One of the further complications of using SROC data is that values for demand are only provided for the years of 2002 and 2015. In order to assess the intervening years it is necessary to interpolate between the two points. In the absence of better information, linear interpolation has been used (as shown in Table 2.1). A similar approach was adopted for the development of banks and emissions estimates between 2002 and 2015 where more specific information is not available. Although such an approach may lead to inaccuracies in the annual emission figures for the period to 2015, it ensures that the analyses of banks and emissions in this Report are consistent with the SROC as each of the sectors enters the post-2015 period.

Table 2.2 provides a full set of sectoral data as adopted from the SROC dataset:

Sector	***Sub-sector***	***Demand*** *2002*	***Demand*** *2005 (int.)*	***Demand*** *BAU-2015*	***Growth Factor***	***Bank*** *2002*	***Bank*** *BAU-2015*	***Growth Factor***
CFCs – Developed					*2005-2015*			*2002-2015*
Refrigeration	Domestic	115	84	3	0.04	38,103	356	0.01
	Commercial	700	511	8	0.02	2,885	64	0.02
	Transport	101	73	0	0.00	376	1	0.00
	Industrial	3,443	2,979	1,743	0.59	19518	9,938	0.51
A/C	Stationary	6,019	4,833	1,672	0.35	49,923	13,871	0.28
	Mobile	35,336	25,702	10	0.00	107,513	50	0.00
Foams		0	0	0	-	1,444,698	1,107,552	0.77
Med. Aerosols		6,100	4,436	0	0.00	6,100	0	0.00
Fire Protection		0	0	0	-	*80,078*[8]	*39,668*[6]	*0.50*
Solvents/Other		0	0	0	-	0	0	-
CFCs – Developing								
Refrigeration	Domestic	6,558	4,960	697	0.14	68,936	36,671	0.53
	Commercial	67,466	49,418	1,291	0.03	183,623	6,282	0.03
	Transport	582	428	17	0.04	1,746	72	0.04
	Industrial	3,263	2,868	1,814	0.63	14,836	10,973	0.74
A/C	Stationary	5,174	4,226	1,697	0.40	33,968	13,131	0.39
	Mobile	20,472	15,605	2,626	0.17	41,779	12,814	0.31
Foams		11,293	8,213	0	0.00	413,623	197,638	0.48
Med. Aerosols		1,900	1,927	2,000	1.04	1,900	2,000	1.05
Fire Protection		*3,604*[6]	*2,621*[6]	*0*	*0.00*	*87,662*[6]	*15,826*	*0.18*
Solvents/Other		0	0	0	-	0	0	-
HCFCs – Developed								
Refrigeration	Domestic	0	0	0	-	0	0	-
	Commercial	35,429	28,803	11,135	0.39	100,948	32,961	0.33
	Transport	372	271	1	0.00	2,113	5	0.00
	Industrial	13,372	11,773	7,509	0.64	79,595	46,412	0.58
A/C	Stationary	110,868	88,187	27,704	0.31	751,126	405,148	0.54
	Mobile	709	543	99	0.18	9,196	3,565	0.39
Foams		106,800	77,673	0	0.00	1,050,366	986,231	0.94
Med. Aerosols		0	0	0	-	0	0	-
Fire Protection		454	397	244	0.61	3,820	4,956	1.30
Solvents/Other		8,000	6,091	1,000	0.16	8,000	1,000	0.13
HCFCs – Developing								
Refrigeration	Domestic	0	0	0	-	0	0	-
	Commercial	125,611	184,427	341,268	1.85	214,690	728,683	3.39
	Transport	543	634	875	1.38	1,583	2,822	1.78
	Industrial	13,131	14,168	16,934	1.20	62,140	80,023	1.29
A/C	Stationary	54,631	61,134	78,475	1.28	276,446	472,774	1.71
	Mobile	2,125	1,840	1,080	0.59	11,285	19,773	1.75
Foams		21,016	28,926	50,020	1.73	76,067	516,252	6.79
Med. Aerosols		0	0	0	-	0	0	-
Fire Protection		68	67	65	0.97	571	1,317	2.31
Solvents/Other		3,000	6,273	15,000	2.39	3,000	15,000	5.00

Table 2.2 Trends in demand and bank data for 2002, 2005 & 2015 - SROC

---

[8] Halon

Growth factors (highlighted in mauve in Table 2.2), as used in the HCFC-surveys and carried forward to this analysis, are defined in such a way that a growth factor below 1 is effectively shrinkage in either annual usage or bank size.

For the CFC data, there is a slight increase in use for medical aerosols in developing countries. Otherwise, declines in use are slowest in the industrial refrigeration and stationary A/C sectors. This is also reflected in the sizes of the residual banks in 2015. For foams, the CFC banks in 2015 are still substantial in both developed and developing countries. However, the bank decline in developing countries is more rapid than in developed countries, reflecting that most CFC use in foams in developing countries is in appliances rather than longer-lived building applications.

For the HCFC data, the most notable aspect in developing countries is that the demand growth in commercial refrigeration and foams is assumed to far outstrip the growth in other refrigeration and stationary air conditioning sectors. This assumption may understate the growth of air conditioning use if unusually high humidity and/or temperatures come to regions with currently low air conditioner penetration or if increasing incomes in hot climates make air conditioning more common. The sub-sector, as defined, covers all A/C uses in domestic and industrial areas, from small HCFC units to large water chillers. It could well be that the country that currently produces the most A/C units (China) will establish a much higher growth in the use of HCFC-22 for stationary A/C units than forecast for all other developing countries in the SROC.

The growth assumed in the commercial refrigeration sector (extrapolated from the 1998-2002 trend) may also be too high. The SEPA/GTZ report presents scenarios, which show an HCFC-22 demand in 2015 between 100,000 and 160,000 tonnes in the A/C sub-sector for China only, with a much smaller growth in commercial refrigeration demand. It has also been mentioned that the Chinese A/C manufacture and servicing already consumes 30% of the total current developing country HCFC-22 consumption. This underlines the fact that China actually has a dominant place in the total demand numbers for the developing countries, certainly in stationary A/C, and that this sub-sector in China can be assumed to be one of the most important sub-sectors if reduction of HCFC-22 needs to be addressed.

It should be noted that the aggregated SROC forecast of HCFC-22 demand from both the commercial refrigeration and the stationary A/C sectors may well give a reasonable estimate for the year 2015. Data have therefore not been adjusted for the separate sub-sectors and have been kept as presented in the SROC for the entire period 2002-2015, since a self-consistent set of BAU (sub)-sector-specific trends are an essential element of the analysis of further practical measures. This re-confirms the need to work with the SROC data as the primary source of data. Nonetheless, it is important to continue to assess the limitations of the dataset and the next sections address in more detail some of the alternative perspectives.

2.1.2 Relationship with the 2006 Science Assessment Panel Report

The A1 baseline scenario of the 2006 Science Assessment Panel (SAP) Report has been developed to include aspects of the SROC methodology. Table 8-4 of that Assessment Report sets out the assumptions made. The A1 scenario uses as its base the UNEP production data adjusted for feedstock use. Stocks within the supply chains are therefore a distinguishing factor of this dataset.

Another major difference between the SAP methodology and that used for the SROC is that annual emissions within the SAP Assessment Report are derived from atmospheric observations, whereas annual emissions within the SROC are generated from demand estimates and by applying relevant emission factors to the respective parts of the product/equipment lifecycle. This requires a reliable time-series of consumption data by end-use. Both methodologies were discussed in depth within the 2006 TEAP Task Force Report on Emission Discrepancies (TFED), leading to the conclusion that both have shortcomings but that, within margins of error, there is a basis of agreement between the two approaches.

The key new linkage between the SROC data and the SAP Assessment Report is that historical bank sizes are adjusted to deliver the same bank size in 2002 as the SROC when the atmospherically derived emissions are applied. For the period beyond 2005, the forward emission factors are adjusted within the A-1 Scenario so that the emissions derived by the SAP lead to the same bank size in 2015 as the SROC.

In addition, demand estimates within the 2006 SAP Assessment Report for HCFCs are linearly interpolated (as in this report) between 2005 and 2015 to align with the SROC demand growth. Since the SROC demand growth is considered to be a relatively conservative estimation (that is low growth compared to other assessments), then the 2006 SAP Assessment Report could also be viewed as providing a relatively conservative view of the impact of HCFC demand growth in the pre-2015 period.

2.2 Other Consumption Estimates to 2015

HCFC-Surveys

The HCFC-Surveys (with the exception of the China survey) were commissioned by the Executive Committee of the Multilateral Fund[9] and conducted under the auspices of the UNDP in the period from late 2005 to early 2007. The work covered four key regions:

Latin America:	Argentina, Brazil, Colombia, Mexico, Venezuela
Middle East:	Lebanon, Syrian Arab Republic
South Asia:	India, Islamic Republic of Iran, Sri Lanka
South East Asia:	Indonesia, Malaysia

The surveys characterise consumption[10] in each country as at 2005 and forecast the impact of unconstrained growth through to 2015. The results of this assessment are summarised in Table 2.1.

---

[9] At its 45th Meeting

[10] As defined by use

Apart from growth estimates, the survey reports also highlight some of the issues facing developing countries in the period up to and beyond 2015. These observations were as follows:

- Refrigerant leakage rates are almost certainly above 50% annually based on the age-range of equipment in use;
- High servicing demand for existing equipment means that it is difficult to shift consumption patterns quickly and that the market penetration of alternatives is difficult; and
- Early transitional action is required to prevent an over-shoot of the Montreal Protocol freeze, scheduled currently for 2015.

The HCFC Survey in China was conducted by SEPA (China) and GTZ (Germany) and bases its assessment on 2004 consumption data. The work was conducted to provide a "Terms of Reference for Development of a Suitable Strategy for the Long Term Management of HCFCs, in Particular HCFC-22 in China". In view of China's strong production base, this work focused on both production and consumption assessments. The report noted that 'expanding the use of alternatives (e.g. R-410A and R-407) is hampered mainly by economic barriers'. Three scenarios were assessed for more rapid transition of the production of stationary air conditioners by 2015 (25%, 33% and 50% respectively).

As noted in Section 2.1, the HCFC-surveys represent an important and detailed 'bottom-up' assessment in a number of key developing countries. They offer important benchmarks for global assessments. Since each survey provides country-specific issues that cannot be extrapolated to others, they are of limited use for general policy discussions.

World Bank analysis

The World Bank delivered a presentation to the Third Meeting of the informal "Stockholm Group" in February 2007. This material has formed a considerable part of the forward thinking that has since emerged from the Stockholm Group. As highlighted in Table 2.1, the World Bank's estimated growth ratio (2.81) is considerably higher than that contained in either the SROC or the HCFC Surveys. This is primarily because the growth rates used for the period between 2005 and 2015 have been assumed to be 10% per annum. This assumption was supported by the fact that annual developing country growth rates in the period 2001-2004 were over twice that amount.

However, in adopting such an approach, consideration needs to be given to whether there were any compounding factors for the period 2001-2004, which might have inflated the growth rates unduly. Since HCFC-22 is not typically a substitute for existing CFCs, it is unlikely that technology transitions will have had a major effect. However, for HCFC-141b and HCFC-142b there will have been significant transitions away from CFC-11 and CFC-12 that could contribute to unusually high consumption over that period. In the light of the various bottom-up assessments (SROC, HCFC-surveys etc.) now available, it seems less likely that aggregate growth ratios would exceed 2.5. Nevertheless, the World Bank analysis represents an important exception, highlighting the possibility that historic growth rates could dictate higher growth factors and that the trends need to be watched carefully.

2006 TEAP and TOC Assessment Reports

Both the Refrigeration and Foams TOC Assessment Reports for 2006 contain quantitative forecasts of demand, based on a re-evaluation of the status in 2005.

The Refrigeration and Air Conditioning Assessment Report notes that future growth patterns in refrigerant use within developing countries are uncertain, although changes in demand for export markets (e.g. the proposed US restrictions on imports of HCFC-22 containing equipment in 2010) could drive transition in those developing countries with thriving export markets. If the US restrictions were globally implemented, demand for HCFC-22 could actually decrease between 2010 and 2015 for some sectors of the refrigerant market. The implication is that the existing SROC 2015 assessment for the refrigeration sector could either be too high, or that the shape of the growth curve could be different than the SROC forecast.

For foams, the big development since the completion of the SROC Report has been the unexpected growth of extruded polystyrene (XPS) foam manufacture and use in China. Although the choice of blowing agent is unclear between HCFC-142b and HCFC-22, the 2006 Foams TOC Assessment Report forecasts that demand for HCFCs in XPS in 2015 could be as high as 33,000 tonnes in China compared to a value of 10,000 or less for 2005. Within the HCFC-survey data for China, there is no specific allocation of HCFC-142b sales by end-use, although the report suggests that overall there is between 5,000-10,000 tonnes of HCFC-22 or HCFC-142b going into this application as at 2005.

The cost of installing foam capacity in this sector is surprisingly low and SEPA/GTZ already believes that there is three times as much capacity as production at present, since growth rates are running at about 20% annually. This is consistent with information available to the FTOC. Taking a more conservative view of the future, SEPA/GTZ forecast a 9% per annum growth rate from 2006-2010 and 7% per annum from 2011-2015, which leads to a growth factor of 2.16. An on-going annual growth rate of 20% would result in a growth factor of greater than 6. The FTOC has estimated a growth factor of approximately 3.3, which would seem a reasonable estimation at this stage.

One of the key aspects of this discussion, is that XPS manufacture tends to be a fairly emissive process (~25% in production) making contributions to immediate emissions substantial. This may be particularly significant in the case of HCFC-142b, which has a Global Warming Potential of 2,270 compared with a GWP for HCFC-22 of 1,780.

Chapter 8 of the 2006 TEAP Assessment Report focuses in a qualitative way on the changes that have been observed since the 2003 HCFC Task Force Report. Interestingly, the 2003 report suggested that total HCFC demand in developing countries in 2015 would be approximately 348,000 tonnes – i.e., only 71% of the SROC estimate shown in Table 2.1. This indicates that the majority of the upward adjustments in forecast consumption were made in the period prior to the finalisation of the SROC.

2.3 Feedstock Uses

The use of ODSs as feedstock has been considered in a number of previous TEAP Reports. With specific reference to HCFCs, the most relevant publication was the 2003 HCFC Task Force Report, which identified the specific uses. In summary, three HCFCs have significant feedstock application. These are:

(1) HCFC-22 - primarily for the manufacture of tetrafluoroethylene (TFE), which is a precursor to polytetrafluoroethylene (PTFE)

(2) HCFC-142b - primarily for the manufacture of vinylidene fluoride (VdF) which is a precursor to poly(vinylidene fluoride) (PVdF)

(3) HCFC-123 - primarily for the manufacture of pharmaceuticals and agricultural products

Individual trends for each of these applications are covered in the following sections.

2.3.1 HCFC-22

The use of HCFC-22 as a feedstock for polytetrafluoroethylene (PTFE) production dates back well into the 20th century. Historically, it has represented a significant share of total HCFC-22 demand. However, as some of the emissive uses of HCFC-22 have been phased out in developed countries, the proportion of HCFC-22 production destined for feedstock applications has increased. Figure 2.1 illustrates this growth.

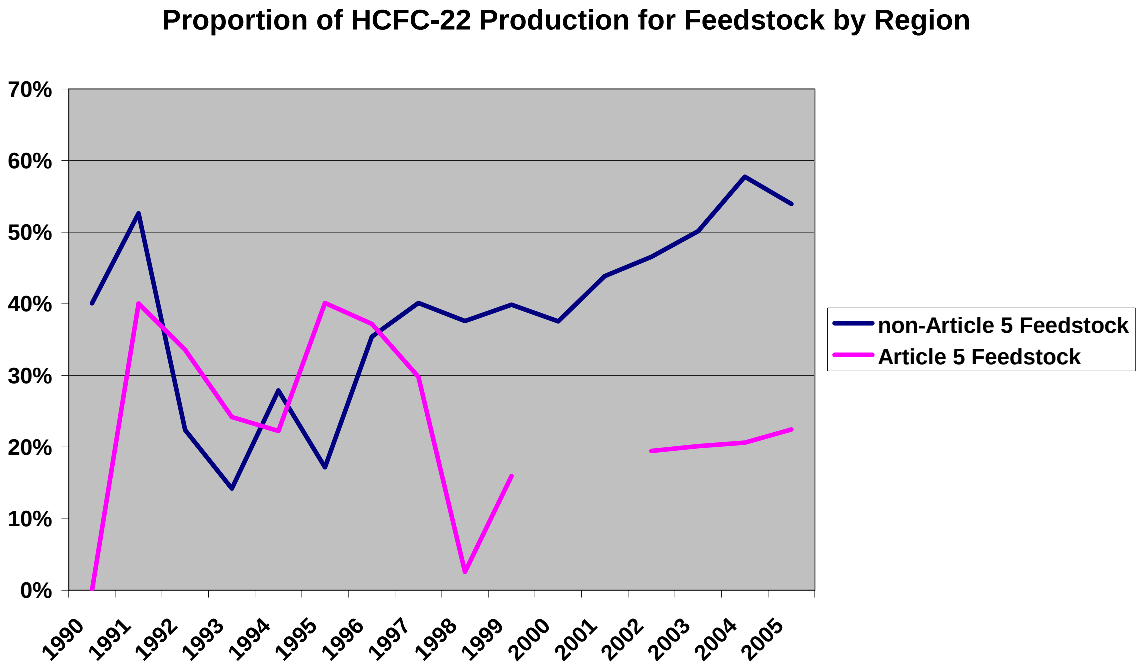


Figure 2.1 - Trends in feedstock production as a share of total HCFC-22 production by region
(no data available for 2000 & 2001 in developing countries)

HCFC-22 demand for feedstock becomes a more significant proportion of the overall HCFC production in the developed countries, while it has typically become less dominant in developing countries as HCFC-22 demand for emissive uses has increased. However, Figure 2.2

illustrates that total production of HCFC-22 for feedstock uses has increased in both developed and developing countries:

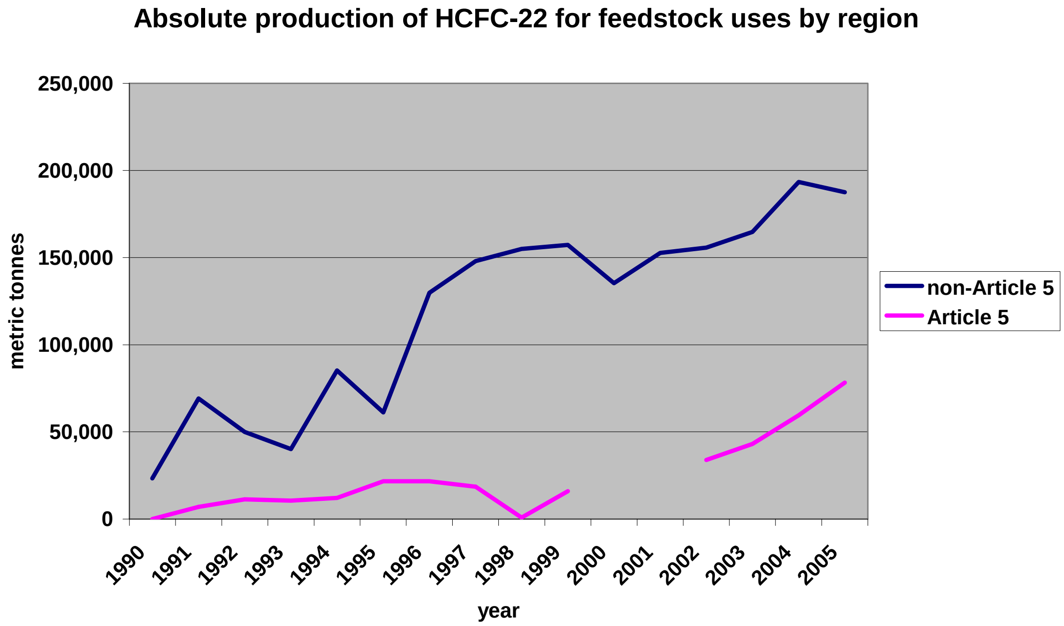


Figure 2.2 - Growth in overall HCFC-22 production for feedstock uses by region

Global HCFC-22 demand for PTFE production was estimated in 2004[11] to be growing at 3-4% annually. Accordingly, Figures 2.1 and 2.2 may reveal the first signs of a possible shift of HCFC-22 feedstock production from developed to developing countries, as capacity increases in the latter. This could be influenced by the lower costs of production in developing countries, which result from low cost raw materials and labour and typically from the cost advantages of a less stringent regulatory environment. The specific impact of the Clean Development Mechanism is treated separately in Chapter 3 of this Report.

The World Bank data may indicate that the transfer of HCFC-22 feedstock production from developed to developing countries, as suggested here, is a compounding factor on the forward growth rates adopted in that analysis. In addition, based on the relatively small shift in production to developing countries observed to date, the estimate made by the World Bank that approximately 40% of developing country production of HCFC-22 is for feedstock may be somewhat too high.

2.3.2 Other HCFCs

The quantities of HCFC-142b and HCFC-123 used for feedstock uses are significantly lower than for HCFC-22. However, feedstock uses of HCFC-142b and HCFC-123 as a proportion of total HCFC-142b and HCFC-123 use is often higher than for HCFC-22. The situation for HCFC-142b is shown in the following Figures (2.3 and 2.4).

---

[11] e.g. European Chemical News 10-16 May 2004, Page 16

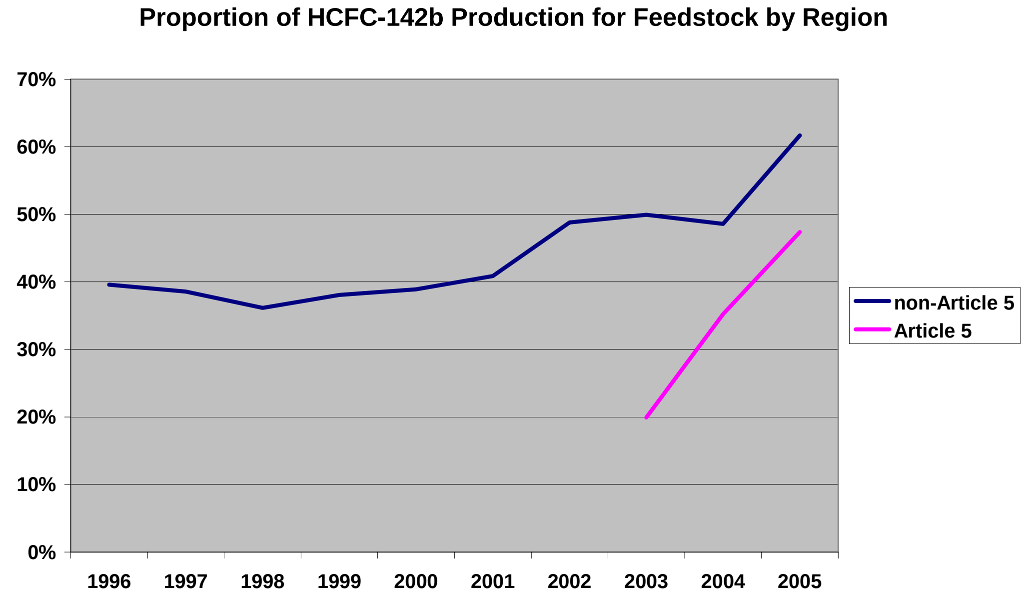


Figure 2.3 - Trends in feedstock as a share of total HCFC-142b production by region

The growth in the proportion of feedstock demand relative to emissive uses in developed countries is a direct mathematical consequence of the phase-out of a number of emissive uses (most notably foam blowing agents) over the same period. The data for developing countries illustrate that production for feedstock is a relatively new phenomenon in developing countries, and, as Figure 2.4 illustrates, the amounts are still only small.

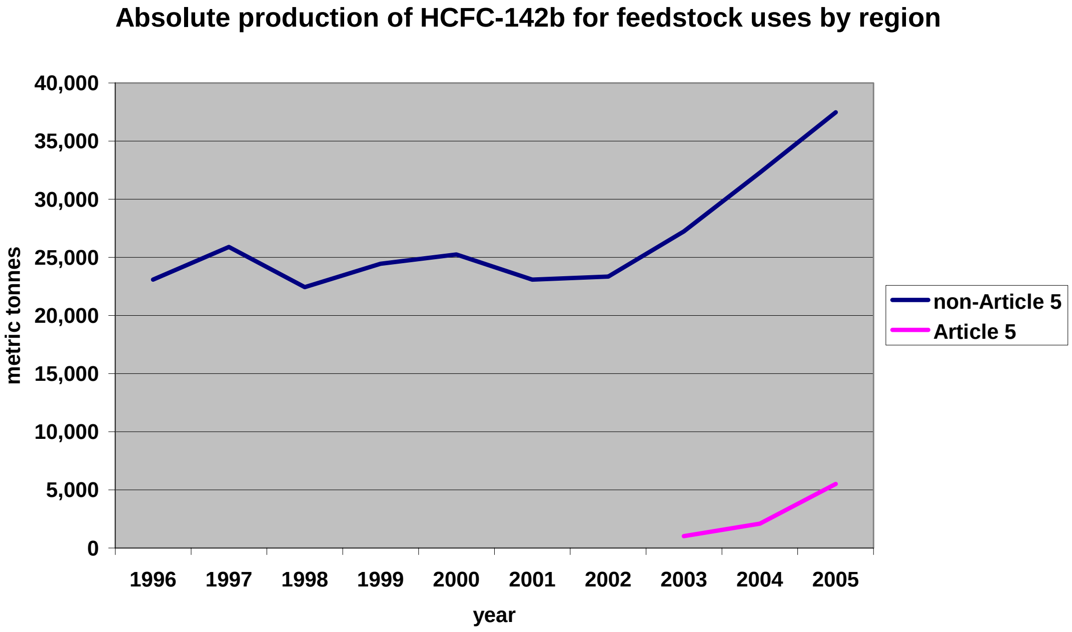


Figure 2.4 - Growth in overall HCFC-142b production for feedstock uses by region

Figure 2.4 shows a significant growth in demand for HCFC-142b as a feedstock in developed countries since 2002. The rationale for this is not clear, but is likely to be related to a growth in demand for PVdF. A further factor could be a decrease in the price for HCFC-142b following the removal of demand for emissive uses (e.g. for foam production) in Europe and elsewhere.

For HCFC-123, feedstock production supports non-polymeric downstream uses in both pharmaceuticals and the agricultural sector. Figures 2.5 and 2.6 provide an overview of the feedstock production of HCFC-123 for these applications.

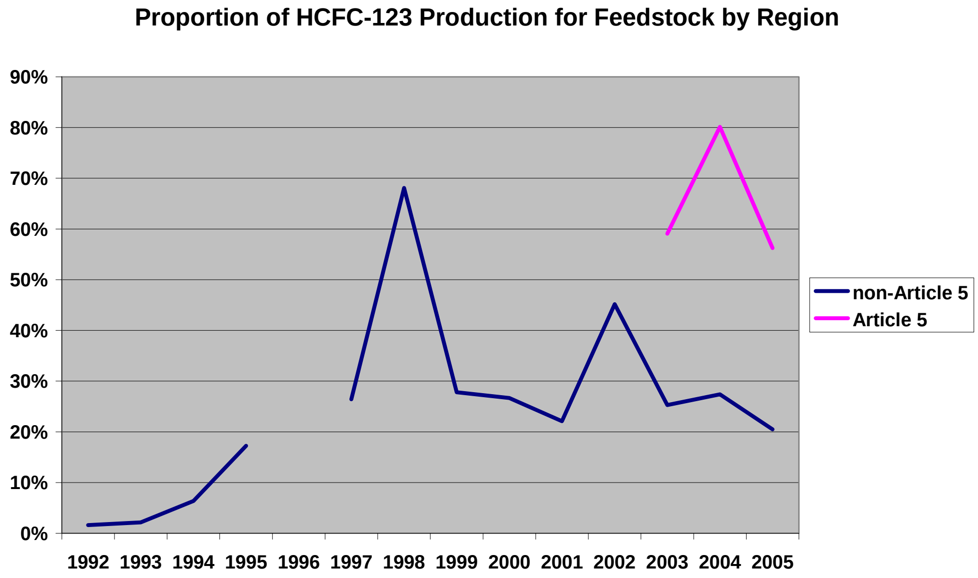


Figure 2.5 - Trends in feedstock production as a share of total HCFC-123 production by region

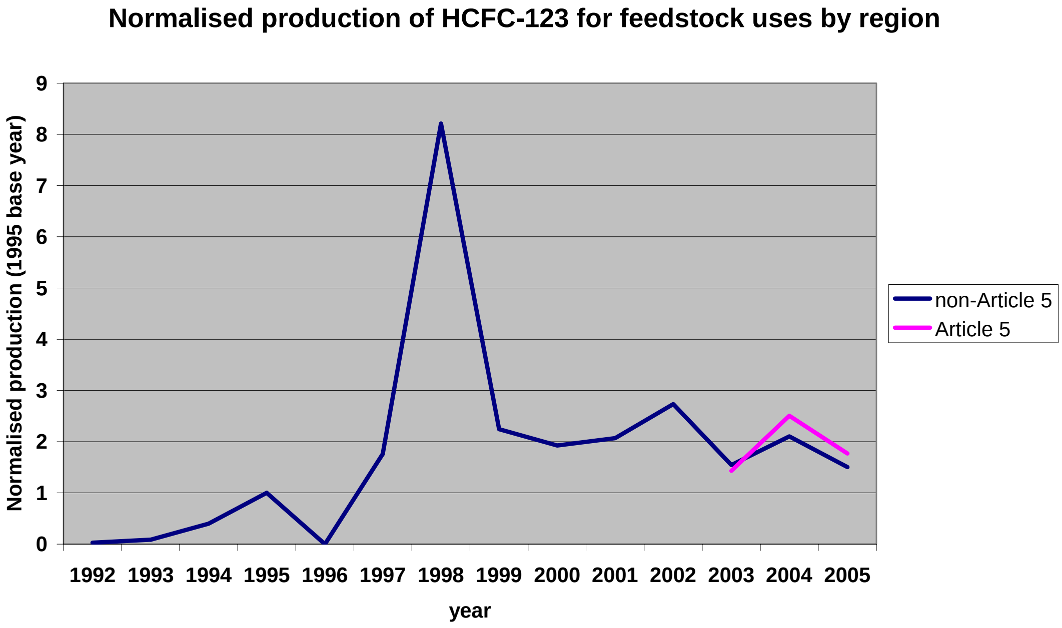


Figure 2.6 - Changes in overall HCFC-123 production for feedstock uses by region

The low overall production amounts for HCFC-123 tend to create substantial fluctuations in annual proportions. However, it is important to note that most HCFC-123 manufactured in developing countries is for feedstock use.

There is no obvious explanation for the high reported feedstock demand in 1998; with low overall volumes such data irregularities can occur.

2.4 Trends in the Location of HCFC Production to 2015

It is important to gain an overall view of the trends in the location of HCFC production since 1990 and how these might be extrapolated through to 2015 in determining baseline HFC-23 emissions related to HCFC-22 production against which later *practical measures* will be assessed.

Although typical HFC-23 emissions are discussed in more detail in Section 3.2.1, for the purposes of this chapter, this Report assumes HFC-23 emissions as 1.5% w/w of HCFC-22 production in developed countries and 3% w/w of HCFC-22 production in developing countries. The origins of these differences tend to lie in the age and design of the plants, with emissions being more difficult to control in ‘swing’ plants.

Figures 2.7 and 2.8 illustrate the trends in regional location of HCFC-22 and ‘other HCFC’ production. The trends are largely driven by changes in local demand for the products in question. However, changes in inter-regional trade have also played an important part over time, as developing country manufacturing bases have matured.

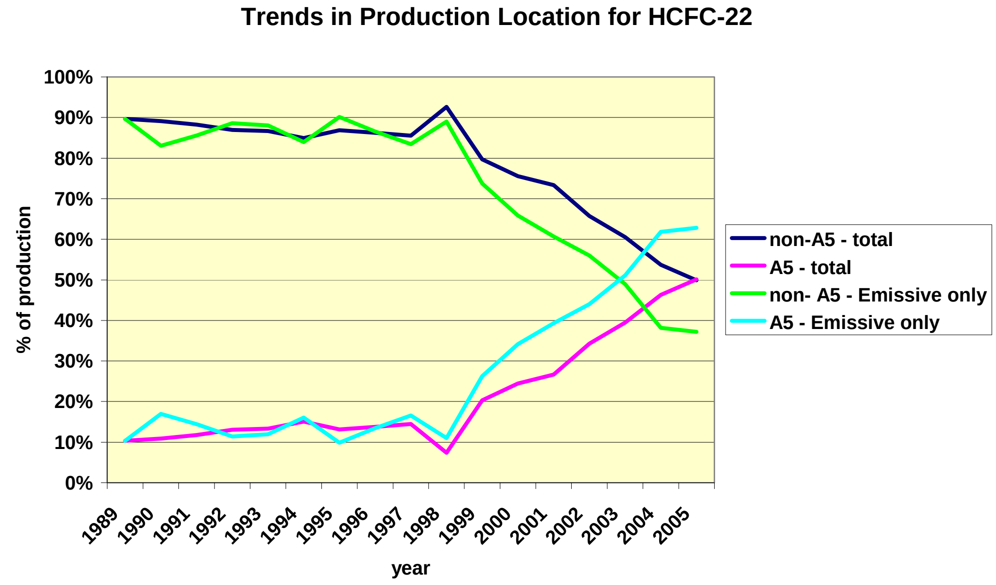


Figure 2.7 – Location of HCFC-22 production reflecting both emissive and total uses

The transfer of production from developed to developing countries is more abrupt for emissive uses than for all uses including feedstock. There is also some stabilisation of production for emissive uses after 2004, although data from subsequent years will be required to see if this trend is maintained. For the purposes of this Report, it has been assumed that the trend for total

HCFC-22 production will continue and equilibrate finally in 2015 at 90% developing and 10% developed. This assumption therefore drives baseline HFC-23 emission estimates, which are related to total HCFC-22 production.

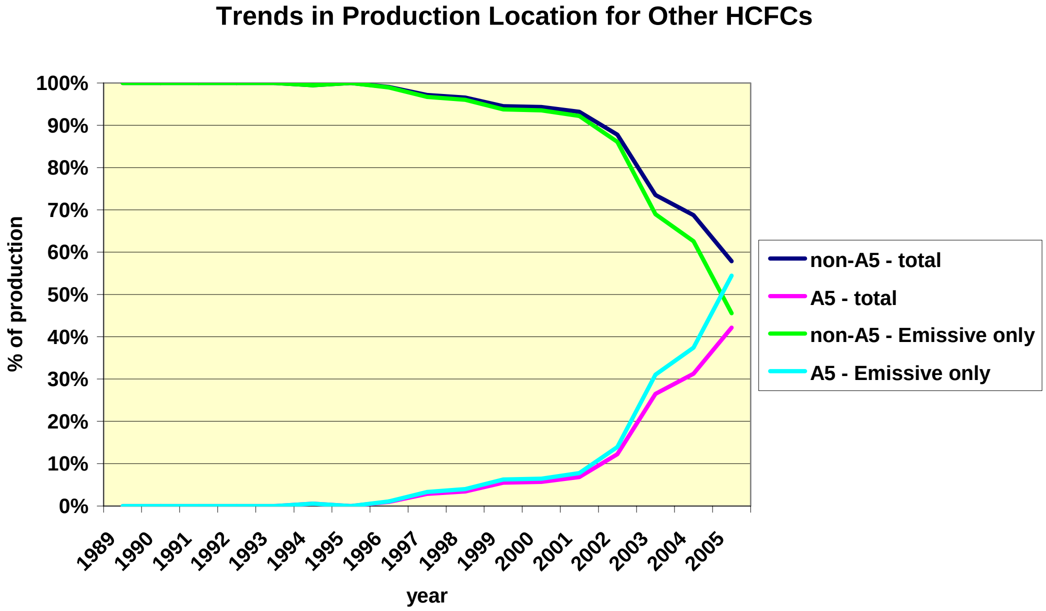


Figure 2.8 – Location of 'Other HCFC' production reflecting both emissive and total uses

For HCFCs other than HCFC-22 ('other HCFCs'), trends are similar to those for HCFC-22, except that the transition started later. For all uses including feedstock, most production remains in developed countries as of 2005, although the 'cross-over' to a majority of production in developing countries is likely to occur before 2008.

In the light of the similarities between the data presented on the curves, the production assumptions used for HCFC-22 in respect of the period to 2015 have been extended to 'other' HCFCs, although these assumptions have no substantial bearing on baseline emissions, since no HFC-23 is produced as fugitive emissions.

2.5 Assessing the Post-2015 Period for Consumption

As noted in Section 1.1.1, the SROC only assesses the period up to 2015. One of the main reasons for this restriction was the difficulty in forecasting beyond 2015 with any degree of certainty, in particular for HFCs since the details of any production or consumption controls could not be reasonably predicted. However, for CFCs and HCFCs the baseline assumption is more certain, since CFCs are scheduled for phase-out in 2010 and use of HCFCs for developing countries will be frozen in 2015, with a phase-out in 2040. Therefore, forecasting post-2015 consumption is less uncertain for this Report than for the SROC.

However, there are two key elements, which are necessary to define the baseline for the post-2015 BAU scenario:

(1) The growth factor between 2005 and 2015 for HCFCs in developing countries

and

(2) The phase-down schedule for HCFC demand in the period between 2015 and 2040

As elaborated in Section 2.1, there is a range of growth factors resulting from the various assessments that have been conducted. The SROC data form one of the more conservative estimates at 1.78, with most others being above 2.00. The reason for choosing the SROC estimates as the baseline for this Report is because there are significant sectoral variations that can be depicted properly only when disaggregated (sub-sectoral) data are available, as is the case for the SROC data. Nevertheless, the application of sensitivity analyses to any of the major outcomes of this Report is important in this situation and is dealt with primarily in Chapter 5.

Predicting the phase-down schedule for HCFC demand has even more uncertainties than growth factor estimation and can be addressed in a number of manners. Section 4.3.1 deals with a selection of accelerated phase-down scenarios but requires a rational baseline against which to evaluate benefits. It is probable that any accelerated phase-out schedule will involve periodic steps, since these are most suited to ensuring compliance. However, the only compliance measure in the post-2015 period under the current regulatory framework is a complete phase-out by 2040.

The Science Assessment Panel in its 2006 Assessment Report opted for a linear phase-down in the last ten years (i.e. between 2030 and 2040). From a modelling perspective, linear trends are much easier to manage and tend to ‘average out’ the actual steps that occur. This Report adopts the same approach for evaluating accelerated phase-down options in Section 4.3. However, there is no real evidence to suggest that, in practice, HCFC users in developing countries will undergo a phase-out over such a long period.

For the refrigeration sector, much depends on when alternatives to HCFC-22 are introduced for new equipment. With well over 50% of current refrigerant demand being for servicing and the lifetime of typical refrigeration equipment being well in excess of 15 years, technology transitions would need to be well underway before 2015 to generate the opportunity to significantly phase-down overall consumption as early as 2030. This lag in the time between technology transition and change in consumption pattern is an important observation of this Report and suggests that preparations for transition should not be delayed.

The Task Force has concluded that the most reasonable basis for evaluation is to freeze consumption at 2015 and leave it unchanged until 2040. Although this approach is likely to over-estimate the cumulative consumption in the 2015 to 2040 period, it provides a baseline evaluation of the emissions saved by any *practical measure* subsequently applied. The baseline adopted is the one shown in Figure 2.9.

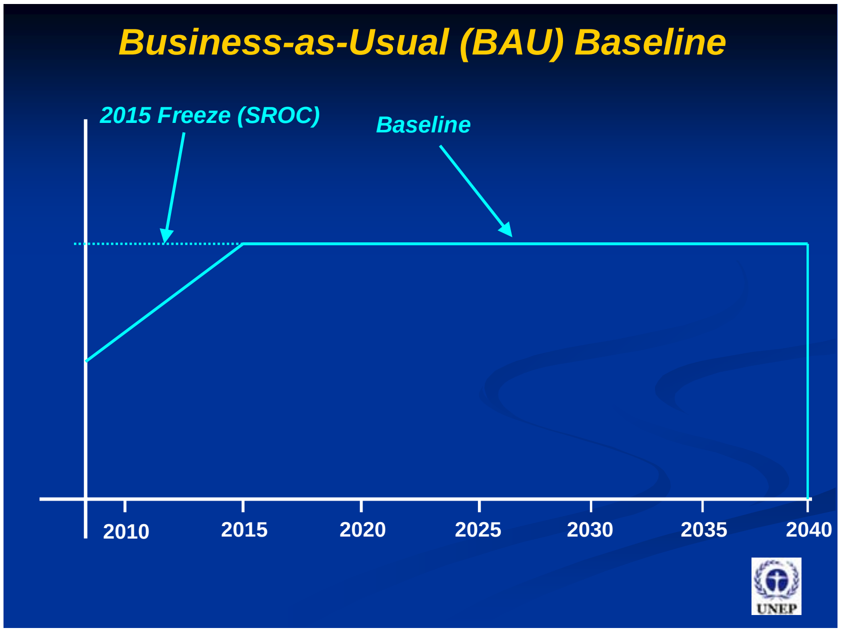


Figure 2.9 Business-as-Usual (BAU) Baseline based on 2040 'instantaneous' phase-out

2.6 Period of Analysis for Emissions

One of the critical elements of modelling emissions is to understand that annual consumption is not equal to annual emissions for a number of ODS sectors where ODS are contained in equipment or insulating foam. The concept of banks was extensively researched and documented within the SROC, which highlighted the fact that, in some product groups (most notably foams), emissions of CFCs could be delayed by up to 100 years. Figure TS-16, taken from the SROC Technical Summary, even suggests that CFCs will still be the most significant greenhouse gas being emitted from foams in 2100. In contrast, for the BAU graphs contained in Section 2.7, the bulk of ODS emissions from the refrigeration sector will have already occurred prior to 2050.

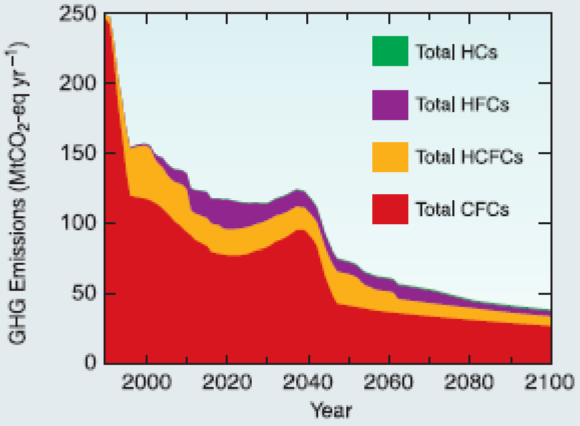


Figure TS-16. GWP-weighted blowing-agent emissions by group (1990–2100) – business-as-usual scenario.

In these circumstances one option would be to plot total cumulative emissions for each sector without reference to a time-scale. However, although this would give a comparison of overall potential impact, it would not give the important time-related series required to assess the specific impact on ozone recovery. One of the key new findings of the 2006 Science Assessment Report was that the timing of emission from banks and their location in the mid-latitudes would have an important impact on the timing of ozone-hole recovery over the Antarctic.

With these factors in mind, this Report provides the full time series to 2050 and, where necessary, then aggregates any post-2050 emissions in order to illustrate the overall size of potential ‘post-2050’ emissions. For the most part, this will have relevance primarily in the foam sector where product lives are long and in-tact products find their way into waste streams.

2.7 Baseline Consumption, Banks and Emissions to 2050

Post-2015 emission factors from banks

The methodologies and assumptions set out in this chapter provide the basis for assessing baseline consumption to 2040 (and to 2050 for feedstock). However, the emission rate for banked materials in the post-2015 period is also required to assess the development of ODS banks and associated emissions.

Although it is possible to forecast emissions from banks with some degree of confidence in some sectors and sub-sectors, in many cases this is not possible. For those sub-sectors for which reliable data are not available, this Report applies annually the ratio of emissions to bank size for 2015 (SROC-BAU) to the remaining bank. This results in an exponential decay of the bank, except where new consumption is being added. In such cases (e.g. HCFC use in developing countries) both factors are applied to the bank annually in order to quantify the bank’s size.

One limitation of this approach is that it does not provide for any differentiation of the mix of life-cycle components. For example, the ‘bump’ in the foam curve depicted at around 2030-2040 in SROC Figure TS-16 referenced above is a reflection of the fact that many building insulation products are reaching end-of-life at around that period. For foams, the most emissive step in their life-cycle is decommissioning at end-of-life – hence the ‘bump’. This would not show up in the default method described above. Nonetheless, the foam life-cycle is relatively exceptional and the default option will be more realistic for more emissive applications such as refrigeration. Table 2.3 provides information on the defaults used by region.

Sector	Sub-sector	DEVELOPED COUNTRIES							DEVELOPING COUNTRIES						
		CFCs		***HCFCs***					***CFCs***		***HCFCs***				
Emission Factor	(%) @ 2015	11	12	22	141b	142b	123	124	11	12	22	141b	142b	123	124
Refrigeration	Domestic	-	8.4	-	-	-	-	-	-	13.8	-	-	-	-	-
	Commercial	-	58.7	33.6	-	-	-	34.4	-	70.3	39.5	-	-	-	33.3
	Transport	-	-	40.0	-	-	-	-	-	88.6	44.3	-	-	-	-
	Industrial	15.8	15.7	15.7	-	-	-	-	17.1	20.4	16.7	-	-	-	-
A/C	Stationary	24.8	24.6	14.8	-	-	9.4	-	25.6	23.4	12.7	-	-	18.8	-
	Mobile	-	36.0	48.6	-	-	-	-	-	35.4	45.6	-	-	-	-
Average	Refrig. A/C	24.3	20.0	20.8	-	-	9.4	34.4	25.4	24.3	28.5	-	-	18.8	33.3
Foams		1.1	0.8	1.0	1.6	0.8			2.2	3.8	0.4	1.6	1.8	-	-
Aerosols	Medical	-	-	-	-	-	-	-	100	100	-	-	-	-	-
	Non-medical	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solvents		-	-	-	50.0	-	-	-	-	-	-	50.0	-	-	-

Table 2.3 Default annual bank emission factors by sector and sub-sector for most common ODS

For both foams and halons, specific emission data is available, and emission factors for halon banks at 2015 have been taken as 2% per annum for developed countries and 4% per annum for developing countries. There is an added complication with fire protection equipment in that emission factors for portable extinguishers tend to be greater than for fixed systems. Accordingly, some weighting should normally be applied for the mix of installed equipment. However, since the emissions from halon banks are extremely small in the context of other emissions assessed by this Report, the figures given above have been applied.

Resulting baselines

Having established the methodology for determining the relevant baselines, it is then possible to assess the outputs. In accordance with the requirements of Decision XVIII/12, the information is presented firstly in terms of consumption, banks and emissions by ODP tonnes and then by Mtonnes CO_2-eq. Where relevant, the data includes information on feedstock use and its implications.

In order to keep the graphs legible, the data is consolidated into fourteen basic categories.

Refrigeration	Developed	CFCs
		HCFCs
	Developing	CFCs
		HCFCs
Foams	Developed	CFCs
		HCFCs
	Developing	CFCs
		HCFCs
Other[12]	Developed	CFCs
		HCFCs
	Developing	CFCs
		HCFCs
Feedstock	Developed	HCFCs
	Developing	HCFCs

- *Baseline impacts on the ozone layer*

Figures 2.10, 2.12 and 2.13 provide BAU assessments of the respective consumption, bank development and emissions of ODSs in ODP tonnes. Each of the graphs covers the period from 2002 to 2050, although it should again be noted that where data have been interpolated between 2002 and 2015, the graphs show more linear trends than there may be in practice. Nevertheless, the graphs illustrate important information on the relative significance of the sources. The feedstock information is relevant only to consumption, and not to banks or emissions, since there are no banks or emissions associated with feedstock in practice. Similarly, the implications of the associated HFC-23 production and emission do not show up in the ODP analysis, but do in the climate impact assessment that follows.

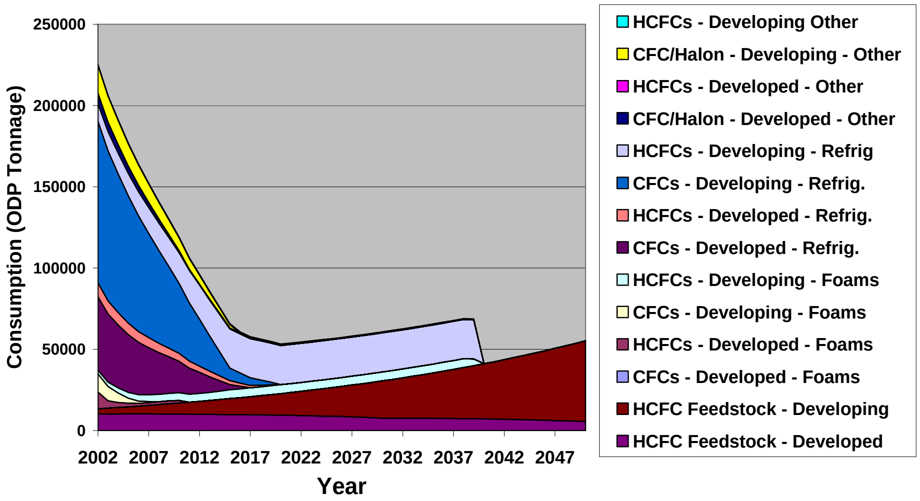


Figure 2.10 Consumption in ODP tonnes for ODS inclusive of feedstock (2002-2050)

---

[12] The ‘Other’ category includes fire protection, solvents and medical aerosols

The growth in feedstock consumption for HCFC-22 is based on the assumption that growth in PTFE demand will continue at 3% per year for the period to 2050. It is also assumed that the regional split of HCFC-22 feedstock production will eventually reach the 10% developed/90% developing ratio envisaged for HCFC-22 production related to emissive uses (see Section 2.4). Under this scenario production in developed countries shows slow decline in real terms, suggesting a lack of regional re-investment. However, overall HCFC-22 production requirements grow significantly, as shown in Figure 2.11.

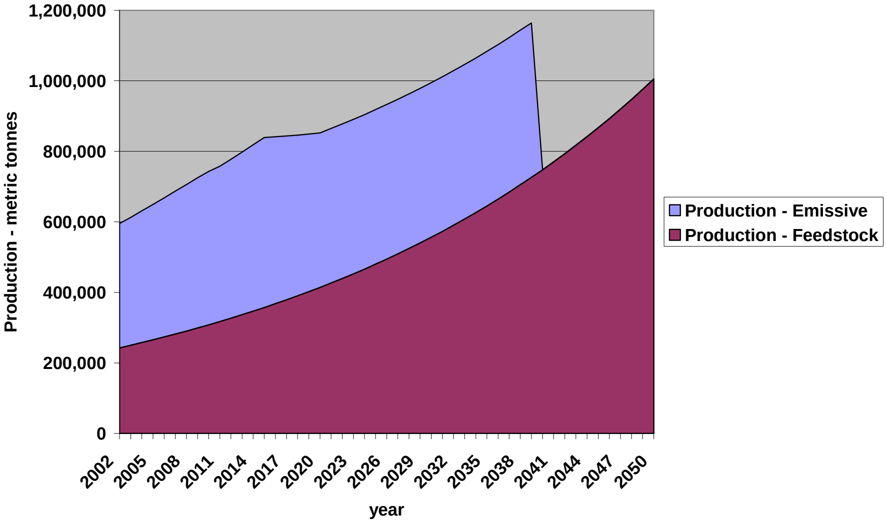


Figure 2.11 – Anticipated growth in HCFC-22 production in BAU case to 2050

Modelling of the baseline scenario results in a significant discontinuity in HCFC-22 production around 2040. However, this is likely to be less severe in practice, since the phase-down of HCFC consumption in emissive uses is anticipated to be less abrupt. Indeed, it may be that total demand is maintained at or below 1,000,000 tonnes, which would imply that the current global capacity of 900-950,000 tonnes would not need to be expanded that greatly. However, with plant replacement and regional redistribution, a considerable number of new plants might be expected to emerge over the next 30 years. Figure 2.12 (below) illustrates the trends in bank development and, as expected, the overall bank size declines in ODP tonnage terms. Even in 2050, the CFCs banked in foams remain the most substantial element, with refrigeration and other applications having less significant banks in ozone terms.

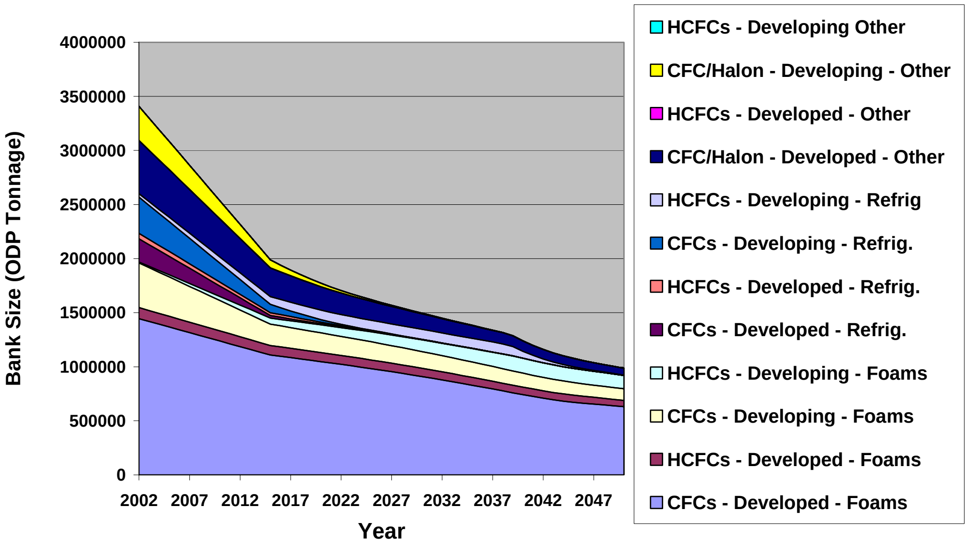


Figure 2.12 Bank development in ODP tonnes for all ODS applications (2002-2050)

With respect to emissions, the refrigeration sector becomes considerably more significant, as is shown in Figure 2.13. Using this analysis, HCFC usage in the refrigeration sectors of developing countries becomes the largest single source of emissions. Figure 2.14 provides a more in depth assessment of the sources of the same refrigeration emissions by sub-sector based mostly on the emission factors set out in Table 2.3. Owing to the relatively emissive design, servicing and disposal practices and the fact that transitions from ODS in mobile air conditioning have largely by-passed the use of HCFCs, the impact of emissions from this source broadly disappears in ODP terms by 2020. The dominant emissions from 2020 onwards are from the commercial refrigeration sector in developing countries. One of the primary drivers for this is the growth of supermarkets and their supporting food supply-chain.

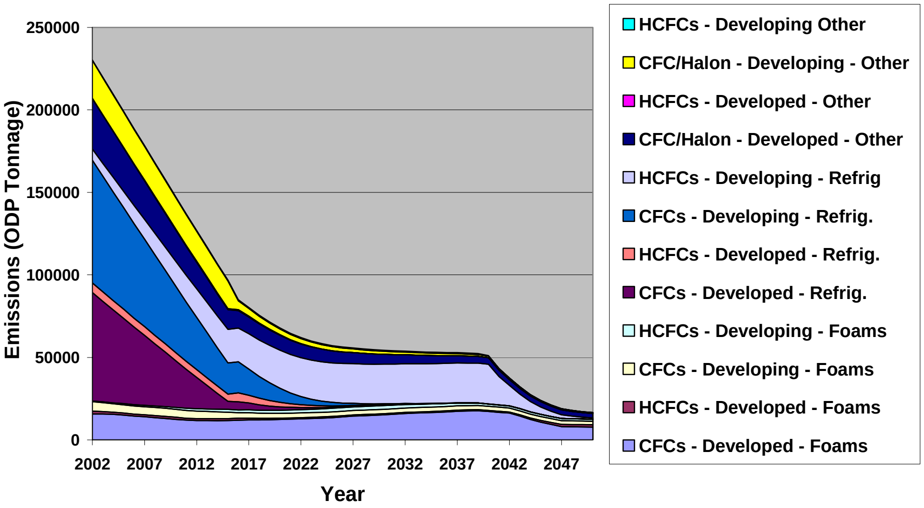


Figure 2.13 Emissions in ODP tonnes for all ODS applications (2002-2050)

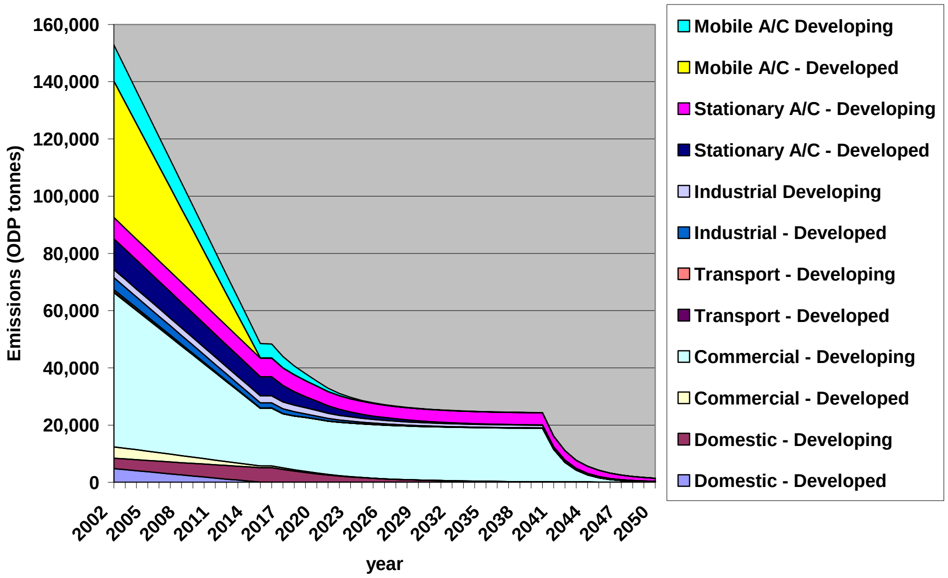


Figure 2.14 Emissions in ODP tonnes for refrigeration applications only (2002-2050)

The ‘bump’ in the foam emissions curve in Figure 2.13 in the 2030-2040 period parallels, in ODP terms, the similar phenomenon demonstrated in climate terms within SROC Figure TS-16. This reflects the substantial amount of building insulation foam being decommissioned in developed countries during that period.

- *<u>Baseline impacts on climate</u>*

For the assessment of climate impacts, a similar series of consumption, bank and emission graphs is presented as the following figures 2.15, 2.16, 2.17 and 2.18. An additional graph is included in reviewing emissions (Figure 2.19), which covers the baseline emission contributions for HFC-23 based on the projections of HCFC-22 production in developed and developing countries for both emissive and feedstock applications.

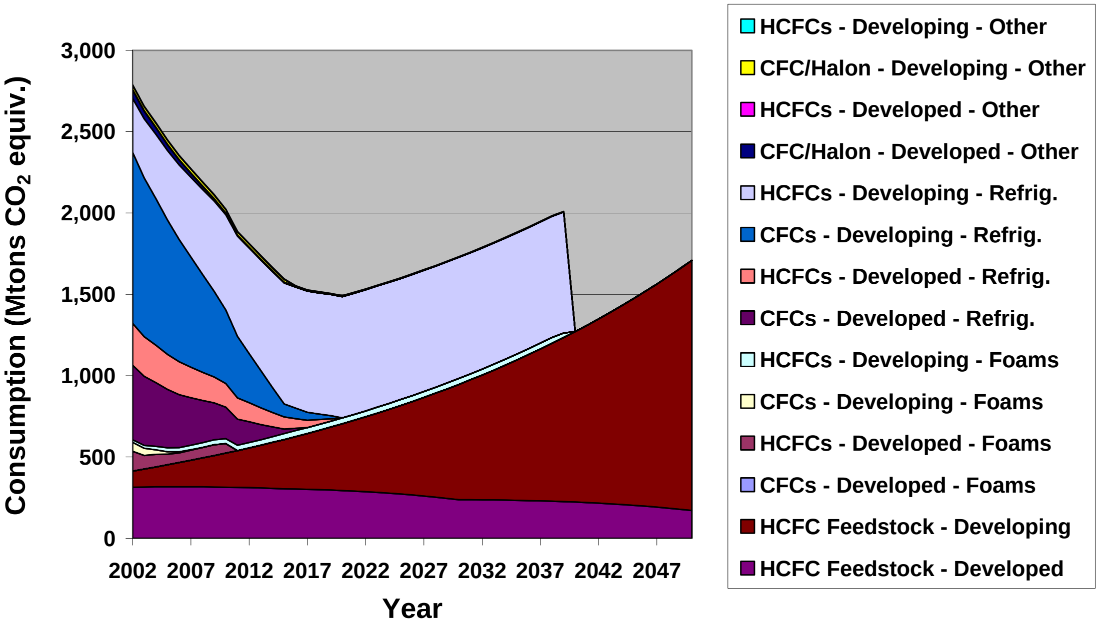


Figure 2.15 Consumption in Mtonnes CO_2-eq for ODS inclusive of feedstock (2002-2050)

Figure 2.15 has similarities with 2.10, but clearly delineates the substantial potential climate burden associated with HCFC-22 feedstock production. Meanwhile, Figures 2.16 and 2.17 do not include bank development (not relevant) or emissions from HCFC-22 feedstock production.

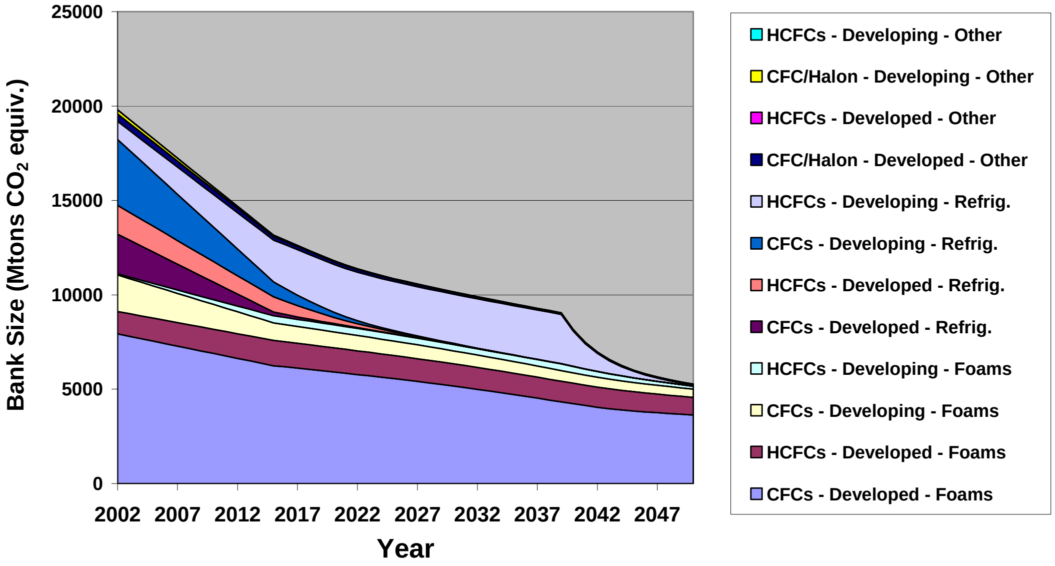


Figure 2.16 Bank development in Mtonnes CO_2-eq for all ODS applications (2002-2050)

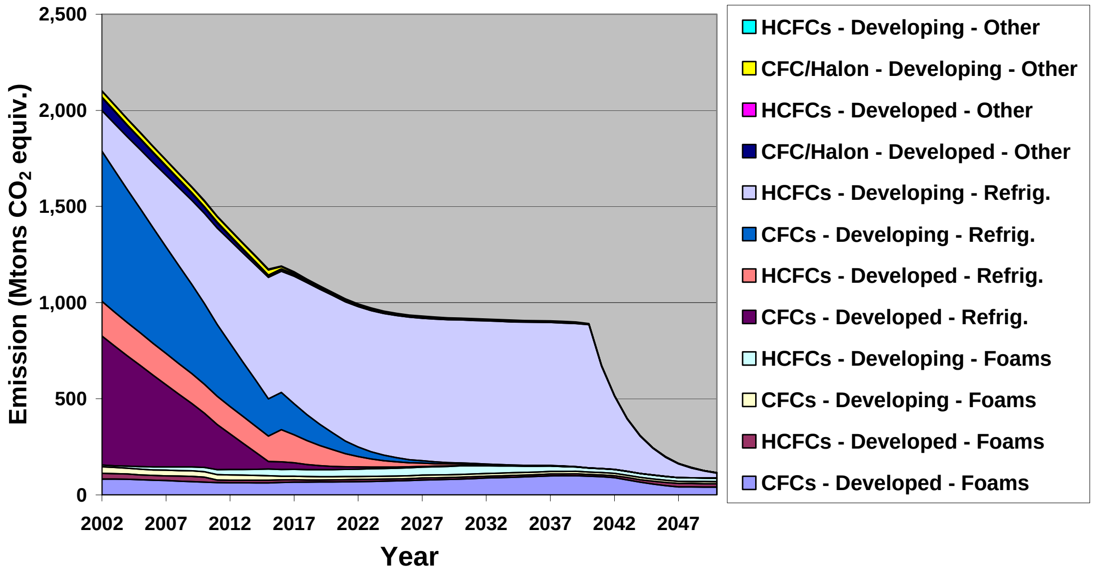


Figure 2.17 Emissions in Mtonnes CO_2-eq for all ODS applications (2002-2050)

To provide some level of context, the generally constant estimated baseline emissions of around 900 Mtonnes CO_2-eq during the period between 2025 and 2040, represent approximately **3.5%**[13] of current global greenhouse gas emissions.

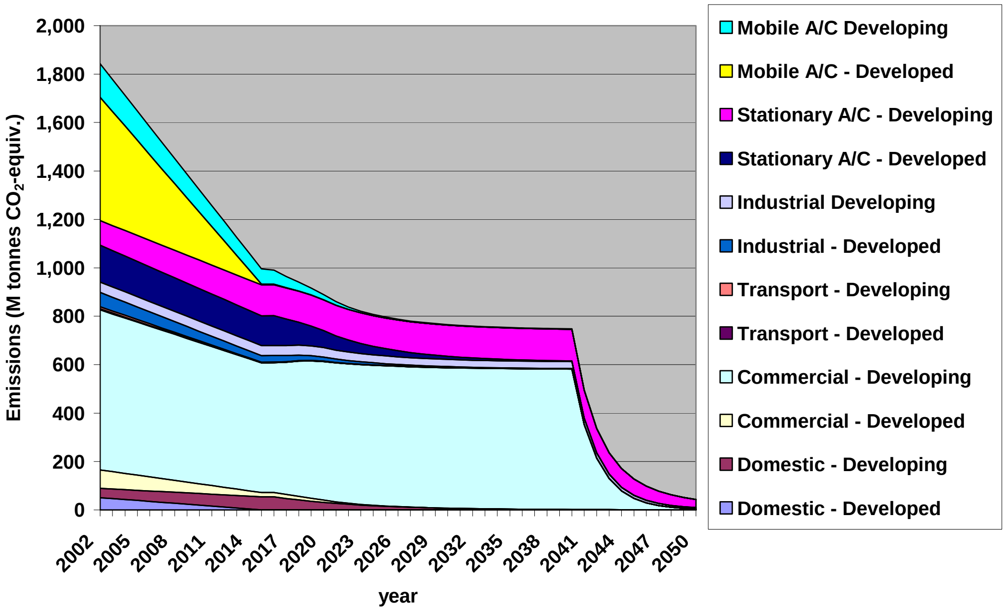


Figure 2.18 Emissions in Mtonnes CO_2-eq for refrigeration applications only (2002-2050)

---

[13] IPCC Fourth Assessment Report (2007) - Value excludes ODSs from the baseline

Figure 2.18 indicates that over 85% of greenhouse gases associated with estimated baseline emissive uses of ODS are from the refrigeration sector in the period from 2025 to 2040. As indicated in Figure 2.14, the contribution from CFC mobile air conditioning is substantial but relatively short-lived, since HFC-134a replaced almost all CFC-12 use in new cars in developed countries by 1994 and in developing countries in 2004.

Figure 2.19 below indicates the significance of unabated baseline emissions of HFC-23 from HCFC-22 production when manufacture for both feedstock and emissive uses is taken into account.

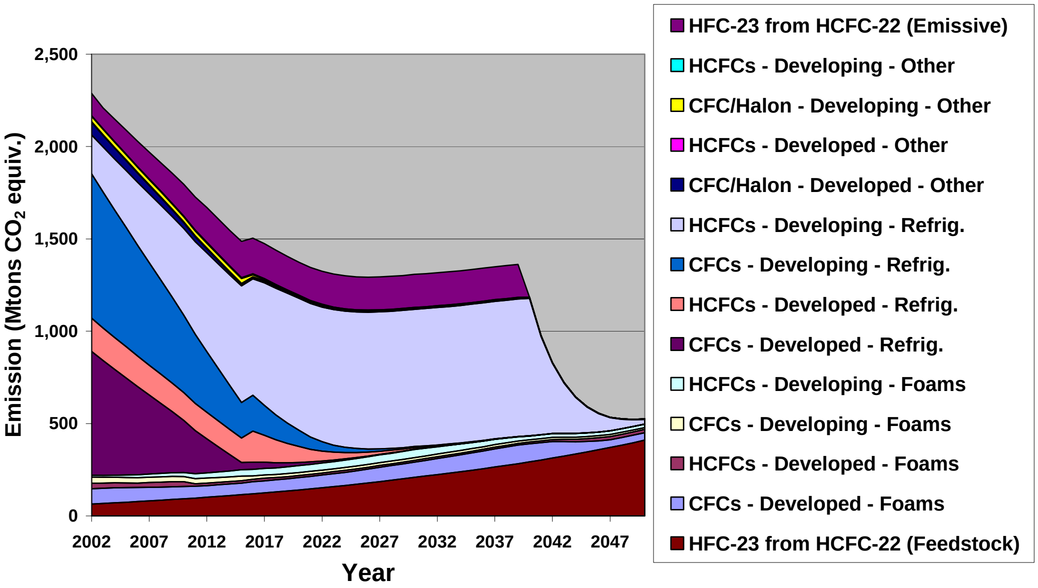


Figure 2.19 Impact of HFC-23 emissions on overall baseline forecast (2002-2050)

Summary

Emission reductions occur in both ozone and climate emissions from ODS sources in the period after 2002 as a result of current actions under the Montreal Protocol. Emissions stabilise at just over 50,000 ODP tonnes in 2025 and remain at that level until 2040 when the phase-out of emissive uses of HCFC-22 in developing countries begins to take effect.

From a greenhouse gas perspective, there is a trend of increasing ODS-related emissions from 2025 associated with the growth in HCFC-22 use as a feedstock and its related HFC-23 emissions. These ODS-related emissions reach approximately 1.35 billion tonnes CO_2-eq in 2039 (i.e. around 5% of current global annual greenhouse gas emissions). In the same year, unabated HFC-23 emissions account for just over 0.450 billion tonnes CO_2-eq, which represents around 35% of the total ODS-related emissions.

Actions to limit the emissions of HFC-23 related to HCFC-22 production are discussed in Chapter 3.

3 The Role of the Clean Development Mechanism (CDM)

Countries that have ratified the Kyoto Protocol are required to meet the targets for reducing greenhouse gas emissions during the first commitment period, 2008 to 2012. Parties that meet their targets will be allowed to trade emission units generated through any surplus reduction on the International Emissions Trading market. Those that do not meet their targets can purchase sufficient emission units to offset their excess emissions. These can be purchased from a Kyoto Protocol Party that has made reductions beyond its targets or through either one of two flexible mechanisms. These are Joint Implementation (JI), which is primarily targeted at countries with economies in transition (CEIT) and the Clean Development Mechanism (CDM), which is the subject of this chapter. Both are project-based mechanisms.

Article 12 of the Kyoto Protocol and the Marrakech Accords (2001) establish the framework for, and requirements of, projects under the Clean Development Mechanism. Essentially, a CDM project is a project undertaken in a 'developing' nation by an 'industrialised' nation or by private entities authorised to participate in the CDM. In addition to providing for 'bilateral' CDM projects between an industrialised nation and a developing nation, the Marrakech Accords enable developing nations to undertake 'unilateral' CDM projects without the participation of an industrialised nation.

3.1 Outline of the CDM Operation

Certified Emission Reductions (CERs) generated by a CDM project can be traded on the international emissions trading market or used by an investor (a state or private party) to offset emissions through retirement of the CERs. The Kyoto Protocol and the Marrakech Accords allow a private entity to participate in the CDM if it is authorised to do so by a Party to the Protocol.

CDM projects must meet a number of requirements to be eligible for registration with the CDM Executive Board and therefore produce tradable CERs. The Board is a committee established under the Kyoto Protocol that supervises the international administration of the CDM. Registration requirements include:

- assisting the host country to achieve sustainable development;
- providing real, measurable and long-term benefits;
- receiving approval from a national authority designated by the host nation in accordance with the Kyoto Protocol;
- satisfying 'additionality' criteria (see below);
- submitting project documents to an independent organisation (accredited by the Board and designated under the Protocol, which can include a private company) for validation and then submitting project documents to the Board for registration;
- ensuring that public funding for the project does not result in a diversion of official development assistance;

Project design documents (PDDs) required for registration include a general description of the project, a description of the baseline methodology and a monitoring methodology and plan. In addition, an environmental impact statement and stakeholder comments are also required.

Projects must satisfy an 'additionality' criterion. ‘Additionality’ is a concept used to evaluate whether a project would have been implemented by the project participants in the absence of CDM benefits. This is normally demonstrated through the use of the “additionality tool” and based on the assessment that, owing to barriers or economic viability an activity other than the project activity (i.e. *the baseline*) would have been implemented in the absence of CDM benefits. Baselines are created on a project-specific basis and take into account a number of relevant factors. Since many projects are similar in nature, it is normal for each type of project to have a specific methodology (or template) assigned to it. These methodologies must be approved by the CDM Executive Board and each project is then scrutinised against it.

The Kyoto Protocol also establishes a fast-track process to assist and promote smaller-scale CDM projects and allow them to compete with larger projects. The fast-track process uses standardised baselines, less stringent eligibility rules, and a simpler project cycle process

3.2 Particular Issues related to HCFC-22 manufacture

3.2.1 HFC-23 emissions from baseline HCFC-22 production

HFC-23 is a member of the HFC (hydrofluorocarbons) family of chemical substances with the formula CHF_3. It is produced as an inadvertent by-product of HCFC-22 by the fluorination of chloroform by hydrogen fluoride (also known as anhydrous hydrofluoric acid). Historically, it has also been produced deliberately by the fluorination of HCFC-22 when commercial quantities of the product were needed as an intermediate to the brominated fire extinguishant halon 1301. HFC-23 is a colourless, low toxicity gas with a boiling point of –84 C and is regarded as a potential narcotic and harmful by inhalation. HFC-23 has a very high Global Warming Potential (GWP) rated at 11,700 under the Kyoto Protocol[14] and an atmospheric lifetime of 264 years. More recent science has increased this GWP assessment to 14,310 (±5,000) which is the value quoted in the SROC. HFC-23 can be used as a refrigerant in ultra-low temperature refrigeration systems, as a fire extinguishing agent and also in the semiconductor industry for plasma etching. In certain countries a total of between 50 and 100 tonnes were used around the year 2000 for this purpose.

Levels of HFC-23 emissions from HCFC-22 production vary according to conditions in manufacturing processes and techniques used in different plants. If not thermally abated, they are generally in a range from 1.4-4.0% of the mass of HCFC-22 produced. In practice, larger producers in developed countries are expected to be operating in the 2-2.5% range, or less (with values as low as 1.5% being cited in many cases). Producers in developing countries might be

---

[14] Value included in the IPCC Second Assessment Report (SAR)

expected to be in the range 2.8-4%. The IPCC TEAP Special Report states that applying best practice to processes result in emissions of 1.4-3.0%, with an average of 2%. Costs of abatement also vary depending on specific plant circumstances and location, and can represent a marginal overall saving or a significant cost. In swing[15] plants, for instance, due to the necessary compromise in design, process optimisation is a more difficult task, and they are therefore expected to operate at the higher end of the emission range, producing about 3-4% emissions. For the consideration of typical emission rates from HCFC-22 plants in developing countries, a value of 3% is generally taken and this has been used for the assessment carried out in this report. For developed countries, a value of 1.5% has been used.

The most effective form of abatement is capture and destruction by thermal oxidation (as used in CDM projects, see below). Allowing for the down-time of oxidation units, this can eliminate about 90% of HFC-23 emissions. If emissions were contained during down-time, such technology can result in the destruction of greater than 99% of the emissions. Costs for the thermal oxidation equipment are quoted as US $2-8 million plus annual operating costs of US $189,000-350,000, dependent on its capacity. The SROC indicates that destruction of HFC-23 from HCFC-22 production could, by 2015, lead to reductions of about 300 Mt CO_2-eq per annum at a cost of less than US $0.20 per tonne of CO_2-eq (a total cost of US $60 million).

3.2.2 Development of the CDM methodology for HFC-23 emission abatement

While a growing number of facilities in developed countries employ some kind of abatement procedure, developing country plants generally do not do so without incentives. The SROC suggests that global application of best practices and recovery methods could reduce emissions of all CFCs, HCFCs and HFCs by 50% by 2015, with 25% of that reduction directly attributable to avoided by-product emissions of HFC-23 from HCFC-22 production. Accordingly, the avoidance of HFC-23 emissions has been seen as a high priority.

At its tenth meeting (September 2003), the Clean Development Mechanism Executive Board adopted a methodology (the AM0001 methodology, see http://cdm.unfccc.int/methodologies) for quantifying emission reductions for projects mitigating emissions of HFC-23 from the production of HCFC-22. Applying a GWP of 11,700 for HFC-23, such CDM projects can potentially deliver very large numbers of credits. Two HFC-23 destruction projects (Gujarat, India, and Ulsan, Rep. of Korea) were submitted for registration around 1 September 2004.

The methodology is applicable under the following conditions, that:

(1) the project activity is the destruction of HFC-23 waste streams from an existing HCFC-22 production facility;
(2) the destruction occurs at the same industrial site as the HCFC-22 production occurs (i.e., no off-site transport occurs), and

---

[15] The term ‘swing’ refers to a plant that is designed to produce more than one type of product. For example, some plants are capable of producing either CFC-12 or HCFC-22, depending on the raw material fed into the process

(3) no regulation requires the destruction of the total amount of HFC-23 waste (otherwise the project would not be ‘additional’).

The baseline quantity of HFC-23 destroyed is the quantity of the HFC-23 waste stream required to be destroyed by the applicable regulations. In the absence of regulations, the baseline is taken as ‘zero destruction’.

Waste HFC-23 is typically released directly into the atmosphere. Thus any HFC-23 not recovered for sale and not destroyed to meet regulatory requirements, is assumed to be released to the atmosphere. The greenhouse gas reduction achieved by the project activity is the quantity of waste HFC-23 actually destroyed less the greenhouse gas emissions generated by the destruction process (from fossil fuel burning, steam or electricity) less leakage due to the destruction process. The methodology also contains a precise description of the monitoring procedures to be used.

3.2.3 Manufacturing Plants currently covered as ‘existing’ facilities

Defining ‘existing’ facilities

At its fifteenth meeting (September 2004), the Executive Board of the CDM, taking into consideration information that had emerged since the approval of the methodology AM0001, put this methodology on hold and requested its Methodologies Panel to undertake a review of the methodology. A call for inputs was also posted on the UNFCCC CDM website and twenty-two submissions were received. At its seventeenth meeting in December 2004 (Buenos Aires), the Board considered the recommendations by the Methodologies Panel and agreed to revise the methodology accordingly.

As a result, the Executive Board decided to limit the methodology’s application to existing plants, as identified at that time. An existing plant was thereby defined as: *a production facility with an operating history of at least three years between the beginning of the year 2000 and the end of the year 2004, and which has been in operation until the start of the project activity.*

It also decided to redefine the emissions cap below which CERs would be issued for the destruction of HFC-23. This now corresponds to no more than the “highest HCFC-22 annual output” multiplied by the lowest HFC-23 generation rate, not to exceed 3 percent, where the “highest HCFC-22 annual output” that is eligible for crediting is defined as the lower of the following two options:

(1) the actual HCFC-22 production in the (latest) year considered;

or

(2) the maximum historical annual HCFC-22 production level at the plant during any of the last three years between the beginning of the year 2000 and the end of the year 2004.

In cases where two or more lines are operated at one industrial site, it was decided that the limit should be applied to the total production at the industrial site and calculated for all production lines together.

Procedures for crediting of existing plants were therefore clearly established. However, it left open the issue of how to deal with HFC-23 emissions from new plants without creating perverse incentives for HCFC-22 investment or, in the absence of abatement measures, harmful environmental consequences (see Section 3.2.4).

Once established as eligible, Parties can submit facilities for approval to the CDM Executive Board for either:

(1) a total period of 10 years

or

(2) three times a period of 7 years.

In the case of option (2), a review of the situation would take place after each 7-year period. The period of 10 years has been used for all facilities in India, while the three times 7 years formula has been adopted for all other (existing) facilities so far approved by the CDM Executive Board.

During these periods the maximum amount of CERs that can be generated is determined by the production level chosen at the point of approval of the facility (which normally is the year 2004). Accordingly, this forms the ceiling even if the production level of HCFC-22 (and the HFC-23 to be destroyed) were to increase in subsequent years. As a result, there is no artificial incentive to increase production above the ceiling value. However, if the production level is lower than the ceiling, the amount of CERs will be adjusted downward, which could encourage otherwise unnecessary production to take place. It might also create interesting production scheduling decisions towards the end of each year. Typically, the production and the amount of HFC-23 destroyed will be measured at the facility at least once per two/three months. CERs for a facility will be made available after the end of each completed year.

The review after seven years is expected to be studying the same type of data as were submittied under the methodology AM0001. If no regulations or other circumstances at the facility have changed, the on-going ceiling level will be taken as either the “highest HCFC-22 annual output” in the period 2000-2004, or the amount in a typical year during the period of the project so far, *whichever is lower.*

For projects adopted under the ten year fixed period (e.g., all current projects in India), the generation of CERs will stop around the year 2016. However, in the case of facilities in other countries, the generation of CERs may continue through to 2026-2028 (virtually all approvals occurred 2005-2007) on the assumption that the CDM will still be functioning as a mechanism at that time. Under such circumstances, an early phase-down of HCFCs under the Montreal Protocol, would require a plan to identify which HCFCs are to be phased out first and which production facilities for HCFC-22 are to close first. In the case of growth scenarios during 2007-2015, it will be very likely that the majority of HCFC-22 facilities that generate CERs can be kept in operation until 2027-2028 (thus generating CERs), even if they would have completely shifted to HCFC-22 feedstock production.

Current plants covered under the 'existing' facility provision

During the period 2003-2007, a substantial number of HCFC-22 production facilities (or production lines) have been approved under the CDM. Based on respective reference years, the annual production covered by the CDM outside of China is slightly less than 60,000 tonnes. These facilities are situated in Argentina, India, Mexico and the Republic of Korea. A plant in Venezuela has yet to be considered. As shown in Table 3.1, the capacity represented by these plants is approximately 75,000 tonnes. As noted in Section 2.3, only a small proportion of the HCFC-22 produced is used for feedstock applications (mainly in India).

Initially, UNFCCC figures suggested that a (maximum) production of slightly more than 195,000 tonnes of HCFC-22 has either already been approved in China or, in the case of a total of ten facilities, will be in the very near future. However, a lower production figure approved (in the order of 155,000 tonnes, for a total of seven production lines) had been mentioned by Chinese officials in various discussions while preparing this Report. This discrepancy was caused by different perceptions of the approval dates of production lines, since two facilities had to re-start the validation process, since they had used an outdated version of the methodology. Both UNFCCC and China now expect that the total HCFC-22 production limit for China that will be CDM approved in the very near future will be slightly larger than 205,000 tonnes of HCFC-22, spread across eleven facilities. Accordingly, the overall assessments are now fully consistent. The total production capacity represented by these eleven facilities is unclear, but is estimated to be in the order of 270-290 kilo-tonnes of HCFC-22.

As noted in Section 2.4, the production capacity for HCFC-22 (both from CDM approved and from new facilities) has been growing rapidly in China. According to Chinese information, the total production capacity in 2006 involved 19 HCFC facilities with 36 production lines and production capacity has increased from about 325-350 kilo-tonnes in 2004 to 400-500 kilo-tonnes in 2006.

For all developing countries, the total HCFC-22 production that has already been approved under the CDM (or will shortly be so) is estimated at about 265,000 tonnes. It is also estimated that the production capacity of these facilities is slightly higher than 360,000 tonnes. There is evidence to suggest that the majority of all developing country production lines, which would qualify, have either already been approved or will shortly be so. This would represent 67-68% of the estimated total developing country production in 2006.

Country	***CDM approved amount of HCFC-22 (t)***	***HCFC-22 production capacity of CDM approved facilities (t)***
China	205,000	270-290,000
Argentina, India, Mexico, Korea	60,000	75,000
Total	***265,000***	***345-365,000***

Table 3.1 – Annual approved production of HCFC-22 under CDM as a proportion of capacity

3.2.4 Potential inclusion of ‘new’ facilities

At its tenth meeting in 2004, the UNFCCC Conference of the Parties (COP) requested[16] the SBSTA to develop a recommendation on new facilities taking into account the implications of CDM project activities for the achievement of the objectives covered by other environmental agreements, in particular the Montreal Protocol. It specifically raised the issue of the establishment of new HCFC-22 facilities by project participants for the primary purpose of seeking credits from HFC-23 abatement activities, taking into account the principles established in Article 3(1) and the definitions in Article 1(5) of the Convention.

At its twenty-second meeting in May 2005, the SBSTA invited Parties, observers and relevant intergovernmental organisations to submit their inputs to the UNFCCC Secretariat by 5 August 2005. At its twenty-third meeting, the SBSTA then considered the submissions by Parties, a technical paper by the UNFCCC Secretariat and input from the Executive Board with a view to preparing a draft decision for COP/MOP-1, at its first session in December 2005 (Montreal). Parties, by its decision 8/CMP.1, recognised that issuing certified emission reductions (CERs) for the destruction of HFC-23 at new HCFC-22 facilities could lead to higher global production of HCFC-22 and/or HFC-23 than would otherwise occur and that the CDM should not lead to such increases. It agreed to further deliberate on providing guidance to the Board on how to treat new facilities under the CDM.

There are two categories of “new HCFC facility” and Parties therefore decided to apply the following definitions shall apply:

(a) for facilities that have an operating history of at least three years between the beginning of 2000 and the end of 2004, “new HCFC facilities” refers to the increase of production of HCFC-22 above the “highest HCFC-22 annual output”, as defined for existing facilities;

and

(b) for facilities that do not have an operating history of at least three years between the beginning of 2000 and the end of 2004, “new HCFC facilities” refers to the total HCFC-22 production at the facility.

At its Bonn meeting in May 2006, the SBSTA discussed the issue again. The decision of the SBSTA-24 recognised that crediting HFC-23 destruction in new HCFC-22 facilities could lead to higher HCFC-22 production and the SBSTA once again invited Parties to submit practical solutions, to address the above issue, for discussion at SBSTA-25 (November 2006, Nairobi). Parties submitted inputs to the process, which elaborated on practical solutions to the potential problem. These addressed the fact that issuing certified emissions reductions (CERs) for the destruction of HFC-23 at new HCFC-22 facilities could lead to global production of HCFC-22 and related HFC-23 that was higher than would otherwise occur. It was agreed that this was an unintended consequence that should be avoided by the CDM.

---

[16] Decision 12/CP10

Although SBSTA-25 addressed the submissions from Parties as mentioned above, it did not conclude its consideration of the issue. However, the Parties in Nairobi (November 2006) came close to agreeing to the third of the following three options:

(1) significantly discounting CERs for such projects;

(2) crediting emissions reductions for project activities that substitute the use of HCFC-22;

(3) issuing CERs for a project activity to entities other than the operator of the HCFC-22 installation, who then reimburse the costs of the HFC-23 destruction, and add a small incentive for carrying out the project activities.

It is understood that the third option was extensively discussed but an agreement could not be reached because Parties had divergent views on who the "entity receiving CERs" would be and how would the excess CERs, over and above those required for meeting the cost of destruction, would be utilised - whether for general environmental purposes or for purposes of phasing out ODS. Informal consultations carried out with governments at SBSTA-26 on this issue did not bring any further progress compared to the situation in November 2006, and the issue has therefore been deferred to SBSTA-27 and to COP/MOP-3 (Bali, Indonesia) in the hope of a possible decision on the means to address such implications and prepare guidance for consideration of new HCFC-22 facilities.

It can be argued that, in order to avoid distortion of the market, the treatment of both existing and new facilities must be the same. However, if new facilities were to be treated in the same way as current 'existing' facilities, careful consideration would need to be given to how many new facilities could be built for HCFC-22 production for emissive uses prior to 2016 (the year that the Montreal Protocol currently requires a freeze). As shown in Section 2.7, of even more significance is the on-going manufacture of HCFC-22 for feedstock applications, since this is not regulated under the Montreal Protocol. As noted earlier and illustrated later in Figure 3.1, the over-riding concern for the Montreal Protocol is the temptation of solely producing HCFC-22 in order to receive CER revenues.

Apart from the impact on the HCFC-22 market itself, the large amount of CERs likely to be issued could lead to a considerably lower price for CERs, which would also affect the feasibility of other types of CDM projects. This is particularly the case for small-scale projects that cannot currently overcome the CDM transaction costs, but could do so if CER values were to increase.

Another option would be to introduce a different treatment for the existing facilities, so that new facilities could be dealt with in a similar manner. However, this could only apply to those facilities already approved once they had reached the end of their first approval period of seven years. Four ways of dealing with the issue have been proposed in the literature:

(1) The issuance of only a fraction of the emission reductions as CERs, which could be a fixed fraction or the amount of CERs or could correspond to a certain monetary value;

(2) The revenues above the costs of implementation (here CERs are issued fully) could be used to support sustainability objectives. In this case, the creation of a

fund seems to be the most suitable option, but this leaves questions open such as "who controls the fund", and "which sustainability objectives shall be served";

(3) The CDM HCFC-22 projects are carried out by an independent institution; and

(4) CDM projects will be restricted to HCFC-22 feedstock production only.

Regardless of which option might be chosen, contractual commitments of the CDM to the existing plants already approved might only be countered by the national intervention of Parties at this stage – perhaps through taxation measures or similar fiscal instruments. If similar agreements could be reached with each of the countries acting as host to an eligible 'existing' plant, it could be possible to 'level the playing field' for both new and existing plants without waiting for seven years to achieve the objective. This issue is covered further in Section 3.2.5.2.

3.2.5 The HCFC-22 competitive environment

3.2.5.1 The potential effect of carbon pricing

Using the data set out in Section 3.2.3 and a baseline emission rate of 3%, the related HFC-23 destruction would reduce GHG emissions by about 88 Mt CO_2-eq annually (347 t of CO_2 for each tonne of HCFC-22). Dependent on the price of a CER (between US$ 3/tonne and US$ 10/tonne of CO_2) this would represent US$ 264-880 million per year if production remained at the 2004 level. The 255,000 tonnes of HCFC-22 would be expected to have a market value of US$ 255-510 million (assuming the market price for HCFC-22 of US$1-2/kg), which means that the net revenue per year for HFC-23 destruction could easily exceed the revenue from HCFC-22 sales. In an environment where the price of carbon is likely to increase with time, this imbalance could become even greater, as indicated in the graph below.

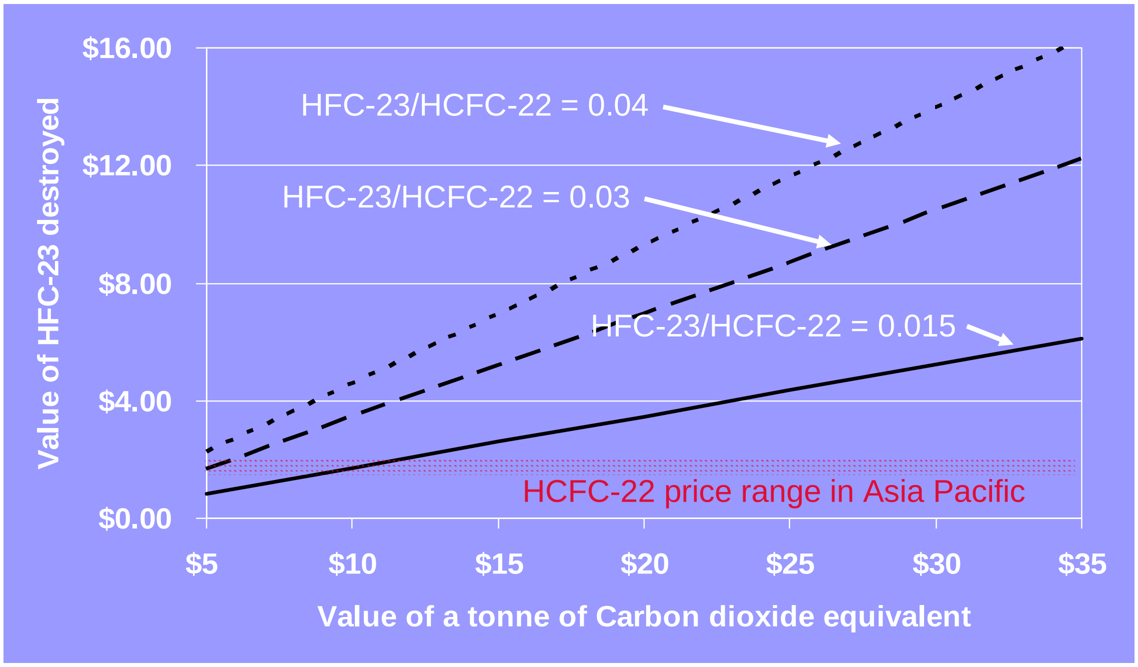


Figure 3.1 – Value of CER credits per kg of HCFC-22 produced as the carbon price increases

The graph also illustrates that the monetary value of CERs is sensitive to the HFC-23 generation rate per unit of HCFC-22 production. As a general principle, however, it is worth noting that the recompense for emission mitigation under the CDM can be as much as 10 times the actual cost of the abatement step.

Accepting that the CDM in its current form will generate substantial money flows, the one question to then ask is 'what will that money be used for?' Some experts argue that the net revenue from the HFC-23 destruction could lead to a lower price for HCFC-22, while others argue that HCFC-22 manufacturers will maintain prices and take greater profits. Clearly, the latter strategy would have less market response. Irrespective of the choice made initially by a specific beneficiary of a CDM project, a distortion in the market could arise through the financial strengthening of one section of the supply-base and not another. For example, a company could afford to take an aggressive pricing position in regions, where they were seeking greater market share while maintaining prices in other regional markets where the existing competitive balance was being maintained.

An additional market distortion arises because production facilities in developed countries will never be eligible for CDM funding because of their location. Accordingly, such facilities will be at a disadvantage even if a method is found to 'level the playing-field' between 'new' and 'existing' plants in developing countries. A solution that could address this imbalance is national actions in the host developing countries that provide a financial correction to the funds already being provided under the CDM to approved 'existing' plants. The alternative would be an even more rapid shift of production from developed to developing countries and the risk of even more 'new' facilities requiring potential CDM support. Adverse impacts on the ozone layer and climate would be maximised if HCFC facilities in developed countries with low HFC and CTC emissions loose market share to facilities in developing countries with high HFC and CTC emissions.

In summary, it is likely that the *universal* HCFC-22 price will be largely unaffected by the CER revenue from the HFC-23 destruction, and that the windfall income will be used in a first instance by the production facilities for other purposes. *However*, localised tactical pricing may be an increasing feature of the market if participating companies have the financial ability to support it.

If the price of HCFC-22 were to fall significantly, it is unlikely that the volumes of HCFC-22 sold for refrigeration applications would increase substantially. There are three primary reasons for this:

(1) For sales of new refrigeration equipment, the proportion of cost related to the refrigerant is low and the number of equipment sales will not be affected;

(2) Lower prices are unlikely to influence the choice of refrigerant selection in new equipment, since HCFC-22 is already the least expensive of the available alternatives and will already be used wherever the market can accept it; and

(3) Servicing accounts for the largest proportion of HCFC-22 demand in developing countries and refrigerant choice for servicing is usually already prescribed.

For other potential uses of HCFC-22, there could be greater market elasticity. For example, in foams, XPS could have its competitive market position improved against other insulation types by a lowering of a major cost element, such as blowing agent. HCFC-22 would also be likely to displace any remaining use of HCFC-142b in XPS formulations.

There is even the possibility that very low market prices could make HCFC-22 the propellant of choice in some aerosol sectors. Such a trend would have substantial consequences on the overall demand for HCFC-22 and would lead to far more emissions than would occur under the BAU case set out in the SROC.

The Task Force is less certain on the potential impact of HCFC-22 price reductions on the demand for the chemical as a feedstock. As noted in Section 2.3, one of the major downstream products from HCFC-22 is PTFE, and it would need a comprehensive study of the current applications of this polymer and its competitiveness with other similar materials to decide whether a reduced feedstock cost would have substantial impact on PTFE market penetration. This subject is beyond the scope of this current report, but may need further investigation if the revenues generated from the sale of CERs continue to flow to ‘existing’ plants.

3.2.5.2 National provisions for managing CDM funds

The Chinese government has introduced a levy of 65% of the CER revenue from HFC-23 destruction projects. The motivation is that high rates are applied to projects, such as the HFC-23 destruction, with the least sustainable benefit to the wider community. The fees levied by the Chinese government are being channelled into a “Clean Development Fund” managed by the government, and these will be solely spent on energy efficiency improvement projects. The prime purpose of the “Clean Development Fund” is not to lower carbon dioxide emissions, but to lower the emissions of all types of pollutants (e.g., sulphates but also dioxins, furans etc.) which are being emitted from energy producing facilities. Additionally, greater energy efficiency would contribute to less need for additional investment in generating capacity and may also cut reliance on the need to import energy, thereby increasing energy security.

The Chinese plan is to increase energy efficiency[17] by 20% through contribution from this Fund between 2006 and 2009.

The potential to expand such ideas to other countries with local HCFC-22 production capacity clearly exists and could be the subject of an inter-governmental agreement which would solve the current impasse on the treatment of “new versus existing” and “CDM versus non-CDM” facilities.

---

[17] As measured by the reduction in energy consumption per unit of GDP

3.2.5.3 The competitive position of alternatives

As noted previously, HCFC-22 refrigerant costs generally are a small proportion of new refrigeration and air conditioning costs. Costs for alternatives, such as HFC blends or low GWP alternatives if applicable are generally are a factor of 3-8 higher than HCFC-22 (at US$ 1-2).

Costs for ammonia and hydrocarbons usually are in the same order as for HCFC-22, however, if additional measures related to safety and toxicity need to be taken, the cost for the type of equipment required for ammonia or hydrocarbons may be substantially higher than the cost for HCFC-22 or HFC equipment.

Although in principle lower prices for HCFC-22 would increase the market share of HCFC-22 against existing alternatives, and would deter the development and introduction of new alternatives, the price difference is already of such an order, that small changes in the price for HCFC-22 (upward or downward) are not estimated to have any significant impact. However, with external drivers (such as import bans for HCFC-22 based equipment, government policies on the efficiency improvement for equipment in domestic markets, as e.g. in the Chinese market, etc.) a conversion to the main alternatives to HCFC-22 (currently HFC blends) is likely.

As covered in more detail in chapter 4, the major alternatives currently available for HCFC-22 in refrigeration and air conditioning (mainly HFC refrigerant blends) have GWPs that are comparable to the GWP of HCFC-22. In addition, until regulatory or market incentives are implemented encouraging not-in-kind alternatives, natural refrigerants, newly announced low-GWP HFC alternatives, and engineering improvements in the design for lower energy consumption, differences in CO_2 emissions from energy consumption in use (related to differences in energy consumption and related efficiency) can be expected to be small for many of the applications covered by the refrigeration and air conditioning sector.

Nevertheless, with a conversion to HFC blends such as R-410A or to hydrocarbons (particularly propane, which should be possible in many of the mass produced smaller A/C units) the energy efficiency, if also combined with manufacturing technology upgrading, could increase substantially. Thus, even in the near term, total related emissions (direct and indirect) could be significantly lower than at present.

If the analysis would therefore address the overall climate impact from both refrigerant and energy related carbon dioxide emissions it should be stressed that the reduction in global warming contribution from the energy related carbon dioxide emissions could be of the same order of importance to the global warming contribution from direct refrigerant emissions. The potential energy efficiency gains are therefore an important argument in favour of replacement of HCFC-22 (e.g., in China, many A/C units do not yet meet the energy standards in place).

In summary, development and introduction of new low-GWP alternatives, the application of HFC blends and the use of e.g. hydrocarbons would require external drivers, and not pure market mechanisms and competition. This makes the signalling of future policy on HCFCs the most important determinant in promoting the development and use of the most environmentally acceptable alternatives.

3.2.6 Future Climate Policy and its Impact on the Operation of the Clean Development Mechanism

Current international climate policy and the CDM operation will continue through the first Kyoto budget period 2008-2012 and will broadly cover the first period of 7 or 10 years for which approval has been granted to projects involving HCFC-22 manufacture.

However, a number of questions can be raised about the future of international climate policy, relevant to HCFC-22 production issues in this Report:

- What will be the emission reduction targets post-Kyoto, and for which budget period will they be set?
- Will a trading scheme be maintained to promote emission reduction projects in developing countries?
- If so, will the CDM operations be continued in the same way as during the 2005-2012 period?
- To what extent will the HCFC-22/HFC-23 destruction methodology be kept in the same form after the first review has taken place?
- How will HCFC-22 policy under the Montreal Protocol influence the need for on-going CDM provisions (e.g., for feedstock use)?
- Will developed country governments express interest in specific projects under the CDM, and not take into consideration anymore CERs from HFC-23 destruction?
- To what extent will the international carbon trading market (i.e. non-governmental sources) be an important player in obtaining CERs from HCFC-22 projects?
- What will be the impact of the phase-out of products containing HCFC-22 in developed countries on the HCFC-22 demand in developing countries (e.g., manufacture for export)?

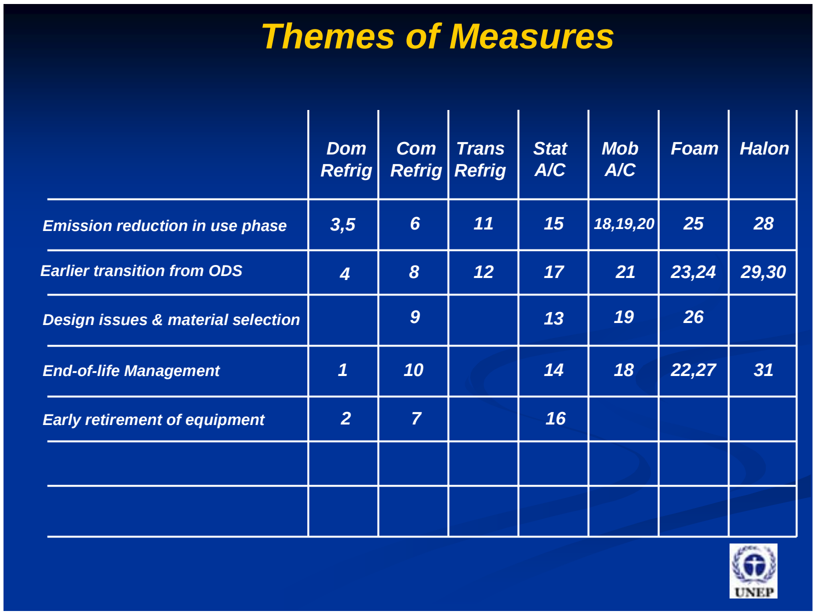
Although in this Report the assessment of consumption and emissions is modelled through to 2050, there is great uncertainty in forecasting regulatory and market environments over the same period. The questions set out above highlight the many uncertainties that exist and the discussion of the impact of *'practical measures'* that follows in Chapter 4 draws conclusions based on the assumption of unconstrained HFC-23 emissions beyond 2015. In doing so, the Report will at least encourage governments to consider the consequences of inaction on HFC-23 in that post-2015 period.

4 Assessment of Practical Measures

4.1 Grouping the Measures

In response to Decision XVII/19, six Parties submitted proposals for *'practical measures'* arising from the Special Report on Ozone and Climate (SROC). There were 62 proposals in all, although it was clear at the outset that there was considerable overlap in a number of the ideas presented. TEAP working with the Ozone Secretariat and the Chair of the Workshop, evaluated the proposals and sought to combine those that addressed the same topic. This led to a simplification of the list to 31 distinct proposals, which were further sub-divided into their respective sectors. The Powerpoint™ slides depicting this sub-division are shown in Annex 7.3. By sub-dividing into break-out groups, it was possible for the Workshop attendees to assess all 31 proposals and, with very little modification, to approve all as appropriate for the list of *'practical measures'* requested by Decision XVII/19. The Workshop Report was duly prepared by the Ozone Secretariat and the process towards Decision XVIII/12 continued as outlined in Chapter 1.

In responding to Decision XVIII/12, the Task Force was mindful that the Workshop had specifically not prioritised the *'practical measures'* identified. Although the purpose of this Report is to '*..further assess the measures listed…'* , the TEAP at its meeting in Rome in March 2007 still viewed it premature for this Report to actually prioritise the individual '*practical measures*' identified by the Workshop. However, the TEAP did believe it important to give a clear indication of the orders of magnitude of impact that could be gained from specific types of measures (themes). In order to facilitate this, the TEAP agreed on a further grouping of the '*practical measures*' into five specific themes: emission reduction in the use phase; earlier transition from ODS; design issues and material selection; end-of-life management and early retirement of equipment. The Powerpoint™ screenshot below shows the five themes and how the 31 original *'practical measures'* are accommodated by this approach.



Themes of Measures

	Dom Refrig	Com Refrig	Trans Refrig	Stat A/C	Mob A/C	Foam	Halon
Emission reduction in use phase	3,5	6	11	15	18,19,20	25	28
Earlier transition from ODS	4	8	12	17	21	23,24	29,30
Design issues & material selection		9		13	19	26	
End-of-life Management	1	10		14	18	22,27	31
Early retirement of equipment	2	7		16			

Figure 4.1 – Allocation of the 31 'practical measures' by theme

This chapter of the Report is therefore structured around these five themes. Recognising the specific interest in earlier HCFC phase-out as reflected in the proposed Protocol Adjustments submitted to the Secretariat in March 2007, the decision was taken to separate this particular aspect out from the others. Section 4.3 is set aside for this purpose.

4.2 Means of Analysis

4.2.1 Life Cycle Climate Performance (including Energy Efficiency)

Life Cycle Assessment (LCA) has been practised in various forms for over 30 years. Early variations in approach led to a high degree of confusion about the applicability and reliability of the outputs, so the International Standards Organisation (ISO) initiated a series of standards (the ISO 14000 series) to document a number of environmental assessment methodologies including LCA. ISO 14040 is the resulting standard that provides a consistent framework for current LCA practitioners.

Even with such a framework in place, there are substantial degrees of freedom available to practitioners. This is necessary to provide an approach which is flexible enough to accommodate a variety of circumstances. One of the main degrees of flexibility is in the determination of the ‘system boundaries’ which define the scope of the analysis and items to be included. There are no ‘right answers’ for the selection of system boundaries, but ISO 14040 ensures that these are properly declared and can be understood by those reviewing the LCA.

In the context of climate change, it is reasonable to adopt a methodology that addresses only those factors that have an impact on climate. These would include emissions related to energy consumption (either those resulting from the direct combustion of carbon-based fuels or from the centralised power station used to generated the electricity consumed within the ‘system boundaries’) as well as direct emissions of other greenhouse gases occurring within the system boundaries. This type of analysis is increasingly relevant in a growing carbon economy where the ‘carbon foot-printing’ is becoming the norm. Despite the growing interest in such an approach, recent discussions with leading carbon foot-printing practitioners indicate that there is no single methodology under the ISO 14040 framework for climate-specific analysis. Any methodology that follows the wider ISO 14040 framework can be adopted and is usually justified by reference to that wider framework.

Life Cycle Climate Performance (LCCP) is one methodology that sits under ISO 14040. It has its origins in the desire to assess the comparative climate impacts of various ODS and non-ODS alternatives for key applications such as refrigeration and foam. In an earlier version, the methodology was referred to as Total Equivalent Warming Impact (TEWI). However, this was considered to be limited in its applicability by ‘system boundaries’ that did not include the manufacture of fluorocarbons themselves. LCCP emerged in the 1998 TEAP Task Force Report on the interrelationships of the Montreal and Kyoto Protocols to address this short-coming and has been used widely within the refrigeration and foam sectors ever since.

As with the ISO 14040 framework itself, LCCP does not fully prescribe the system boundaries, but, in practice, there are some aspects that are widely accepted in certain technology areas. As a result, both the American Society of Heating, Refrigerating and Air Conditioning Engineers

(ASHRAE) and the Society of Automotive Engineers International (SAE) are discussing, or in the process of developing, LCCP standards for their respective industries, which will formalise and standardise the approach in those sectors.

For stationary air conditioning, the definition of system boundaries is particularly challenging, since the efficiency and related energy consumption associated with such equipment varies according to the building in which it is operating. A similar challenge exists for foams, where the design and location of the building can also make a significant difference to the amount of energy saved by the product in application. In these circumstances, it is more logical to use only LCCP for evaluating and comparing alternative solutions in the same building or other such environment. Often the 'system boundaries' can be extended to take in the whole building under such circumstances, since this provides a wider context in which to evaluate the impact of the equipment or product choice.

This level of versatility has sometimes led to criticisms that systems (buildings) and 'system boundaries' have been selected in such a way as to bias the result in favour of one technology over another. However, it is important to realise that the same opportunities exist within the ISO 14040 itself and other carbon foot-printing methodologies operating under that framework. In summary, therefore, it is important that any specific LCCP analysis is accompanied by a clear definition of the system and its boundaries. With this provided, it is for the audience to review and validate that the choice of system is appropriate to the assessment being made. Each assessment is application-specific.

This conclusion brings with it a challenge for the use of any LCA approach within a Report such as this. While this Report focuses on LCCP as a means of comparing options, the resulting assessment is an overview of a number of specific LCCP outputs in that technology sector. References to LCCP in this Report are therefore mostly qualitative in nature and are the best attempt of the Task Force to provide a technically balanced and objective overview of often highly complex technology sectors.

4.2.2 Adoption of Direct GWPs rather than Net GWPs

Since ozone is a greenhouse gas, the result of ozone depletion is that the greenhouse effect is also diminished in regions where the ozone is depleted. However, since ozone depleting chemicals themselves have high global warming potentials, they also contribute directly to the greenhouse effect through their own radiative forcing wherever they are in the atmosphere. Since these two effects can be argued to counter each other, there is a temptation to offset the effects and to generate a net global warming potential.

However, the SROC states that it is technically inappropriate to make such an offset. In its Technical Summary (Page 31) the SROC states:

> *'Given the very different levels of scientific understanding and relative uncertainties associated with direct and indirect radiative forcing of ODSs, the lack of cancellation in their effects on surface climate and the dependence of*

> *indirect GWPs on the year of emission, this report does not consider the use of net GWPs combining direct and indirect effects'.*

This reference to the spatial and seasonal differences in the effect on surface climate, and the dependence of indirect GWPs on the year of emission, clearly provides a strong scientific basis for not opting for net GWPs.

Consequently, this Report only considers impacts in the context of direct radiative forcing (i.e. a Direct GWP) with all of the subsequent analysis based on this approach.

4.2.3 Other Environmental Considerations

The call for proposals identifying *'practical measures'* also asked Parties to highlight other environmental considerations that should be taken into account when evaluating the measure. In principle these could be either in a positive direction (e.g. the potential to recycle metal) or in a negative direction (e.g. more hazardous to human health). In the submissions made and, for the analysis undertaken that took place at the OEWG Workshop in July 2006, it was not considered possible to make any meaningful quantitative estimates of such benefits or dis-benefits.

Similarly, with its focus on ozone and climate issues, this Report also only makes reference to possible benefits and dis-benefits on a qualitative basis. Further investigation would be required as part of a wider life cycle assessment to provide quantitative estimates. It may be that some LCCP analyses may include the savings in embodied energy arising from a demonstrable recycled content, however, this is not explicitly identified in this Report unless it is a distinguishing factor between technology choices.

4.3 Earlier Transition from HCFCs

As shown in Figure 4.1, earlier transition out of ODSs is a theme that straddles all of the sectors covered in this Report. Recognising this, and also the fact that the impact of accelerating the phase-out of HCFCs is likely to be the single largest *'practical measure'*, it was decided to treat this separately from the other *'practical measures'*. By doing so, it would then also be possible to look at the impact of accelerated HCFC phase-out on the other *'practical measures'* since there might be a significant inter-relationship.

Subsequently, it emerged that nine Parties were to submit six proposals for Adjustments to the Protocol dealing with this policy option.

4.3.1 Accelerated HCFC scenarios considered in this Report

As explained in Chapter 2, the developing country HCFC demand Growth Factor for the period between 2005 and 2015 could be justifiably placed at a number of levels, but in practice, the most detailed basis for assessment of *'practical measures'* is the SROC data, with its Growth Factor of 1.78. Within this, HCFC-22 consumption in the refrigeration sector has a forecast Growth Factor of 1.74. Since sensitivity to the choice of Growth Factor is an important aspect of evaluating the impact of scenarios, an alternative Growth Factor of 2.5 has also been modelled for HCFC-22 growth in the refrigeration sector.

Along with the baseline, three scenarios have been modelled for developing country HCFC consumption. These are:

- Freeze at 2015 with linear phase-down of HCFC use from 2021-2030 (10 year advance)
- Freeze at 2015 with linear phase-down of HCFC use from 2016-2025 (15 year advance)
- Freeze at 2012 with instantaneous phase-out in 2040. (3 year advance in the freeze date)

Figure 4.2, 4.3 and 4.4 reflect schematically, these three options.

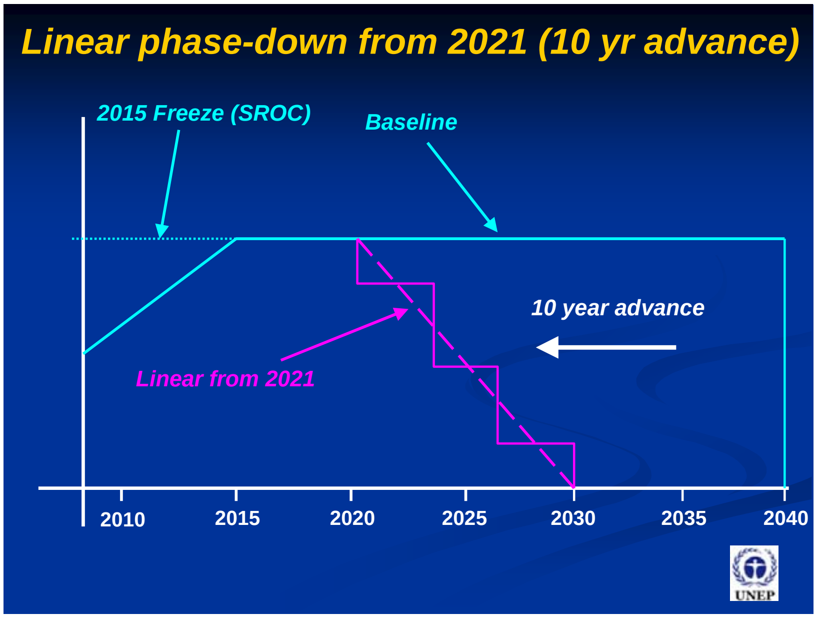


Figure 4.2 Linear phase-down from 2021 (10 year advance in phase-out date)

The choice of a linear phase-down approach is primarily for ease of modelling and to avoid selecting specific steps in both timing and magnitude. However, it is recognised that step-wise phase-downs are more likely to take place in practice to avoid the burden of having to demonstrate annual compliance. This concept is shown within Figures 4.2 and 4.3.

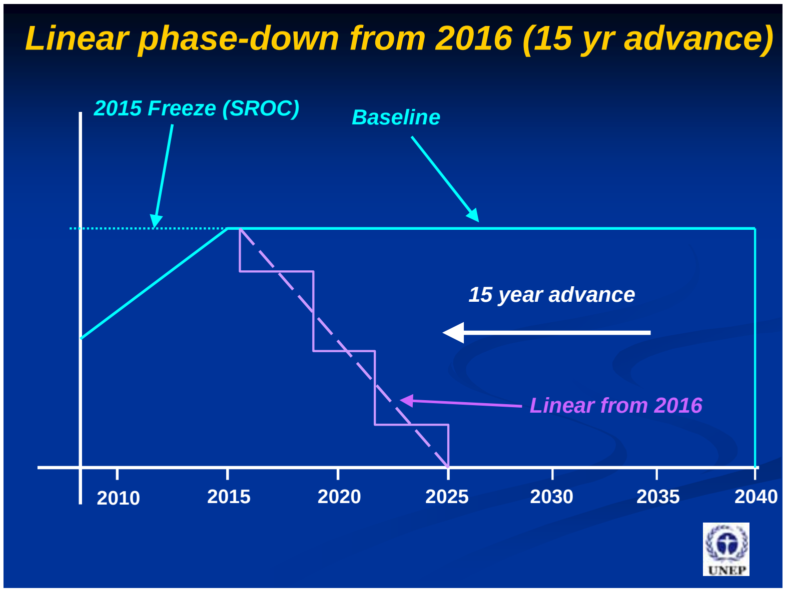


Figure 4.3 Linear phase-down from 2016 (15 year advance in phase-out date)

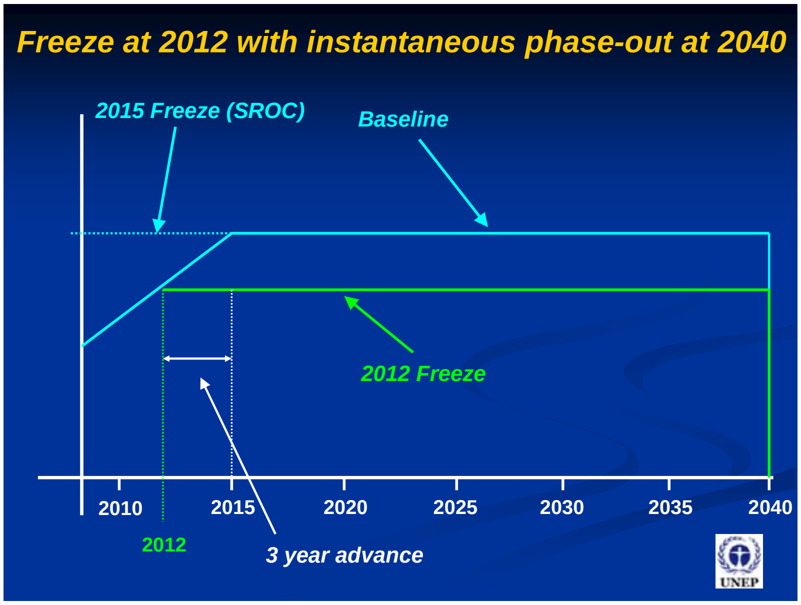


Figure 4.4 Advance in freeze date to 2012 with instantaneous phase-out in 2040

This Report illustrates the related reduction in ODS emissions arising from various types of HCFC phase-out approaches, rather than analysing specific proposed Adjustments already submitted by Parties.

The Task Force evaluated a three-year advancement of the freeze because it is clearly technically and economically achievable. A freeze in 2010 was also discussed as an option, but the Task Force judged it too technically and economically challenging when aspects such as pre-determined servicing requirements were factored in.

4.3.2 Impacts of scenarios by sector

Throughout this Chapter, impacts are measured in terms of time-related emissions savings, both in ozone and climate contexts. This Section is structured to treat the key sectors individually to allow comparisons of the scenarios while keeping the graphs relatively simple by not illustrating the relative savings for each sector at the same time. These further comparisons are addressed in Chapter 5 (Section 5.1). The following analysis has resulted from the above treatment.

4.3.2.1 Refrigeration and Air Conditioning

Against the baseline refrigerant emissions for each ten-year period, an acceleration in final HCFC phase-out dates is predicted to have more significance than an advance in the freeze alone. Figure 4.5 illustrates the situation in terms of ozone-related emissions, while Figure 4.6 assesses the impact in terms of climate.

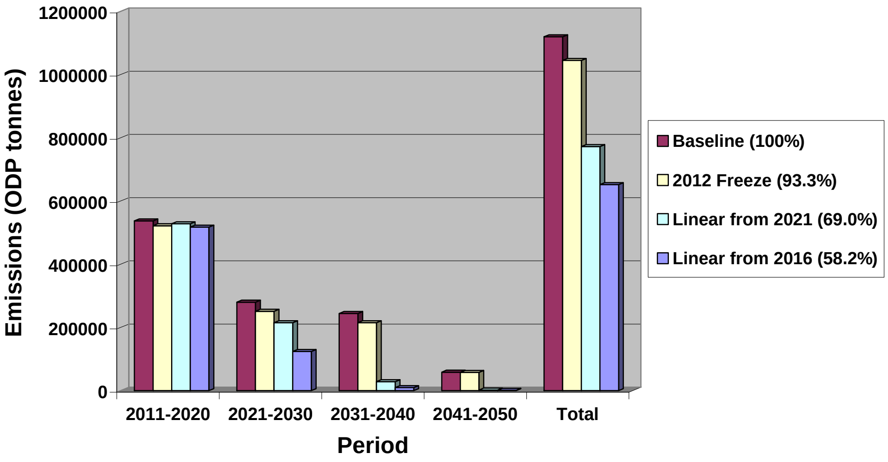


Figure 4.5 Comparative refrigerant emissions under different scenarios in ODP tonnes

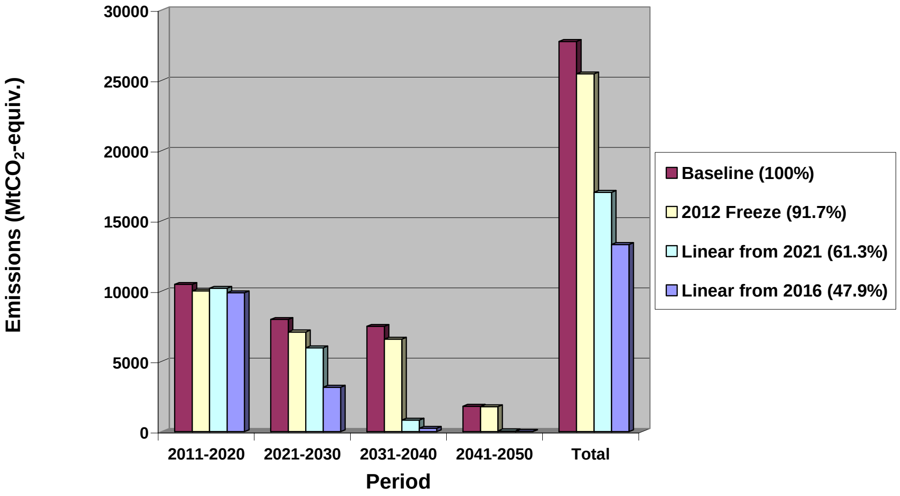


Figure 4.6 Comparative refrigerant emissions under different scenarios in Mtonnes-CO_2-eq

None of the scenarios are seen to make a significant contribution in the first ten year period (2011-2020) but, when compared with the baseline, contributions from the scenarios become really significant in the subsequent decades. For the 'linear from 2016' scenario, the estimated cumulative emission savings for the period to 2050 amount to just under 14.5 billion tonnes CO_2-eq (i.e. about six months worth of global greenhouse gas emissions as at 2005). The cumulative ODS emissions savings for the same scenario is approximately 468,000 ODP tonnes. With most of the savings occurring in the later years, the impact on the speed of ozone-hole recovery could be significant and is the subject of further consideration in Section 5.2.

In climate terms, there is additional emission abatement arising from HFC-23 emission savings, based on the avoidance of the need for HCFC-22 production. These are shown in Figure 4.7.

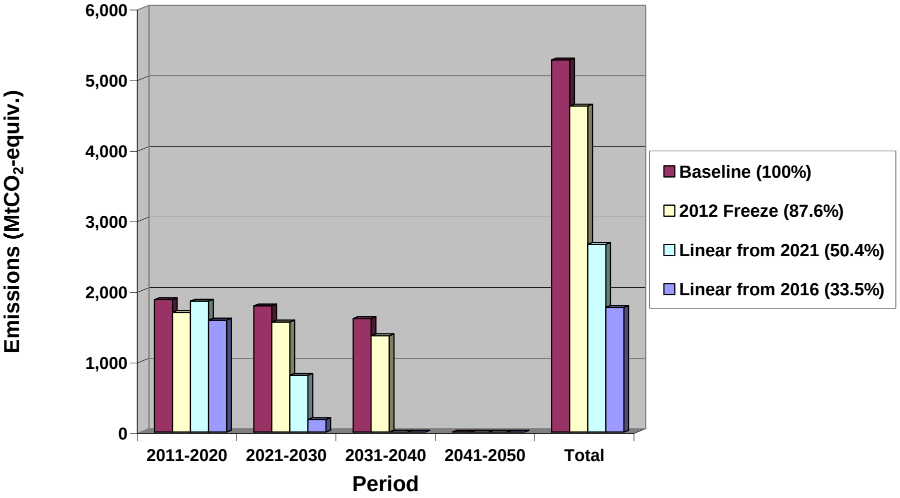


Figure 4.7 – HFC-23 emissions related to HCFC production under the different scenarios

The HFC-23 emissions savings for the 'linear from 2016' scenario amounts to approximately 3.5 billion tonnes CO_2-eq (i.e. a further 24% over that gained from ODS emission avoidance itself). It should be noted that all of this occurs in the period prior to 2040, since no HCFC-22 production for emissive uses (specifically refrigeration in this case) would have been permitted, even in the baseline case.

Taking into account a more rapid Growth Factor of 2.5 for HCFC-22 to 2015 as the baseline, the emissions savings from an accelerated HCFC phase-down become even more significant. Table 4.1 provides the comparison.

Scenario	***Growth Factor as SROC***		***Growth Factor of 2.5***	
	ODP tonnes	*Mtonnes CO_2-eq*	*ODP tonnes*	*Mtonnes CO_2-eq*
Freeze at 2012	74,781	2,926	133,142	5,203
Linear from 2021	347,531	13,351	498,875	19,164
Linear from 2016	467,997	17,962	671,818	25,790

Table 4.1 Impact of high growth factors on refrigeration emission abatement (2002-2050)

Furthermore, there may be additional benefits or dis-benefits that may be achieved indirectly from an accelerated phase-out through improved equipment efficiency. For instance, if an HCFC refrigerant is phased out more quickly, the price of recovered and recycled material could rise to the point that the owner of equipment may decide that it is more economical to replace that equipment than continue to service it with the phased-out refrigerant. If the new unit is more efficient, then savings in CO_2 emissions from power plants used to generate electricity to power that equipment would be achieved. Likewise, if the owner decides to retrofit the equipment to use a different refrigerant, and that retrofit results in a change in energy efficiency, savings in or additions to CO_2 emissions may occur. These issues are too specific to be analysed in depth in this report, but need to be recognised as real-life scenarios.

4.3.2.2 Foams

The following three graphs (Figures 4.8, 4.9 and 4.10) provide comparative information on the impact of the different control scenarios on emissions from foams. As an overall trend, it is clear that the impacts in terms of both ozone and climate are very limited.

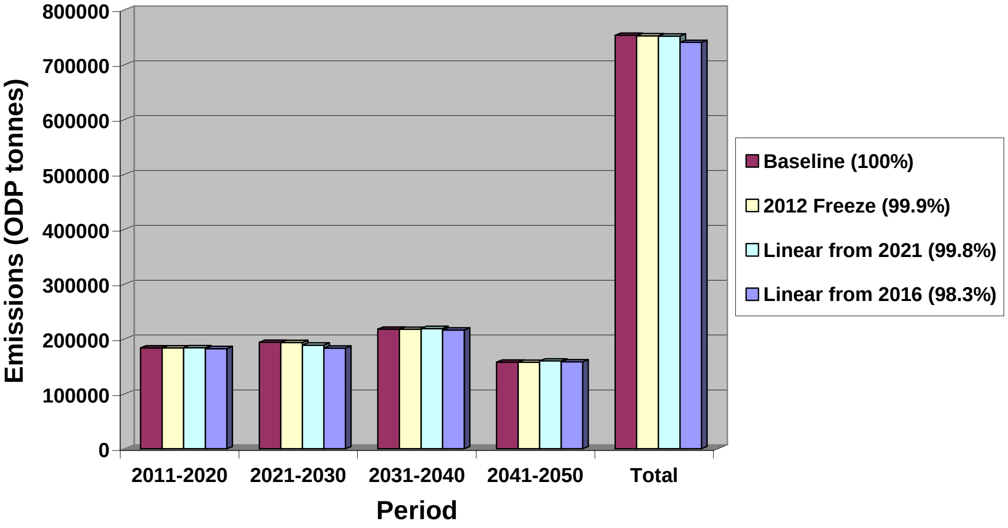


Figure 4.8 Comparative ODS blowing agent emissions for different scenarios in ODP tonnes

There are two primary reasons for this. The first is that most of the emissions taking place over the period relate to foams already manufactured prior to 2010. This is particularly the case in the 2031-2040 period where end-of-life of many building foams will be reached. The second aspect is that foams are relatively low in emission during the early phases of the life-cycle and changes in post-2010 consumption take some time to work through into detectable differences in emissions.

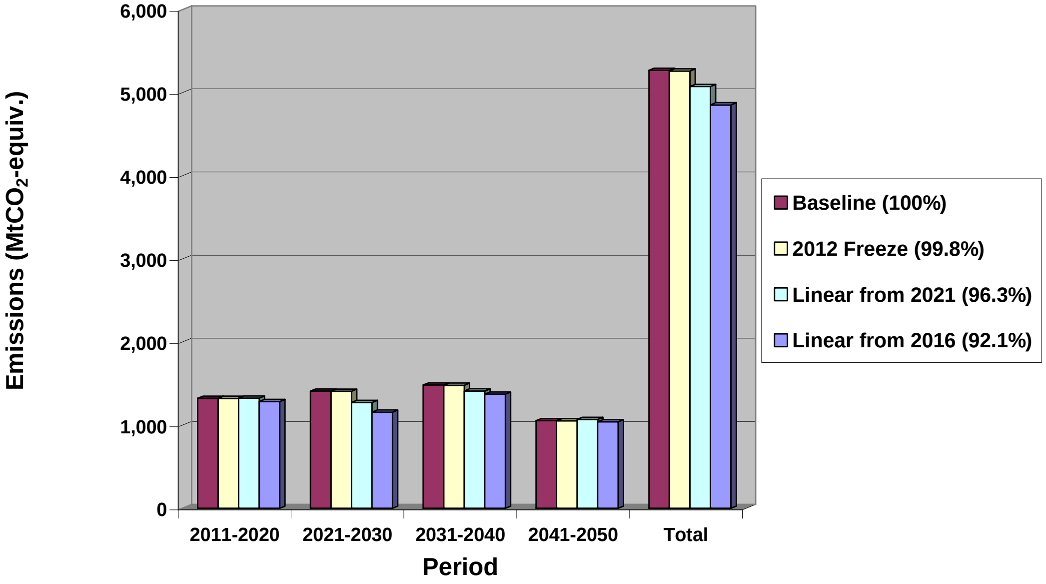


Figure 4.9 Comparative ODS blowing agent emissions for scenarios in Mtonnes-CO_2-eq

When viewed in terms of climate impact (Figure 4.9), the differences are slightly more noticeable. This reflects the fact that the main differences in emission relate to HCFC-22 and HCFC-142b used in extruded polystyrene, which have GWPs of 1780 and 2270 respectively. Added to this, the XPS process is among the more emissive during the foam manufacturing phase, leading to greater changes in emissions when HCFC phase-out is accelerated.

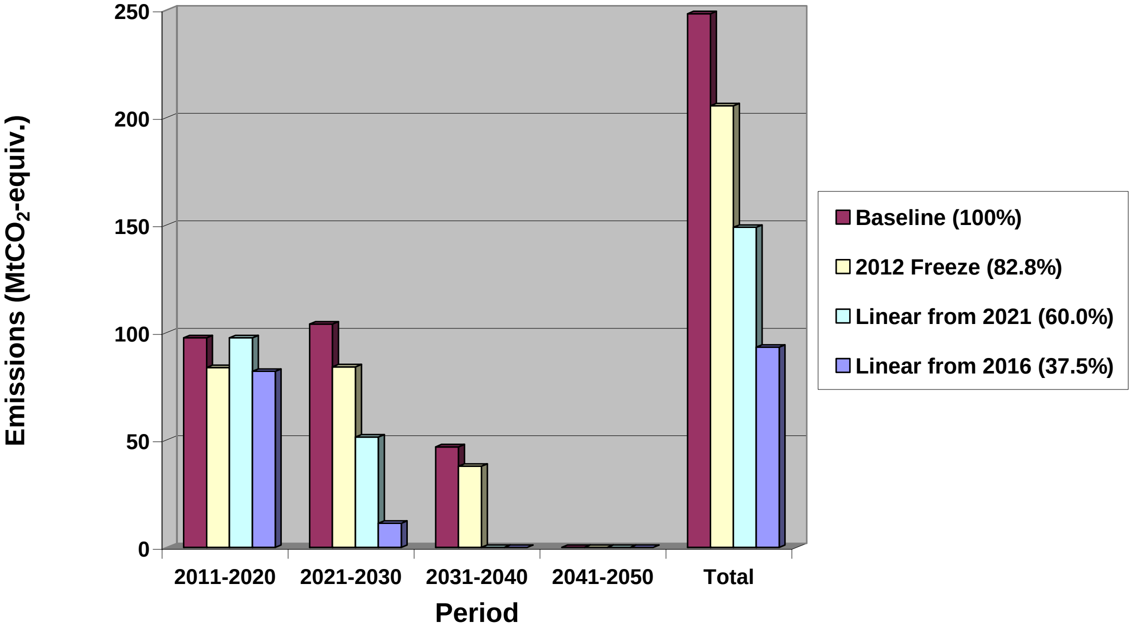


Figure 4.10 – HFC-23 emissions from HCFC production for foams under different scenarios

The most significant contribution from the foams sector under the scenarios outlined arise from the avoided emissions of HFC-23, which in turn relate back to reductions in HCFC-22 demand. Nonetheless, it is important to compare the scales of Figures 4.7 and 4.10, since the refrigeration-related HFC-23 emissions are over 20 times larger than those from resulting from foam manufacture.

Taking into account a more rapid growth factor of 3.3 estimated in 2006 by the Foams Technical Options Committee (see section 2.2), the emissions savings from an accelerated HCFC phase-down become more significant:

Scenario	***Growth Factor as SROC***		***Growth Factor of 3.3***	
	ODP tonnes	*Mtonnes CO_2-eq*	*ODP tonnes*	*Mtonnes CO_2-eq*
Freeze at 2012	920	7	946	9
Linear from 2021	1,375	70	9,703	194
Linear from 2016	4,265	112	15,841	416

Table 4.2 Impact of high growth factors on overall foam emission abatement (2002-2050)

4.3.2.3 Other sectors

The remaining sectors of significance to this assessment are medical aerosols, fire protection and solvents.

Medical Aerosols

For medical aerosols, there is anticipated to be demand for CFCs beyond the Montreal Protocol phase-out of consumption in 2010. However, this could potentially be met through final campaign production of an estimated 4,000 tonnes of materials (CFC-11, CFC-12 and CFC-114) in 2010[18]. Such an approach is preferred to the operation of an essential use provision after 2010, since pharmaceutical-grade CFC production efficiencies do not favour the manufacture of smaller annual requirements. In either instance, there is expected to be no reliance on HCFCs as alternatives in the post-2010 period and hence proposals to accelerate phase-out of HCFCs in developing countries should have no impact on this sector.

Fire Protection

Only a small continuing use of HCFCs (most notably HCFC-123 and HCFC-22) is expected in developing countries in the post-2015 period. Therefore, application of any of the three scenarios predicts only minor impacts on emissions abatement because of the low consumption expected and the relatively low baseline emissions. Nonetheless, for completeness, the outcome of the analysis is shown in Figures 4.11 and 4.12 that follow:

---

[18] Response to Decision XVIII/16 – TEAP Progress Report (2007)

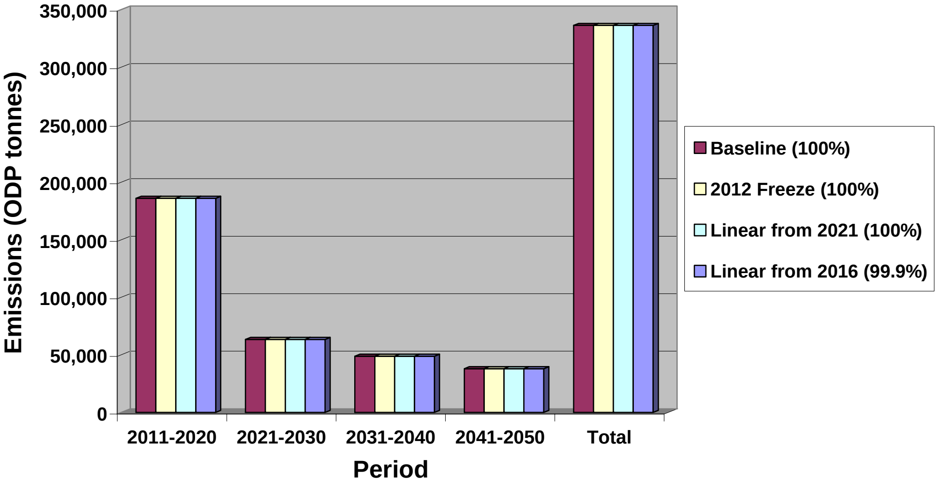


Figure 4.11 – ODS emissions for Fire Protection under different scenarios in ODP tonnes

In Figure 4.11, the relatively high emissions of ODS, as measured in ODP tonnes, is indicative of the high ozone depletion potential of halons, but the lack of differentiation in emissions resulting from the different scenarios reflects the relatively low ODPs of the HCFCs in question (HCFC-123 and HCFC-22) as part of the total.

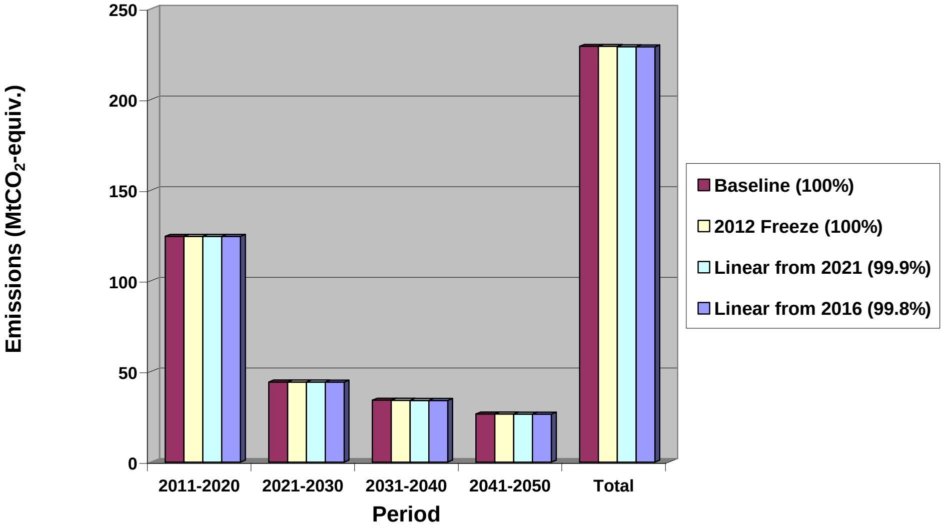


Figure 4.12 – ODS emissions for Fire Protection under different scenarios in Mtonnes CO_2-eq

Again in Figure 4.12, the lack of differentiation in emissions resulting from the different scenarios is a combination of low emission rates and the fact that the GWPs of the HCFCs in question are 76 (HCFC-123) and 1780 (HCFC-22). However, in this instance, the low climate contribution of halons can also be seen (see also Figure SPM-2, page 8) in that 10 yearly emissions do not exceed 150 M tonnes CO_2-eq.

Solvents

Conducting the same analyses on solvent uses provides a more significant differentiation between scenarios because of the demand for solvents that may extend beyond 2015 in developing countries in the baseline case (8,000 tonnes/annum), and also the greater emission factors involved. Figures 4.13 and 4.14 illustrate these aspects in both ozone and climate terms.

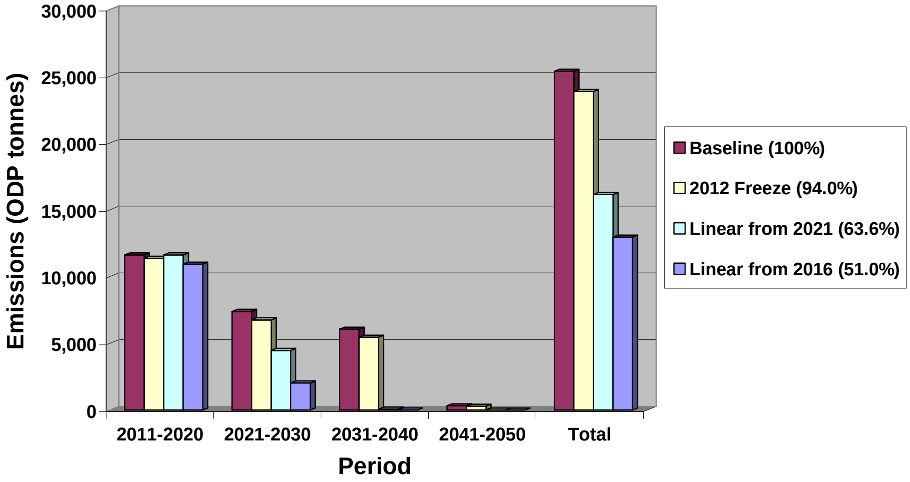


Figure 4.13 ODS emissions from solvent uses under different scenarios in ODP tonnes

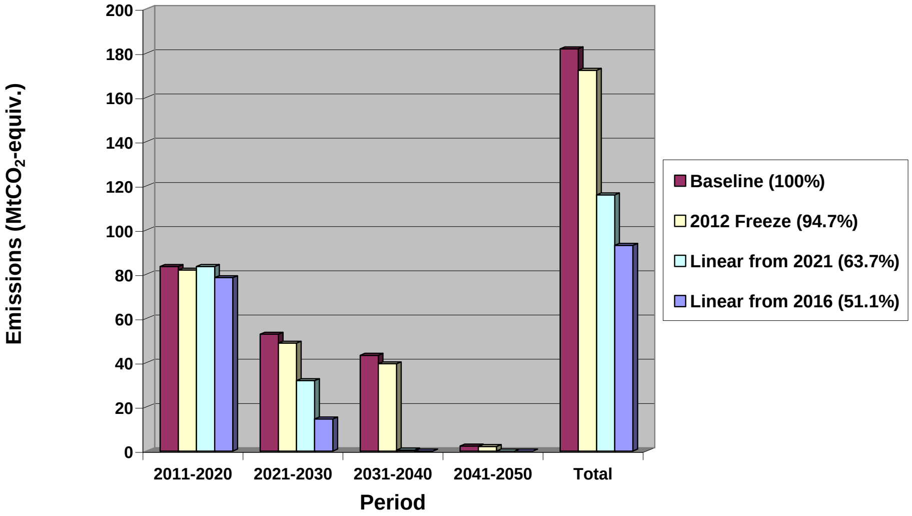


Figure 4.14 ODS emissions from solvent uses under different scenarios in Mtonnes-CO_2-eq

The emissions contribution of the solvents sector is still relatively low when compared with others, primarily because of the fact that large banks of solvent do not tend to accumulate. The climate impact of emissions is particularly low because of the limited GWP of HCFC-141b (713) and HCFC-225ca/cb (376).

4.3.3 Performance of alternative technologies to HCFCs

Taking the sectors assessed within this Section, it can be seen that, for example, applying a scenario of linear phase-down of HCFCs in developing countries between 2016 and 2025 could, in theory at least, abate in excess of an estimated 18 billion tonnes CO_2-eq in the period to 2050. However, the key assumption in this assessment is that all of the alternatives considered have minimal or no global warming impact of their own – or, if they do, that such global warming impacts are offset by improvements in energy efficiency. Such outcomes are unlikely in totality and it is clear that some of these climate benefits may not be delivered in practice. A key question, however, is whether the acceleration of the HCFC phase-out would result in the more widespread adoption of sub-optimum solutions in climate terms.

In order to illustrate the complexity of climate assessments, Tables 4.3, 4.4 and 4.5 illustrate the vast array of refrigerants available as alternatives to currently used materials. Most are blends, which often makes it difficult to identify impacts arising. Those blends not containing ODSs are highlighted in yellow. Some HCFC-containing blends can still be used as 'drop-ins' or for retrofitting CFC-containing equipment. The most popular of these are shown in Table 4.3.

Refrigerant	***Blend Components***	***Mass Ratio***
R-401A	HCFC-22/HFC-152a/HCFC-124	(53.0/13.0/34.0)
R-401B	HCFC-22/HFC-152a/HCFC-124	(61.0/11.0/28.0)
R-402A	HFC-125/HC-290/HCFC-22	(60.0/2.0/38.0)
R-402B	HFC-125/HC-290/HCFC-22	(38.0/2.0/60.0)
R-408A	HFC-125/HFC-143a/HCFC-22	(7.0/46.0/47.0)
R-409A	HCFC-22/HCFC-124/HCFC-142b	(60.0/25.0/15.0)
R-409B	HCFC-22/HCFC-124/HCFC-142b	(65.0/25.0/10.0)

Table 4.3 – HCFC-containing refrigerant blends used as replacements for CFCs [19]

For HCFC-22 replacement in commercial refrigeration and some stationary air conditioning applications, Table 4.4 provides an overview of some of the most popular HCFC-free blends available today, with the two most popular marked with an asterisk:

Refrigerant	***Blend Components***	***Mass Ratio***
R-404A*	HFC-125/HFC-143a/HFC-134a	(44.0/52.0/4.0)
R-417A	HFC-125/HFC-134a/HC-600	(46.6/50.0/3.4)
R-419A	HFC-125/HFC-134a/HE-E170	(77.0/19.0/4.0)
R-421A	HFC-125/HFC-134a	(58.0/42.0)
R-421B	HFC-125/HFC-134a	(85.0/15.0)
R-422A	HFC-125/HFC-134a/HC-600a	(85.1/11.5/3.4)
R-422B	HFC-125/HFC-134a/HC-600a	(55.0/42.0/3.0)
R-422C	HFC-125/HFC-134a/HC-600a	(82.0/15.0/3.0)
R-422D	HFC-125/HFC-134a/HC-600a	(65.1/31.5/3.4)
R-507 (also called R-507A)*	HFC-125/HFC-143a	(50.0/50.0)

Table 4.4 – HCFC-free refrigerant blends used primarily for commercial refrigeration[16]

---

[19] Extracted from the 2006 IPCC-NGGI Reporting Guidelines – Chapter 7 ODS Substitutes

The prime alternatives for the stationary air conditioning sector are shown below in Table 4.5.

Refrigerant	***Blend Components***	***Mass Ratio***
R-407C	HFC-32/HFC-125/HFC-134a	(23.0/25.0/52.0)
R-410A	HFC-32/HFC-125	(50.0/50.0)
R-417A	HFC-125/HFC-134a/HC-600	(46.6/50.0/3.4)
R-419A	HFC-125/HFC-134a/HE-E170	(77.0/19.0/4.0)
R-421A	HFC-125/HFC-134a	(58.0/42.0)
R-421B	HFC-125/HFC-134a	(85.0/15.0)
R-422A	HFC-125/HFC-134a/HC-600a	(85.1/11.5/3.4)
R-422B	HFC-125/HFC-134a/HC-600a	(55.0/42.0/3.0)
R-422C	HFC-125/HFC-134a/HC-600a	(82.0/15.0/3.0)
R-422D	HFC-125/HFC-134a/HC-600a	(65.1/31.5/3.4)

Table 4.5 – HCFC-free refrigerant blends used primarily for stationary air conditioning[16]

It is clear that some of the blends are offered for multiple applications, including both stationary air conditioning as well as commercial refrigeration. Additional blends exist but have not to date been as successful. Furthermore, additional blends are constantly being developed and commercialised.

The various blends listed are tailored to meet relatively specific and tightly defined needs: only three or four may be suitable for any specified application. The vast majority of the blends listed carry a relatively substantial GWP and there is thermodynamically little (perhaps 0-10% difference) to choose between them in terms of their energy efficiency. As a result, the energy performance of a piece of equipment tends to be derived more from its design than from the specific choice of refrigerant

The most versatile and most commonly referenced alternatives are R-404A for commercial refrigeration and R-410A for stationary air conditioning. These have composite GWPs of 3,862 and 2,160 respectively – both considerably higher than HCFC-22. Since the savings of HCFC-22 related greenhouse gas emissions are often a primary driver for accelerated HCFC phase-out in the refrigeration sector, careful consideration needs to be taken when choosing such alternatives to confirm that climate benefits can be realised.

The question also arises as to whether giving sufficient advanced notice (e.g. 8-10 years) of an accelerated HCFC phase-out in developing countries would assist in stimulating the development of further low-GWP alternatives. The answer is almost certainly ‘yes’, although the factors considered in Section 3.2 concerning the impact of the CDM on the market for alternatives also need to be borne in mind.

SROC data indicates current consumption of HCFC-22 for refrigeration applications in developed countries continuing at around 125,000 metric tonnes since the year 2005, despite the fact that many developed country regions have already banned the use of HCFC-22 in new equipment. These consumption levels reflect demand for HCFC-22 in the servicing of existing equipment and highlight the lag between the change of technology and the resulting adjustment of HCFC demand patterns. It also reflects the continued production of new equipment reliant on HCFC-22 in the United States, where such production is not scheduled for phase-out until 2010.

For other sectors, alternatives to HCFCs are generally available, but often at an additional cost, either in terms of the alternative itself or the capital requirement to convert the technology safely. A prime example of the latter is the onward conversion of foams currently blown with HCFC-141b to hydrocarbons. While hydrocarbons represent the lowest GWP alternative available, existing foam plants require additional engineering to accommodate them in the manufacturing process as well as to adjust foam products to achieve similar performance (e.g., insulation value) blown with hydrocarbons compared to fluorocarbons.. The alternative would be to choose a more expensive, higher GWP alternative, such as an HFC.

The issue of cost is not specifically addressed in this report, but it is clear that the interaction between the following criteria will be at the heart of the debate that follows:

1. the ozone benefit of earlier HCFC phase-out

2. the climate benefit of low GWP alternatives and/or energy efficiency improvements

and

3. the cost of transition

The foam example already cited is a particularly interesting one because of the relatively low emission rates (particularly in the use phase) related to many foam applications. For the period to 2050, Section 4.3.2.2 shows that the emissions savings for the foam sector in ODS terms could be relatively small compared with other sectors, such as refrigeration. With the phase-out of ODS already mandated under the Montreal Protocol, the question is only whether money is spent earlier or later. This assumes that a drop-in, low-GWP and inexpensive alternative would fail to emerge in the intervening period.

From the information presented in this section, there is evidence to suggest that a sectoral approach to HCFC phase-out might be more technically and economically feasible than a chemical-by-chemical approach suggested in some of the proposed Adjustments. A sectoral approach would have the benefit of being able to tailor the rate of phase-down of HCFC consumption based on the three criteria highlighted above. However, such an approach would require far better knowledge of use patterns in developing country markets than is currently generally available. Nevertheless, the ability to be selective could greatly assist the optimisation of climate benefit as new alternatives emerge.

4.3.4 Potential technical challenges with transition

In some applications, there is concern that no real alternatives exist. Some clear examples have already been identified in the solvent, medical and fire protection areas for HCFC-225 as explained in the following paragraphs.

HCFC-225

While the military, aerospace, electronics, and medical sectors have eliminated CFC-113 in nearly all critical applications, in a few applications HCFC-225 cleaning solvent, and more specifically a special version of the solvent consisting almost entirely of the less toxic HCFC-225cb isomer (see Table 7-2), is the only currently available alternative that has proven acceptable as a safe and technically satisfactory replacement for these few applications.

Critical use considerations might apply to specialty military, aerospace, and medical use of HCFC-225, which is the closest chemical substitute for CFC-113. The use of HCFC-225 has to date been limited by its cost, thereby encouraging companies to seek alternatives.

- *Cleaning of critical oxygen life support systems and components*

Oxygen is a strong oxidizer that contributes to the likelihood of ignition and vigorously supports combustion. As the concentration, pressure and temperature of oxygen increase, so does its reactivity. Common contaminants such as particulate and hydrocarbon oils and greases easily ignite in an oxygen-enriched atmosphere. This, combined with the fact that all plastics and rubber, and many metals, burn quite vigorously in oxygen-enriched atmospheres at high pressure, mandates rigorous cleaning of oxygen components and piping systems. In an oxygen enriched environment, the fire typically cannot be extinguished until the oxygen source is isolated or depleted, and over 20 kilograms of stainless steel can vaporise in less than 1 second. The dangers involved with oxygen fires are real and both historic and recent. Between 1990 and 2002, the British Health and Safety Executive (HSE) reported 280 oxygen incidents in the commercial and medical sectors with 5 fatalities and 187 injuries. In 1967, the oxygen fire on the Apollo 1 launch pad killed three astronauts. In 1960, an oxygen fire on the *USS Sargo* killed one crewman, and it was only the flooding of the stern of the submarine at the pier to cool the affected area that prevented weapons from exploding and causing a far more devastating event.

CFC-113 was well suited for the cleaning of oxygen components and piping systems. The solvent possessed excellent ability in removal of contaminants such as hydrocarbon, silicone and fluorinated oils and greases. Additionally, CFC-113 was non-flammable, had low toxicity, and was compatible with many metallic and non-metallic materials. Furthermore, the solvent was easily analysed for residual contamination by infrared (IR) spectroscopy or evaporative non-volatile residue (NVR). This permitted quantitative verification of cleanliness, which provided a level of confidence commensurate with high value platforms such as nuclear submarines and nuclear aircraft carriers.

Most oxygen cleaning applications have switched from CFC-113 to other non-ozone depleting alternatives such as aqueous cleaners or HFE (hydrofluoroether) solvents. However, some applications with very complex geometries will not allow the mechanical agitation necessary to support these alternatives because these non-ODS alternatives generally have marginal performance without agitation. In similar complex geometries, HFE and HFC solvents are combined with other more aggressive solvents such as trans-1,2-dichloroethylene to enhance their performance. However, using a solvent blend like this in an oxygen-enriched environment presents risk since any solvent remaining behind acts as a flammable contaminant in the system, potentially resulting in catastrophic fires. Additionally, in some cases, very small quantities of the blended solvents can be acutely toxic and could rapidly disable a user, such as a high performance jet aircraft pilot, further increasing the risk of a catastrophic event.

One example of a complex geometry that requires HCFC-225cb usage is the flush cleaning of liquid oxygen producers installed on aircraft carriers and hospital ships. The equipment produces breathing oxygen for aircraft and medical usage, and also produces liquid nitrogen for aviation usage. The configuration of the liquid oxygen producer is inherently difficult to clean. They are composed of large distillation columns that are over 2 meters tall and 50 centimetres in diameter with multiple plates having small passages (1/3-cm holes) combined with spiral wound heat exchanges. Additionally, since the producers are installed within confined shipboard spaces and provide breathing oxygen, worker and user exposure to toxic chemicals is a major concern. While naval technical authorities have approved aqueous and HFE alternatives for other oxygen cleaning applications on a basis of cleaning performance, in this application the same level of safety could not be assured and the risk associated with a potential fire on ships with several thousand people aboard, often powered by a nuclear reactor, and potentially carrying large amounts of conventional and nuclear weapons was considered unacceptable. So, while commercial industry has in similar applications moved to non-ozone depleting substance alternatives, the naval technical authorities have chosen not to adopt these practices because of the inherent risk of failure, regardless of how remote. Instead, the naval technical authorities have established extraordinarily high quality assurance criteria for acceptable alternatives to protect these high value tactical and strategic systems whose failure could risk national security, result in serious injury or death to military personnel, or have unintended consequences to civilian populations and the environment.

While precise amounts of HCFC-225 used in cleaning of oxygen systems is unknown, it is estimated that the total world-wide annual emissions from these types of cleaning processes is on the order of 5 ODP-weighted metric tons.

- *Cleaning of precision inertial guidance systems*

Inertial guidance systems used in many existing spacecraft and missiles consist of gyroscopes and accelerometers surrounded by electronics components and assemblies. Mechanical tolerances on these components can be as small as 0.15 millimetres resulting in a unique requirement for a near-perfect cleaning solvent to manufacture and maintain these systems. Necessary solvent properties include a volatile solvent with near-zero residues, sufficient solvent power to remove organic soils, low surface tension to penetrate small spaces, high density to assist the lift off of small particles, rapid drying, low toxicity and non-flammability. The solvent must also be compatible with the many materials and substrates of the system. Guidance systems include exotic metals such as beryllium, which is reactive or incompatible with many traditional solvents. In addition to the metallic components, there are numerous elastomers, epoxies, wire insulations, and organic coatings, which could swell unacceptably or be damaged by a solvent that is too aggressive. The solvent of choice that met all of these properties was CFC-113. However, as early as the 1970s, military and space organisations began to look for an alternative to CFC-113 due to its environmental impacts. Over the next two decades many solvents including HFCs, HFEs, and others were evaluated as possible alternatives with no success. It was not until the introduction of HCFC-225 that a solvent was found with properties that very closely replicated CFC-113 (see Table 7-1).

As the failure of a guidance system on a missile or spacecraft could compromise scientific investigations or national security, risk loss of a high value spacecraft or satellite, or result in serious injury or death of personnel, extensive testing is required to qualify an alternative solvent in these applications. Testing usually begins with preliminary materials compatibility testing, followed by longer term mechanical, dimensional, and electrical properties testing on each component, and finally system testing. The final test on these systems often consists of manufacture and cleaning of the systems with the alternative followed by a multi-year operational test or system tear-down and inspection after it has been in storage for several years. As a result, it is not uncommon for the entire qualification cycle to take 6-8 years. Accordingly, even if an alternative to HCFC-225cb were identified today it would be 2015 before it could be fully qualified. Since many of these systems support a small number of spacecraft and missiles that have limited operational lives (although they may be very long inventory lives), it generally would not be economically feasible to invest in a multi-million dollar qualification program after such a program investment already occurred over the last decade to qualify HCFC-225cb as an alternative to CFC-113. In addition, chemical manufacturers are no longer investing in extensive research and development to find alternative solvents since these remaining critical uses do not provide a large enough market to receive a return on their investments.

While precise amounts of HCFC-225 used in cleaning of precision guidance systems is unknown, it is estimated that the total world-wide annual emissions from all precision cleaning processes (military, aerospace, electronics, medical, etc) is less than 40 ODP-weighted metric tons. It is likely that only a small portion of these emissions result from cleaning of precision guidance systems.

- *Electronics manufacture*

There are a variety of miscellaneous uses in electronics manufacturing such as defluxing of flexible circuits made of polyimide, which may not be compatible with other cleaning processes or no-clean, and in the manufacture of high production rate electronics assemblies, particularly electronics assemblies and components with conformal coatings. HCFC-225 is used in these few specialised applications.

- *Medical applications*

HCFC-225 is used to clean some implantable or surgical medical devices and plastic medical equipment that are not compatible with other solvents or where soils residue must be very low.

HCFC-22 and HCFC-142b in XPS foams

Another area that might create some significant transitional challenges is the replacement of HCFC-22 and/or HCFC-142b used for extruded polystyrene foams in China. Although the transition in Europe has been made successfully to CO_2 and HFC blends, this has primarily been as a result of the narrow board widths produced. In Japan, hydrocarbons have been the primary alternatives based on specific fire criteria and building practices in that market. Plant investments have been necessary in many instances. In North America, it is still not clear which alternatives will be preferred, since the specific requirements of that market demand wide and thin panels for sheathing applications. HFCs are the most likely option when transition occurs in 2010, but the technology is still in its final proving stages.

In China, the growth of XPS foam use has been very rapid and has been facilitated by the availability of relatively inexpensive foam manufacturing equipment. This is in stark contrast to the developed countries where XPS plants are usually multi-million dollar investments. It is not yet clear whether the Chinese equipment base will support the use of the HCFC alternatives identified in other regions. Much will also depend on the specific product requirements for the Chinese market.

4.3.5 Other considerations (including Basic Domestic Needs)

The scenarios evaluated in this Report have also been reviewed against the HCFC-22 production base. Section 2.7, and particularly Figure 2.11, shows the anticipated HCFC-22 production for feedstock and emissive uses for the baseline scenario. Figure 4.15 below shows how the various phase-down options considered would impact total HCFC-22 production.

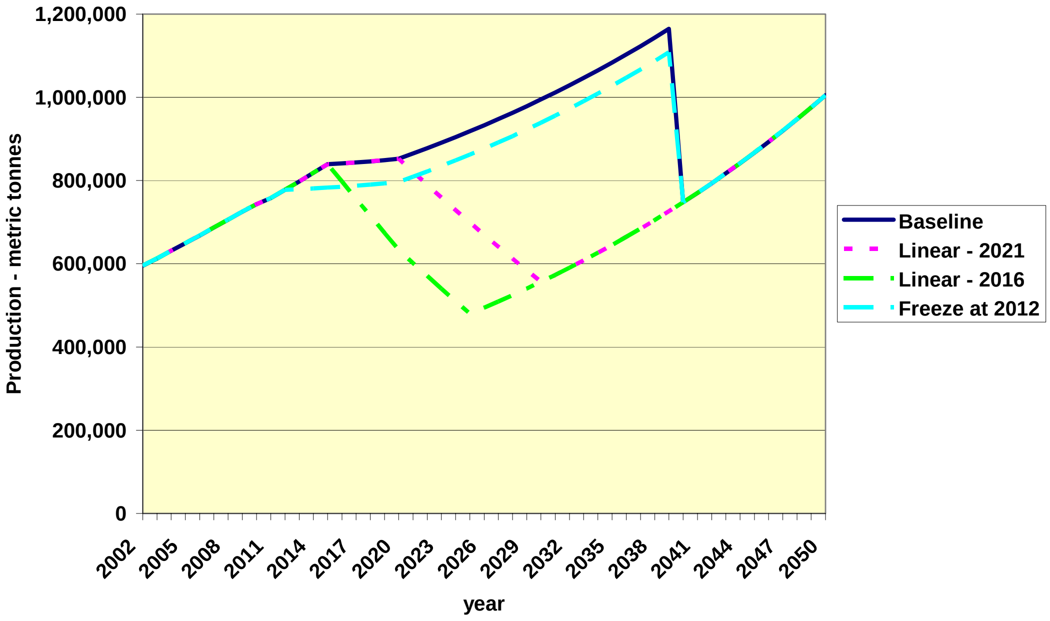


Figure 4.15 – Impact on HCFC-22 production under the various scenarios

The earlier HCFC phase-down in emissive uses results in a peak demand that remains below the expected feedstock demand in 2050. A freeze at 2012 is not quite sufficient to do this in isolation, but could still be a contributor to reducing HCFC demand in the pre-2040 period.

Although the availability of HCFC-22, HCFC-123 and HCFC-142b may well be assured by the on-going demand that will exist for feedstock, access to supplies of HCFC-141b and other HCFCs by Article 5 Parties may need to be under-pinned by a provision for Basic Domestic

Needs (BDN). This would particularly facilitate the transfer of relevant HCFCs from one Article 5 country to another. Although BDN was not specifically a part of Decision XVIII/12, some Parties at OEWG-27 held in Nairobi requested the opinion of the Task Force on this matter. The following paragraphs address this issue.

The need for a production allowance for meeting the Basic Domestic Needs (BDN) for ODS of Article 5 Parties arises because only a few Parties in the world produce ODS. Many of the ODS producers are non-Article 5 Parties whose production (and consumption) phase-out is mandated to be considerably earlier than that of Article 5 Parties. The Article 5 Parties have always been concerned that while they are allowed to consume ODS for a longer period, their supplies of ODS may dry up totally or the number of suppliers reduced drastically, potentially leading to exploitative pricing by the few final suppliers. Hence the Protocol provides that producers can produce up to 10% more (than allowed by the control measure applicable) to meet the BDN of Article 5 Parties and up to 15% of their baseline production after the production phase-out.

It should be noted that there were no production controls on HCFCs till 1999 and a freeze in HCFC production in non-Article 5 Parties was mandated through the Beijing adjustments and amendment in 1999. At that time, in response to the concerns of Article 5 Parties about the supply of HCFCs a production allowance of 15% was allowed to meet the BDN.

It is worth noting that, owing to the Multilateral Fund projects, by 1999 the consumption of CFCs by Article 5 Parties was falling even before their first mandatory freeze date in the year 2000. It was estimated that owing to the Fund’s projects, future consumption of Article 5 Parties would also be much lower than mandated in future too and that production allowances of 10% and 15% of the baseline production would be excessive compared to the demand for ODS. It was realised that excessive production would result in cheaper ODS and would be a disincentive to the phase out. Hence the Beijing adjustment made the production allowance proportional to the allowed consumption by Article 5 Parties. For example, the permitted production allowance for meeting the BDN of Article 5 Parties for Annex A, Group I (CFCs) were the following quantities:

- Until the end of 2002: annual average of its production to meet the BDN for the period of 1995 to 1997 inclusive (base).
- Until the end of 2004: 80 per cent of the base.
- Until the end of 2006: 50 per cent of the base.
- Until the end of 2009: 15 per cent of the base.
- From 1 January 2010: zero.

Some proposals to accelerate the phase-out of HCFC production currently under consideration by Parties provide for 10% to 15% of the production for BDN up to 2020 and lesser percentages of up to 1% after 2020

It is important that any allowances for HCFC production for BDN are not in fixed percentages of a baseline production and that they are reduced progressively with consumption, as was provided for other ODSs through the Beijing adjustment. The details for production allowances for BDN for HCFCs can be determined only after any new consumption reduction schedule for the Article 5 Parties is known. It is likely that Article 5 Parties will choose to reduce HCFC consumption faster than mandated by the accelerated control schedule if the Multilateral Fund can provide adequate resources for this purpose. It is also likely that the pressures on Article 5 Parties to preserve their export markets to non-Article 5 Parties may provide an incentive for Article 5 Parties to phase out faster. The production allowance should therefore keep pace with such changes. TEAP could review periodically (e.g. every 4 years) the need for the production allowance for specific HCFCs).

Article 5 Parties may have the same concerns for the reliability of affordable supply of HCFC-141b and HCFC-142b[20] as were expressed for the CFCs because they are produced in a limited number of countries. Phase-out will ultimately result in an increasingly declining number of manufacturers. However, developing countries are likely to halt rapidly the use of HCFC-141b and HCFC-142b where they offer no technical and economic advantage and where export markets either now or in the near future, restrict import of products made with or containing these substances. If an agreement to accelerate the HCFC phase-out provides access to financing on a schedule at or faster than compliance, HCFC-141b and HCFC-142b are likely to be phased out within the next few years when their supply is more than adequate from existing plants. Therefore, production and trade in HCFC-141b and HCFC-142b could be allowed consistent with the control schedule.

Article 5 Parties will have less immediate concern for the reliability of affordable supply of HCFC-22 because it is manufactured in many countries world-wide and because large quantities of HCFC-22 are produced for uses currently exempted as feedstocks or process agents. However, because it is likely that enterprises operating in Article 5 Parties will phase-out HCFC-22 later than other HCFCs, it will be important for Parties to ultimately guide production for BDN. TEAP could propose conditions for the supply of HCFC-22 for BDN that 1) authorises production for uses compliant with a new accelerated control schedule; and 2) specifies conditions of BDN supply that take into account environmentally responsible manufacture with minimum emissions of HFC-23 and carbon tetrachloride.

While the term ‘basic domestic needs’ has not been precisely defined, Parties have clarified that allowance for ‘basic domestic needs’ does not allow production in the Article 5 Parties of products containing controlled substances to expand for the purpose of supplying other countries. This clarification needs to be reiterated for HCFCs.

---

[20] despite its use as a feedstock

4.4 Other Practical Measures

The other *'practical measures'* (OPM) dealt with in this report are those that were specifically addressed at the July 2006 Workshop (see Section 1.2) and do not necessarily represent all of the measures that might be considered in specific regions or circumstances. In general, these are measures that, unlike the accelerated HCFC phase-out considered in Section 4.3, are not targeted specifically at control of consumption. More typically, they control, or otherwise impact emissions. However, this does not rule out the possibility that a measure to control emissions might have an additional effect on future consumption. A prime example is the measure to reduce leakage in the commercial refrigeration sector, where such a reduction results directly in a decrease in refrigerant demand for servicing (see Section 4.4.1.2).

Throughout this section it is assumed that measures can be implemented in full from 2010 onwards. Therefore all analysis deals with the impact of the measures for the four decades that follow that date (2011-2020, 2021-2030, 2031-2040, 2041-2050). A measure can be valued in terms of both its overall impact and the timing of that impact. This subject is elaborated further in Chapter 5 where the timing of grouped measures (Section 4.1 refers) is discussed. This section, however, limits itself to a description of each proposed measure and the assumptions used to evaluate its significance.

4.4.1 Emission Reduction Measures in the Use-Phase

Emissions during the use-phase of a product or piece of equipment can vary substantially depending on a number of characteristics such as design, location or weather conditions to name just a few. In ODS terms, one of the key factors that distinguishes between groups of products is whether the ODS, once emitted, is replaced during its service life. In the context of this Report, all applications for which a *'practical measure'* has been listed fall into this category except for foams.

4.4.1.1 Domestic Refrigeration

Since most domestic refrigerators have been, and continue to be, designed with hermetically sealed compressors, it is unlikely that these will be maintained routinely unless a specific inspection procedure is established. Such an inspection procedure could be expected to identify two different types of event:

- The imminence of a catastrophic failure accounting for perhaps 75% of total use-phase losses

and

- A chronic leakage problem (i.e. low leakage rate) accounting for the other 25% of total use-phase losses.

The refrigerants used in domestic refrigerators globally include mainly CFC-12, HFC-134a and HC-600a. The primary area of interest for this Report is CFC-12. Banks of CFC-12 within domestic refrigerators amounted to an estimated 90,880 tonnes in 2005.

Baseline emission rates for CFC-12 from domestic refrigerators are usually quoted as a percentage of the total bank. This means that they are often a composite of both use-phase and end-of-life emissions. The SROC quotes a composite figure (Table TS-9) as 6% for CFC-12 in 2002, which increases to 8.4% by 2015 because of a greater end-of-life component. Emissions in developing countries by that time are estimated to be above 10% of the bank annually.

For HFC-134a and HC-600a the emission rates for 2002 are quoted as 1% which represent only use-phase losses, since normally none of these units would have yet reached end-of-life. Bearing in mind that CFC-12 units are older and might have more propensity to leak, it would be reasonable to establish a baseline of 2.5% of the bank annually for use-phase losses only.

One possible scenario is that annual inspections could intercept one third of pending catastrophic failures and 100% of chronic leaks. However, since chronic leaks will have already been occurring for some time, it is assumed that 50% of the annual emission is lost. On this basis, it is therefore assumed that 37.5%[21] of use-phase emissions might be prevented. Commencing at 2010 and applied to the expected bank over the period to 2050, this would equate to cumulative ozone-related savings of **4,505 ODP tonnes** and climate-related savings of **47.75 Mtonnes CO_2-eq**, all of which would be additional to any accelerated phase-out of HCFCs covered in Section 4.3.

One further question that needs to be addressed is whether a CFC-12 domestic refrigerator which has lost its charge, would ever be refilled. If not refilled, it would be possible to consider the loss as ‘premature end-of-life’ rather than use-phase emission. This has relevance, particularly where end-of-life emissions would otherwise be controlled. In such circumstances, the saving from inspection would be genuinely additional, whereas where end-of-life emissions happen in any event, the only impact of inspection is a delay of that pending emission.

4.4.1.2 Commercial Refrigeration

Figure 2.14 in Section 2.7 illustrates well that the commercial refrigeration sector is expected to be the largest single contributor to ODS emissions in the post-2010 period. This results in part from the sheer size of the bank, although it should be noted that both the foam and stationary air conditioning banks are larger. The main consideration is therefore the leakage rate from equipment. The analysis presented in Table 2.3 suggests that emission factors could range between 33% and 71% annually for the reference year of 2015. Since these emissions are replaced periodically when equipment is serviced, there is a regular reservoir of future emission sources available.

These sources have been recognised for many years both by the industry and by regulators. However, the diffuse nature of the refrigeration industry has made it difficult for trade associations and other industry bodies to organise a response. However, the introduction of well-documented emission control regimes, (for example, the STEK initiative in the Netherlands in the late 1990s) provided an important breakthrough, driven in part by the need to demonstrate responsible use ahead of a switch to HFC refrigerants. The STEK initiative has been so successful that it has become the basis for the implementation of the Fluorinated Gases

---

[21] (33.3% x 75%) = 25% + (50% x 25%) = 12.5%

Regulation in the European Union. Similarly, regulations in the U.S. require commercial refrigeration owners to track emissions and repair leaks if they exceed a certain trigger rate.

With such emission abatement programmes in mind, the Task Force has considered it reasonable to adopt a 50% reduction in leakage rates in the post-2010 period. However, it is also clear that the equipment base is growing rapidly, particularly in some developing countries. A global growth rate of 5% has therefore been assumed. Coupled with an average equipment lifetime of 12 years, the measure, if applied globally, would deliver cumulative savings of approximately **260,000 ODP tonnes** of emissions in the period to 2050, which would equate to **8 billion tonnes CO_2-eq**, since most of the refrigerant emissions avoided would be HCFC-22. These calculations are based on the assumption that no accelerated HCFC phase-out is implemented.

Where an accelerated HCFC phase-out is applied, there will be less future use of HCFC-22 as a refrigerant and this would have an impact on the amount of emissions that would be mitigated under the proposed use-phase measure. For the most stringent regime considered in this report, 'linear 2016', the emissions savings are reduced to **87,500 ODP tonnes**, equating to **2.44 billion tonnes CO_2-eq.** This is reflected in the later analysis shown in Chapter 5.

As noted in the introduction to this section, this is also a measure that would contribute to a reduction in servicing demand for HCFC-22. This would carry with it a reduction in HCFC-22 production and a consequential avoidance of HFC-23 emissions.

It is difficult in a regulatory environment where a number of measures may be in force to apportion the emissions savings created by each. In practice an accelerated phase-out would also contribute to the avoidance of HFC-23 emissions. However, for the purposes of this report, the savings described above are attributed to the use-phase measure since they are expected to occur *irrespective of* any accelerated HCFC phase-out.

4.4.1.3 Transport Refrigeration

The term 'transport refrigeration' covers a number of applications including ships, refrigerated containers and trains. In general, cabin cooling systems for driver comfort in trucks are not normally included but are instead considered under the mobile air conditioning sector.

Table 2.3 again indicates relatively high emission factors for this sector (40-85% per annum). Responsibility for servicing is often more difficult to ascribe because of the movement of equipment around the world. Nonetheless, there are a number of relatively straight-forward procedures that can deliver substantial savings. On this basis, the Task Force has considered that a 50% reduction in leakage is technically and economically feasible. The annual market growth rate is assumed to be slightly lower than for commercial refrigeration at 4% and the equipment life is forecast to be 10 years. Reflecting the smaller market size of the sector, the cumulative savings to 2050 are estimated at just **314 ODP tonnes,** equating to **7.4 Mtonnes CO_2-eq** in climate terms.

4.4.1.4 Stationary Air Conditioning

The stationary air conditioning sector, like the commercial refrigeration sector, offers a substantial opportunity for emissions savings in the use phase. However, unlike the commercial refrigeration sector, the incentive to maintain the existing stock is not as strong. Often equipment is in the hands of estate managers who have other priorities. Another factor that works against the maintenance of performance of some air conditioning equipment is the fact that much of the equipment is old. In line with many products used in buildings, the average lifetime of a piece of air conditioning equipment can be in excess of 20 years. This makes the availability of spare parts a particular challenge, especially in more remote parts of the world.

Nevertheless, the use of air conditioning equipment is growing rapidly – partly driven by the increasing economic capacity of regions in which the prevailing climate would normally demand the installation of such equipment and partly because of changing climatic conditions in regions hitherto unaffected by conditions of extreme heat. With these trends in mind, the Task Force has assumed a growth rate of 6% per annum in stationary air conditioning stock and a 25 year life-time for the installed equipment. Baseline emission factors are a little lower than for the commercial refrigeration sector at 15-25%, but it is assumed that only a 20% reduction in emissions is achievable, based on the factors described earlier. Using these assumptions, cumulative emissions savings of approximately **24,000 ODP tonnes** could be achieved, equating to a saving of about **800 Mtonnes CO_2-eq.** In the light of the earlier discussion (see Section 2.1.1) on the possible under-estimation of stationary air conditioning equipment within the SROC, it is reasonable to assume that these numbers are probably conservative.

4.4.1.5 Mobile Air Conditioning

For the mobile air conditioning sector, the opportunities for use-phase emission reductions can come from improvements in initial design and engineering, as well as from improved service training. The automotive sector, with its relatively low charge volumes, has been notoriously difficult to control. This has led many to invest preferentially in non ozone-depleting, low GWP alternatives. Indeed, the introduction of the regulations on fluorinated gases for this application in the European Union has fostered a number of recent announcements for very low GWP refrigerants to replace the HFC-134a that has already replaced CFC-12 in new vehicle air conditioning world-wide.

Nevertheless, the Task Force considers that there are still considerable opportunities for use-phase reductions, driven by the desire of automobile manufacturers to offer more reliable air conditioning within their vehicles. A reduction of 20% on baseline emissions is considered achievable. Growth rates in the industry are more difficult to forecast and this report has therefore assumed zero growth as a conservative estimate. The lifetime of MAC equipment has been assumed to be 10 years. On this basis, cumulative emissions savings of about **5,000 ODP tonnes** and **100 M tonnes CO_2-eq** are estimated.

4.4.1.6 Foams

There is little potential to reduce ODS emissions from insulating foams in the use-phase since the intention of product design has always been to prevent the loss of blowing agent during this period in order to retain thermal performance. The main opportunity for saving is therefore at the outset of the lifecycle, during production and initial installation.

Although emission factors during the production phase vary considerably depending on the product being manufactured and the process operated, the general average across the industry would be about 5-10% losses over this first period. While some losses are unavoidable, it is reasonable to assume that engineering enhancements and improved installation practices might reduce the losses by an average of 2%. When applied across the industry at current and projected production rates, this would equate to a cumulative saving of approximately **3,000 ODP tonnes**. However, with one of the main blowing agent emissions avoided being HCFC-141b (GWP 713) the contribution to climate protection is relatively less significant than for some other sectors at approximately **20 Mtonnes CO_2-eq.**

4.4.1.7 Halons

For halons, the primary use-phase emissions arise from any of the following:

1. the discharge of the fire protection equipment in an emergency for its intended purpose,
2. accidental release (particularly from automated systems)
3. the testing of equipment
4. the use of equipment for practice
5. losses when extinguishers or cylinders are serviced, sent for inspection or disposed of.

At least one developed country has achieved extremely low emission rates (<1%) for fixed systems based on better management practices and the avoidance of automated systems. However, portable extinguishers generally have more frequent discharges than fixed systems.

Based on the baseline emission factors given in Section 2.7, the Task Force has considered that it may possible to reduce emissions by up to 50% through a variety of better management processes that do not compromise personnel safety. Bearing in mind the significant size of the global banks and the high ozone depleting potentials of the individual halons, the cumulative potential savings in the period to 2050 are substantial at over **160,000 ODP tonnes**, although this does not transfer into such significant climate savings in this instance. Cumulative greenhouse gas emission reductions are relatively low at around **114 Mtonnes CO_2-eq.**

4.4.2 Design Issues and Material Selection

This section seeks to address those measures that either avoid the use of products containing ozone-depleting substances or which, through their design, minimise the amount of that use. This is distinct from those design initiatives that minimise emissions in the use-phase, since these have already been covered in the previous section.

4.4.2.1 Commercial Refrigeration

There are few opportunities to make design changes in relatively complex operating equipment such as that used for commercial refrigeration. This is particularly the case when performance and energy efficiency are often of paramount importance. However, one area that has attracted attention is the possibility of reducing the required refrigerant charge size for equipment. In many cases this can be done very effectively and substantial reductions in volume can be achieved. However, the impact that this will have on emissions depends more on the emission rates related to the re-engineered equipment. Often the overall process of re-design in its own right is sufficient to upgrade the emission characteristics of the unit and the reduction in charge size might only impact emissions in the case of a catastrophic failure.

On the basis of a 50% reduction in charge size, the cumulative saving in emission to 2050 is projected to be about **15,000 ODP tonnes**, reflecting the sheer size of this market. This equates to approximately **480 Mtonnes CO_2-eq.**

4.4.2.2 Stationary Air Conditioning

For stationary air conditioning equipment, less routine maintenance makes the potential for catastrophic failure higher. The impact of a 20% charge size reduction is therefore likely to be greater. Proportionately, the savings are therefore higher when compared with commercial refrigeration than they were in the other use-phase scenarios. Overall cumulative savings to 2050 are estimated at about **5,000 ODP tonnes** and **150 Mtonnes CO_2-eq.**

4.4.2.3 Mobile Air Conditioning

For mobile air conditioning, catastrophic failure is even more prevalent than in the other two sectors previously considered. Accordingly, further reductions in charge size, beyond those that have already been achieved, have an even greater impact. Cumulative estimates of savings to 2050 from this measure amount to about **1,500 ODP tonnes** and **50 Mtonnes CO_2-eq,** respectively.

There are other design issues to consider for the MAC sector. These relate to weight and energy efficiency. Smaller charge sizes often result from smaller equipment components and other design considerations, which have the potential to decrease weight and thereby save fuel. However, the energy demand of the unit itself is the most significant greenhouse gas emission factor to consider. The focus initially created by the need to change refrigerants may ultimately have had substantial co-benefits for climate protection and other environmental impacts of the automotive sector.

4.4.2.4 Foams

Extruded polystyrene boardstock is the largest and fastest growing use of HCFCs. Its major use is for thermal insulation of buildings. Polyurethane foam is the preferred material for appliance, commercial refrigeration, refrigerated containers, discontinuous panels for cold stores, district heating pipe in pipe insulation because of its effective thermal insulation (low thermal conductivity), processability and its contribution to the structural integrity of the finished product.

The following table illustrates the thermal conductivities of the different materials currently used (Gibson, L.J., Ashby M.F., *Cellular Solids*, Second Edition, Cambridge University Press, Cambridge, p. 286):

	W/mK
Polystyrene Foam	0.029 - 0.035
Polyurethane Foam	0.025
Glass Foam	0.050
Glass Wool	0.042
Mineral fibre	0.046

Table 4.7 Relative thermal conductivities of the most prevalent insulation materials

Major uses for HCFCs in foams are outlined in the table below:

Application	***Tonnes /year of HCFC*** *(approximate)*	***Comments***
Extruded polystyrene boardstock	42,000	19,000 tonnes used in developed countries (primarily North America) and 23,000 tonnes used in developing countries. There has been substantial growth in markets for extruded polystyrene boardstock in a number of Article 5 countries.
Spray foams	6,230	Developing country use. In developed countries, transition has primarily been to HFCs although supercritical CO_2 systems are gaining in Japan.
Domestic refrigerators	4,600	Use comes from Latin America; half of the industry in Latin America has already switched to HC, it may be that the remaining HCFC use switches to HC as well. In developed countries, transition to HC or HFC is completed.
Refrigerated containers (reefers)	2,600	Developing country use. Europe has switched to hydrocarbons in this sector. Some other developed countries use HFCs.
Polyurethane discontinuous panels	2,400	Use comes from Latin America. In developing countries, some CO_2 (water) and other non-fluorinated technologies have been used.
Commercial refrigeration and other appliances	2,000	Developing country use. Cyclo-pentane is used for commercial refrigerators and freezers in areas where the market (in some cases driven by government policy) demands a zero ODP, low GWP option.
Polyurethane pipe-in-pipe	2,000	Used in Northeast Asia. Replacement of HCFC-141b with cyclopentane is the most likely next step in developing countries."
Other foams	16,300	Several other categories of foams use smaller amounts of HCFC (less than 2000 tonnes). These are described in detail in the 2006 Foams Technical Options Committee report.

Table 4.8 – Major uses of HCFCs in the foam sector as at 2005

Not-in-kind insulation alternatives for building insulation

Today, building insulation designers can select from a variety thermal insulation materials. Not-in-kind alternatives to foam boardstock include other insulating materials traditionally used in the building industry, such as mineral wool and fibreglass. The large variety of insulation options and their features are elaborated in the following table.

Type of Insulation		**Where used**
Batts, rolls		
	Fiberglass	Wall, floor & ceiling cavities
	Rock wool	Wall, floor & ceiling cavities
	Cotton	Wall, floor & ceiling cavities
Loose, poured, or blown		
	Fiberglass	Ceiling cavities
	Rock wool	Ceiling cavities
	Dry cellulose	Ceiling cavities
	Wet-spray cellulose	Wall cavities
	Perlite	Hollow concrete block
	Blown fiber with binder	Wall and ceiling cavities
	Polyurethane	Wall and ceiling cavities, roofs
	Open-cell Isocyanurate	Wall and ceiling cavities
	Magnesium silicate	Wall cavities
Rigid board		
	Expanded polystyrene (EPS)	Wall, ceiling, roof
	Extruded polystyrene (XPS)	Foundations, sub-slab, wall, ceiling, roof
	Isocyanurate	Wall, ceiling, roof
	Phenolic foam	Wall, ceiling, roof
	Rigid fiberglass	Wall, ceiling, roof, foundation walls

Table 4.9 – Insulation types and applications

Several not-in-kind insulation options with high market penetration in the building insulation market are described below.

-Fibreglass

Fibreglass batts or rolls are a very a common insulation choice used to insulate walls, floors, and ceiling cavities. Fibreglass is installed by fitting it between studs, joists, or rafters. It has good resistance to water, excellent resistance to moisture damage, to direct sun, and good resistance to fire. It is available in a variety of thicknesses. When properly installed, its insulation value is comparable to some expanded polystyrene foam. It is considered environmentally acceptable. Loose, poured, or blown fibreglass is also used for ceiling cavity insulation. It is poured and fluffed, or blown by machine. Rigid fibreglass board is also used, and has even higher insulation values than fibreglass batts, rolls, or poured fibreglass. It is used in walls, ceilings, roofs, and foundation walls where it is either glued or nailed. It is available in small thicknesses, making it a workable option for tight spaces.

-Rock wool

Rock wool insulation is another common environmentally-acceptable non-foam insulation. It is used for wall, floor, and ceiling insulation, and is installed in the same manner as fibreglass. It has good resistance to water, fire, moisture damage, and direct sun, making it a highly desirable choice. In batt or roll form, it is available in a variety of thicknesses. Rock wool is also available loose, poured, or blown for use in ceiling cavities.

-Cotton

Cotton is another environmentally-friendly, non-foam insulation material for walls, floors, and ceiling cavities. It is available in batts or rolls ranging in a variety of thicknesses. It has good resistance to direct sun and fire, but poor resistance to water and only fair resistance to moisture damage. When used, it is fitted between studs, joints, or rafters.

-Cellulose

Cellulose insulation comes in two forms: dry and wet-spray. Dry cellulose is commonly blown by machine into ceiling cavities. Wet-spray cellulose is sprayed into open wall cavities. Cellulose is an attractive insulation as it provides market for recycled paper materials. It has better resistance to fire than foam insulation. However, where fire codes are stringent, rock wool and fibreglass are sometimes preferred over both foam and cellulose.

Energy Efficiency in Building Design

Energy efficiency in buildings and residences can be achieved in a variety of ways and is not only dependent on foam insulation. Building thermal insulation can be improved through not-in-kind insulation materials; or through multiple strategies to improve windows, lighting and heating, ventilation and air conditioning (HVAC) efficiencies. These building technologies and strategies designed and operated as integrated systems, will deliver buildings that use substantially less energy than they do today. This is true for homes as well. In the United States, ENERGY STAR qualified homes can include a variety of energy-efficient features, including high performance windows, tight construction and ducts, and efficient heating and cooling equipment.

Most foam insulation applications can use non ozone depleting substances as blowing agents without sacrificing thermal capacity. For foam products that still rely on the use of HCFCs and possibly HFCs, not-in-kind materials or other foam products can be used without affecting the overall energy performance of the building. For example, in the US, buildings earn the ENERGY STAR if they demonstrate top energy performance as compared to other similar buildings nationwide. These buildings are verified to use 35% less energy than average buildings in the US , are $0.50 per square foot (US) less to operate, their energy use persists over multiple years and they are found to have higher occupancy, increased asset value, and lower carbon emissions than average buildings. With over 3,600 buildings having earned the ENERGY STAR, there is no one technology or combination of technologies that bring a building to top performance. The common features of the buildings are efficient technologies, integrated systems that are sized properly, and strong controls, management and operations. Some buildings compensate for relatively poor thermal envelope features by improving efficiency in other areas.

Low-GWP alternatives

There are exceptions where foam insulation alternatives may be necessary for buildings due to material selection and design issues (see box below). For example, insulation for flat roofs and below grade foundation walls benefits from the compressive strength and moisture resistance of closed cell foam and cannot easily be replaced with other insulating materials. Low-GWP blowing agent alternatives are available for these applications and are documented in the 2006 Foam TOC Report.

A study by AD Little reported that XPS boardstock blown with liquid CO_2 has the best life-cycle climate performance for flat roofs in commercial and industrial buildings, leading to a reduction of 74 kg of CO_2-eq per square foot of roof area over XPS board blown with HCFC-142b; and 33 kg of CO_2-eq per square foot compared to XPS board blown with HCF-134a.

Applications where foam may be necessary for top energy efficiency:

Insulation for steel deck/steel truss-joist roof construction that is typical for low rise, flat roof commercial and industrial buildings. The foam is applied directly over the steel deck and covered with membrane or built-up roofing. In this application, foam insulation may be required, because the insulation must support compressive loads. Polyisocyanurate board stock, XPS, and Spray Polyurethane Foam are used for this purpose.

Insulation of below grade foundation (basement) in commercial and residential construction. Closed cell foam is required, because the insulation must withstand compressive loading and continuous exposure to water in the ground.

The SROC also provided a substantial analysis of insulation selection criteria. In doing so, it provided an important overview of trends over the previous decade. In virtually all global markets, fibrous materials are the most popular insulation products driven primarily by price considerations. However, the regional trend, at least in Europe, is towards greater use of foamed products as was shown in Figure TS-12 of the Technical Summary of the SROC and is re-produced here. Whether there are any factors considered here that might reverse this trend is a point of conjecture but, for the purposes of this report, the Task Force has evaluated the scenario that 10% of the current ODS-blown foam demand globally might conceivably be switched back to other insulation materials.

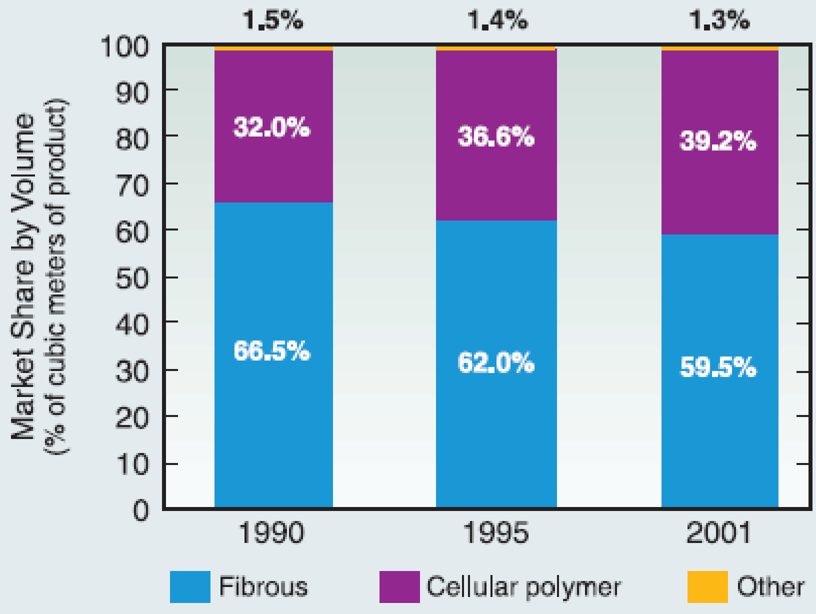


Figure TS-12. Variation of insulation volume by product type (1990–2001) in Europe.

Under these circumstances, the cumulative savings of ODS emissions to 2050 are estimated to be about **1,000 ODP tonnes**, equating to approximately **6.3 M tonnes CO_2-eq.** The relatively low savings seen from such a measure is related to three primary factors:

1. By 2010 the large use of HCFCs in extruded polystyrene foam will have been eliminated

2. The emission rates from foams in their use-phase is typically 1% per annum or less (2% has been assumed as a conservative average based on the total bank of new ODS)

3. That end of life emissions will occur, for the most part, after 2050

Since much of the emission could take place after 2050, it is important to look at the full potential. The total ODS consumed in the period after 2010 when using the baseline HCFC assumption of continued use until 2040 are estimated at about **160,000 ODP tonnes** (i.e. approx. 10% of the estimated foam bank at 2015). This amount could also represent the total potential cumulative emissions that might ultimately occur unless end-of-life measures are implemented. Although the figure would drop to below 150,000 ODP tonnes under the 'reduced demand' scenario described in this section, the analysis reinforces the fact that bank management will remain a critical priority for the foam sector over the coming years.

4.4.3 End-of-Life Management

4.4.3.1 Domestic Refrigeration

End-of-life management for domestic refrigerators and freezers is among the most advanced in the ODS sector. There are numerous regulations around the world requiring the recovery of CFC-12 from refrigeration circuits, although the onward treatment depends on the location. In some developing countries and fewer developed countries the refrigerant is recycled, while, in other countries, it is mandated for destruction. Recent information from one developing country suggests around 70% of refrigerators returned as part of take-back schemes still contain their refrigerant, while these are split 75% CFC-12 and 25% HFC-134a at this time.

Based on an 80% recovery level of the available CFC-12 as a global average, it is estimated that, in the period from 2010 to 2050, about **25,000 ODP tonnes** of refrigerant could be recovered from approximately 250 million refrigerators. This equates to approximately **270 Mtonnes CO_2-eq.**

There is increasing interest in extending the end-of-life management of refrigerators to include the recovery and/or destruction of the blowing agent in the foam. This is already mandated in the European Union and Japan, although the enforcement in the EU is patchy. Current estimates suggest that only 50-55% of refrigerators being disposed of are reaching the appropriate waste streams. Another approach is being considered in some developing countries where voluntary carbon finance might be available as an alternative incentive to recovery. The related emission savings are included in the wider foam related savings under Section 4.4.3.5.

4.4.3.2 Commercial Refrigeration

For the commercial refrigeration sector, it is the sheer size of the market that provides the opportunity for substantial emissions savings. Although the equipment base is quite fragmented, the existence of a network of servicing personnel means that the end-of-life emissions reductions can be achieved, provided that adequate equipment and training is made available. As with domestic refrigerators, it is assumed that 80% of the refrigerant can be recovered and recycled/destroyed. Where recycling takes place, the emission saving is achieved through avoided new production. If practised on a global basis, cumulative savings of about **130,000 ODP tonnes** can be achieved in the period from 2010 to 2050. This is lower than the savings achieved during the use-phase, since the end-of-life measure represents a one-time management task on the bank, whereas, with emission rates as high as 70% annually, many more savings can be made through good leakage control in the use-phase. For the end-of-life measure described here, the climate-related savings are approximately **3.8 billion tonnes CO_2-eq** reflecting the high GWP of HCFC-22.

4.4.3.3 Stationary Air Conditioning

For stationary air conditioning, the potential for practical end-of-life recovery is assumed to be 80% of installed stock. This assumption may be a little more optimistic than for the other sectors if the perception of a less well developed servicing industry is upheld for the stationary air conditioning sector. In addition, since leakage reduction is expected to be less effective in this sector, the savings at end-of-life are a more substantial fraction of what can be done.

Cumulative emissions reductions to 2050 of about **40,000 ODP tonnes** are estimated, which is about 65% higher than that expected from leakage reduction measures. The parallel savings in greenhouse gas emissions equate to about **1.3 billion tonnes CO_2-eq.**

4.4.3.4 Mobile Air Conditioning

As noted in Section 4.4.1.1 for domestic refrigerators, there is an uncertainty about whether MAC units that have already lost their refrigerant prior to reaching end-of-life should be treated as having lost its refrigerant as part of their use-phase losses or as having prematurely reached their end-of-life. What matters is that the total of the use-phase and end-of-life savings is optimised. This Report assumes that total flow of units arrives charged and that 80% of refrigerant could be recovered given the right incentives and environment. This would lead to cumulative emissions savings of **26,300 ODP tonnes** over the period to 2050, equating to just under **560 Mtonnes CO_2-eq.**

4.4.3.5 Foams

For foams, the bank sizes are particularly large and the potential benefits arising from initiatives to recover blowing agents at end-of-life are highly significant. However, there are a number of barriers to realising these potentials, especially in the buildings sector. Amongst these barriers is the fact that foams will reach waste streams over an extended period of time, as buildings are decommissioned. Given the geographic spread, it is unlikely that a critical mass of foam for destruction will be achieved without significant transporting from place to place, assuming that the foams can be identified and appropriately segregated. In some instances (e.g. spray foam), the insulation is adhered directly to the masonry, making it difficult, if not impossible, to isolate and process the foam.

This combination of barriers makes the recovery of blowing agents at end-of-life very difficult to regulate. As noted in Section 4.4.3.1, even where segregation is relatively straight forward, enforcement of regulations can be variable. Fiscal incentives could offer an efficient way of maximising blowing agent recovery and destruction. This could legitimately involve voluntary carbon finance, since the emission saving can certainly be demonstrated as ‘additional’ in climate terms – primarily because the relevant ODSs are outside of the Kyoto basket. Such an approach would require appropriate methodologies to define baselines and assess savings.

In summary, there is still time to evaluate options for the sector, particularly where it relates to the demolition of buildings. The assessment of potential savings in this report follows closely the assumptions used for the mitigation scenario in the SROC, in which recovery of blowing agent is anticipated from:

i. all domestic refrigerators and freezers (see Section 4.4.3.1),
ii. all ‘other appliances’, such as display cabinets and drinks dispensers
iii. all steel-faced panels
iv. 20% of all other building-based foams

The last assumption listed may prove to be conservative in practice, but it is still too early to predict higher levels of recovery. Using these assumptions, the cumulative saving in emissions from 2010 to 2050 is predicted to be approximately **82,000 ODP tonnes**. However, since a considerable proportion of the bank recovered in this period would be HCFC-141b (most notably from domestic refrigerators and freezers in North America), the climate protection benefit would be relatively modest at around **535 Mtonnes CO_2-eq.**

4.4.3.6 Halons

For halons, the situation is rather complex. Although the fire protection sector has been included here in this assessment of potential end-of-life measures, no savings have been identified (see Annex 7.6). The prime reason for this is that halons are expected to remain in demand for the foreseeable future, driven by the needs of militaries, commercial aviation and oil and gas production among others. This means that it would be inappropriate to destroy or otherwise decommission banks of halon that legitimately can be recycled, since such destruction might ultimately result in the need to remanufacture under a subsequent essential use provision.

The implication is that there should be no end-of-life measures for halons at all (hence no savings at end-of-life). However, it is known that banks of decommissioned halon exist in a number of countries and, in one particular country, this includes a bank in excess of 30,000 tonnes of halon 1211. It is not known how contaminated this material might be or what plans exist for its re-use and/or destruction. However, the concern is clearly to avoid the inadvertent emission of such a large quantity of material (**90,000 ODP tonnes).** Therefore, while the generalised view remains that there is no need for end-of-life measures for the halon sector, the potential release of contaminated banks must be avoided.

4.4.4 Early Retirement of Equipment

The early retirement of equipment provides the opportunity to accelerate the recovery and destruction of ODS from existing banks. This carries with it two significant benefits:

(1) The avoidance of use-phase emissions of ODS for the remaining design life cycle of the equipment, and

(2) Potential benefits in energy efficiency likely from the newest generation of equipment.

The value of (2) can be substantial and has been demonstrated, for example, where utility companies have sponsored the early retirement of old domestic refrigerators in order to gain the energy efficiency benefit of a new appliance. For example, regional product labelling programmes and initiatives such as the Japanese ‘top runner’ programme have strongly encouraged the improvement of energy efficiency performance over the last 20 years. Early retirement programmes have particular value in regions where there is strain on electricity generation capacity – for example the West Coast of the USA and several Latin American countries.

It is, however, very difficult to quantify the climate benefits of early retirement programmes over such a diverse product-base and geographic mix. Often the benefit of early retirement programmes is highly contingent on the carbon intensity of the local power generation, either in terms of the average value or that of the incremental capacity. This report does not therefore include a quantitative assessment but seeks to highlight the importance of this source of energy efficiency gain.

In contrast, it is possible to quantify the ODS savings arising from early retirement programmes provided that leakage rates of old and new equipment during the use-phase can be estimated. So, for example, if the end-of-life of a piece of equipment is brought forward by five years under an early retirement programme, the emissions savings attributable to the measure are those additional emissions that would have occurred in the absence of early retirement. Accordingly, the end-of-life emissions are not included in the early retirement calculation, since end-of-life emissions would normally be the same whether the equipment is retired early or not and alre already accounted for elsewhere in the overall analysis. The only time that such a contribution might be relevant would be if the act of early retirement somehow caused lower or greater end-of-life emissions than would otherwise have occurred if the equipment had been left in operation to the end of its normal lifecycle.

Early retirement schemes are of most relevance in domestic and commercial refrigeration and stationary air conditioning, where the related energy efficiency benefits are at their most significant.

4.4.4.1 Domestic Refrigeration

For domestic refrigeration, this report has considered the impact of shortening the average life cycle of a refrigerator from the current assumption of 15 years to 12 years. The implication of such a measure would be a cumulative further saving of emission to 2050 of approximately **1,900 ODP tonnes**, equating to **20 Mtonnes CO_2-eq.** in climate terms.

4.4.4.2 Commercial Refrigeration

A similar assessment can be applied to the commercial refrigeration case. In this case, a reduction of the average life cycle from 12 years to 10 years is considered. This generates cumulative emissions savings to 2050 of about **96,000 ODP tonnes**, providing climate protection benefits of **about 2.8 billion tonnes CO_2-eq.**

4.4.4.3 Stationary Air Conditioning

For stationary air conditioning, the benefits are less marked because use-phase emission rates are lower than in the commercial refrigeration sector. However, the equipment is generally longer-lived, so the average life cycle reduction is larger, being from 25 years to 20 years. Using these assumptions, cumulative emissions savings to 2050 are estimated at approximately **36,500 ODP tonnes**, equating to a climate benefits of **1.2 billion tonnes CO_2-eq.**, noting that this does not take into account any energy efficiency benefits.

To conclude this analysis, Table 4.10 contains a summary of the various assumptions used for this assessment.

Sector	Sub-Sector	Annual Growth Rate	Product Lifetime	Use-phase annual emissions	Use-phase reduction	E-o-L Recovery Level	Early Retirement
Refrigeration	Domestic	N/A	15 yrs	2%	37.5%	80%	12 yrs
	Commercial	5%	12 yrs	30%	50%	80%	10 yrs
	Transport	4%	10 yrs	60%	50%	N/A	N/A
	Stat. A/C	4%	25 yrs	15%	20%	80%	20 yrs
	Mobile A/C	0%	10 yrs	40%	20%	80%	N/A
Foam	Appliance	N/A	15 yrs	0.5-1%	N/A	100%	N/A
	Steel Panel	N/A	30-50 yrs	0.5%	N/A	100%	N/A
	Building	N/A	50 yrs	1-2%	N/A	20%	N/A
Halon		N/A	N/A	4%/2%	50%	N/A	N/A

Table 4.10 – Summary of assumptions used in assessing other practical measures

5 Comparison of Emission Reduction Benefits

5.1 ODS and Direct Climate Benefits by HCFC Phase-out Scenario

Chapter 4 addresses the potential emission savings benefits on a sector-by-sector basis, but does not makes comparisons between sectors. Section 5.1 makes these comparisons. Figures 5.1 and 5.2 illustrate the comparative emissions by sector arising from the baseline scenario outlined in Chapter 2.

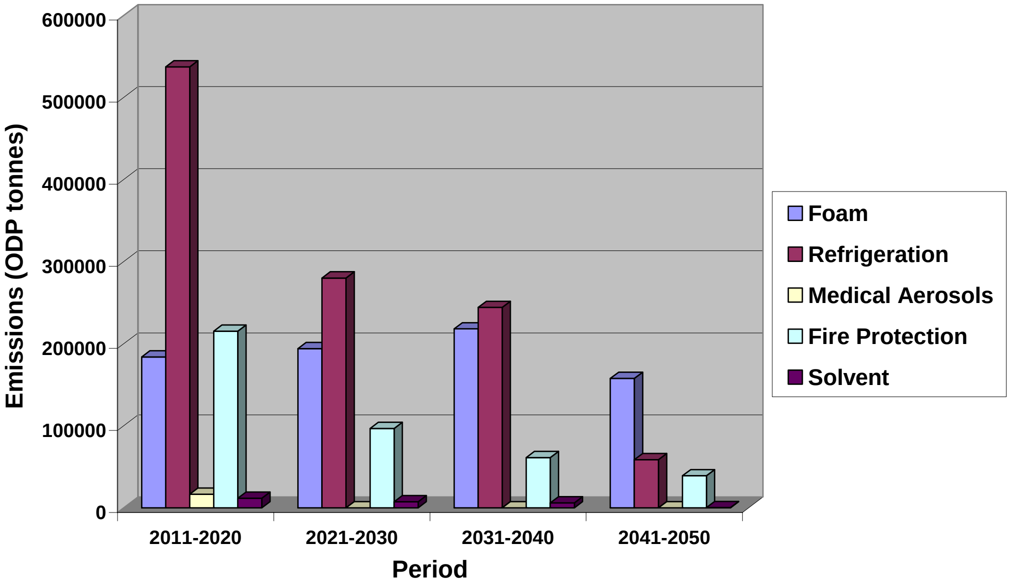


Figure 5.1 – ODS emissions by sector under the baseline scenario in ODP tonnes

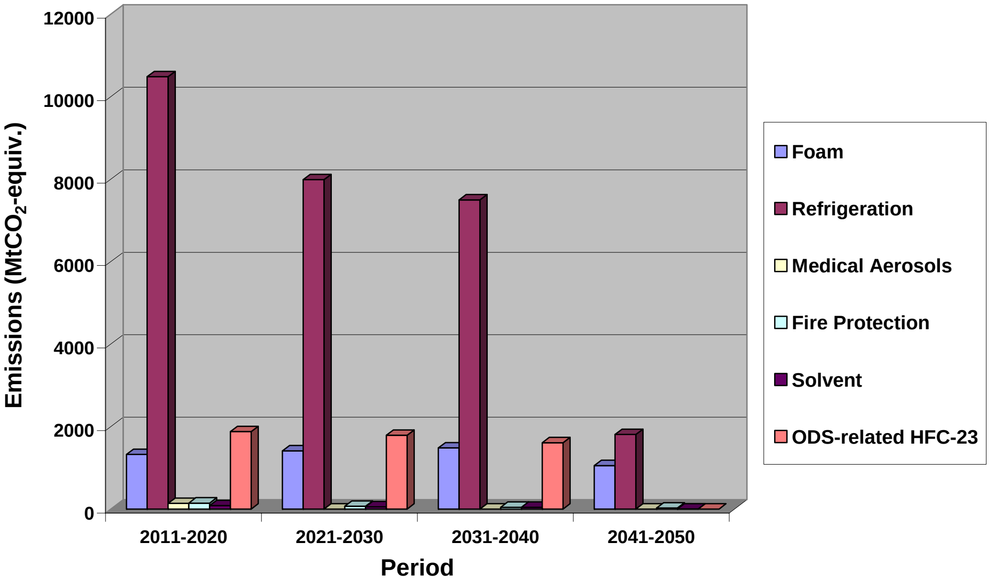


Figure 5.2 – ODS emissions by sector under the baseline scenario in Mtonnes CO_2-eq

Emissions from the refrigeration sector dominate, particularly in terms of climate impact and especially in the early years (2011-2020) when some CFCs are still being emitted. The relative impact of HFC-23 emissions is also significant, as seen in Figure 5.2.

In order to compare the emissions savings from all sources, Figures 5.3 and 5.4 show the cumulative savings from 2010 to 2050 from accelerated HCFC phase-out and the other *'practical measures'* addressed in Section 4.4.

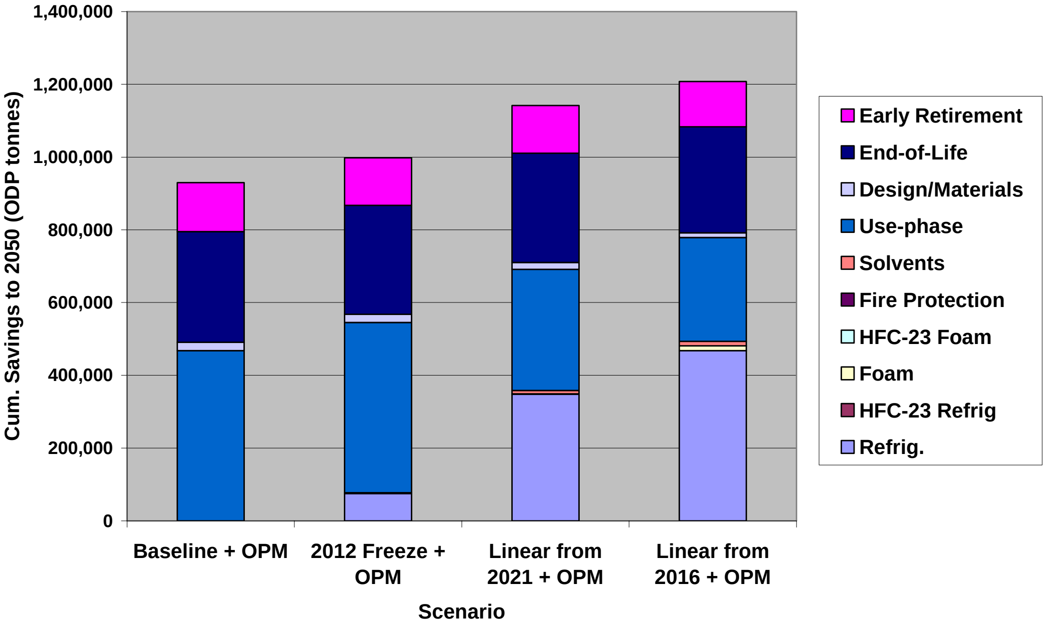


Figure 5.3 – Cumulative savings under different scenarios for all measures in ODP tonnes

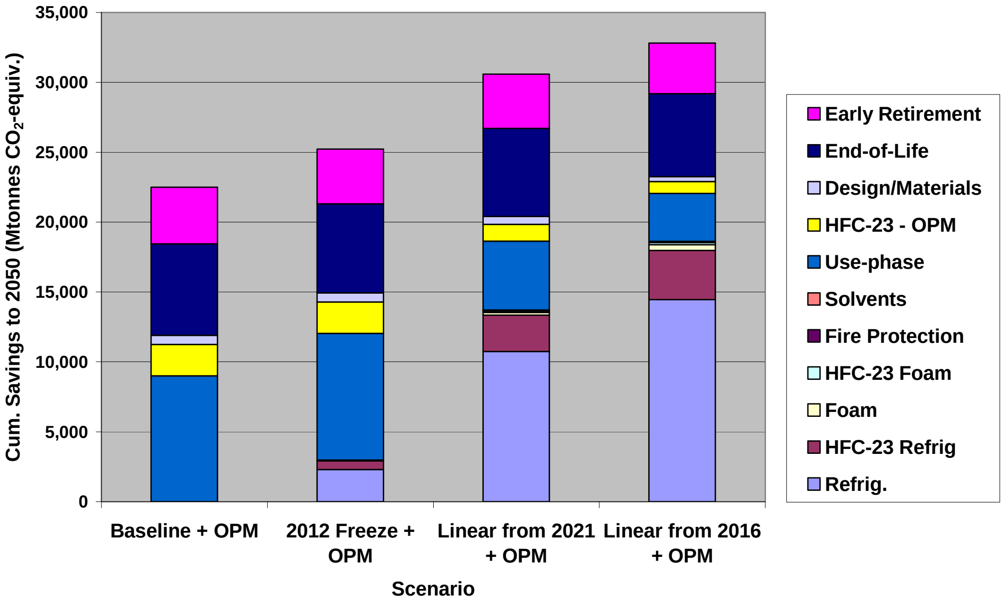


Figure 5.4 – Cumulative savings under different scenarios for all measures in Mtonnes CO_2-eq

Figures 5.3 and 5.4 combine information on both the accelerated HCFC phase-out scenarios and the other practical measures (OPM). In the period from 2010 to 2050, cumulative emission savings of other practical measures in alone (assuming no change to the HCFC phase-out schedule) are approximately **930,000 ODP tonnes** and, in terms of climate protection, in excess of **20 billion tonnes CO_2-eq.** As increasingly advanced accelerated HCFC phase-out scenarios are introduced, the cumulative savings increase, although the incremental amounts from other practical measures are smaller than that attributable to the accelerated phase-outs alone. For example, the impact of the 'linear-2016' scenario is approximately 493,000 tonnes in isolation, but the difference between the baseline and 'linear-2016' scenarios are only 278,000 ODP tonnes when all other practical measures are taken into account in both cases. This recognises the fact that actions to accelerate HCFC phase-out would make redundant some of the savings that would otherwise have been attributable to the other practical measures.

For climate savings, Figure 5.4 illustrates the additional contribution from avoided HFC-23 emissions. These arise both from the transition away from HCFC-22 as replacement technologies are introduced and from the prevention of emissions of HCFC-22 during the lifecycle of the refrigeration equipment. The latter would result in lower servicing demand. This is labelled in Figure 5.4 as "HFC-23 OPM".

In summary, the other practical measures, when combined, can contribute more to cumulative savings than accelerated HCFC phase-out alone. Nevertheless, in both of the 'linear' phase-out scenarios, the cumulative savings arising from accelerated HCFC phase-out remain the single biggest component of the total. In practice, decisions about which combination of measures to adopt will depend largely on comparative cost effectiveness evaluations. However, these are beyond the scope of this report. The other factor that will influence policy decisions is the timing of the benefits gained. Figures 5.5 and 5.6 show the relative savings over time, in ozone terms, for the baseline and 'linear-2016' cases:

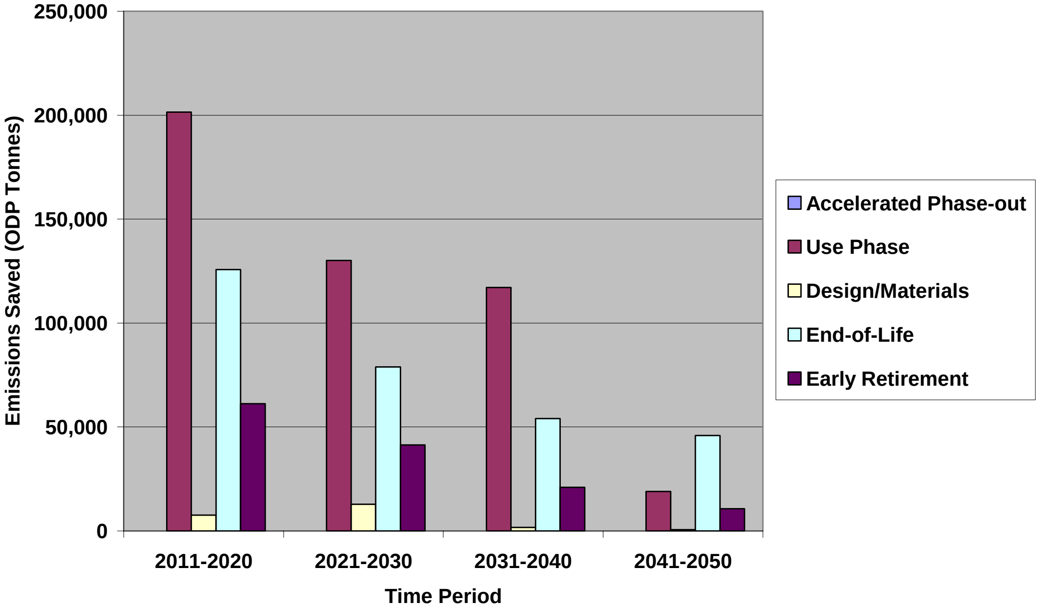


Figure 5.5 – Timing of savings from other practical measures in ODP tonnes - Baseline

Figure 5.5 reveals that the actions in the use-phase are particularly significant in the first three decades. The two major sources of these savings are leakage reductions in the commercial refrigeration sector and bank management options in the halons sector (see the detailed tables in Annex 7.6). End-of-life measures also play a significant, although declining, role throughout the period.

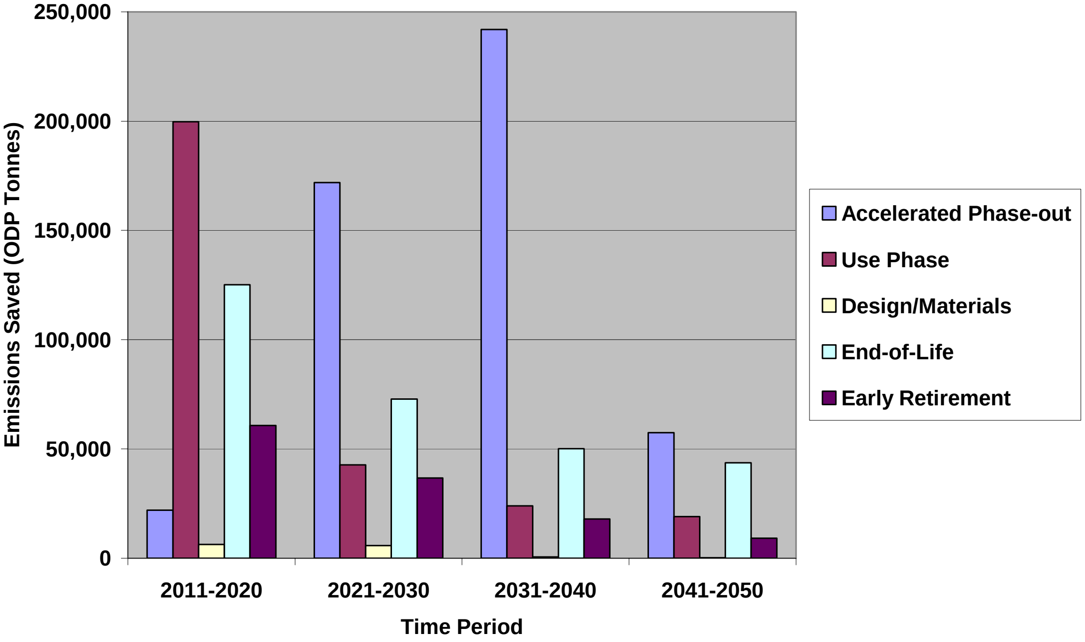


Figure 5.6 – Timing of savings from all measures in ODP tonnes – 'linear 2016'

Figure 5.6 demonstrates the impact that the accelerated HCFC-phase-out has on use-phase emission reduction measures, particularly in the period from 2021-2040. End-of-life measures are less affected, primarily because of the larger foam component.

Figures 5.7 and 5.8 provide these same emissions savings in terms of climate protection. In this context, the timing of the savings may be argued to be less significant because the build-up of greenhouse gases in the atmosphere is primarily an additive effect. This contrasts with ozone recovery scenarios where the timing of release can be a critical part of the recovery cycle. This is evaluated further in Section 5.2.

It is worthwhile comparing the projections contained in this report with those derived in the SROC. One of the key conclusions of the SROC was that annual emissions under the mitigation scenario could be reduced in 2015 by 1.2 billion tonnes CO_2-eq. Assuming this to be something of an average for the decade, cumulative emission savings for the decade would be **12 billion tonnes CO_2-eq.** Through the implementation of the other practical measures included within this report, the cumulative savings for the period 2011-2020 range between **8-8.6 billion tonnes CO_2-eq.** This could suggest that the savings identified from other practical measures in this report are more conservative than for the SROC. However, the difference is primarily due to the inclusion of HFC emission reductions in the SROC assessment, as confirmed by the fact that, under the SROC 2015 mitigation scenario, the total annual emission reductions of CFCs, HCFCs and HFC-23 by-product is 760 Mtonnes CO_2-eq, which, as an average for the decade would yield 7.6 billion tonnes CO_2-eq.

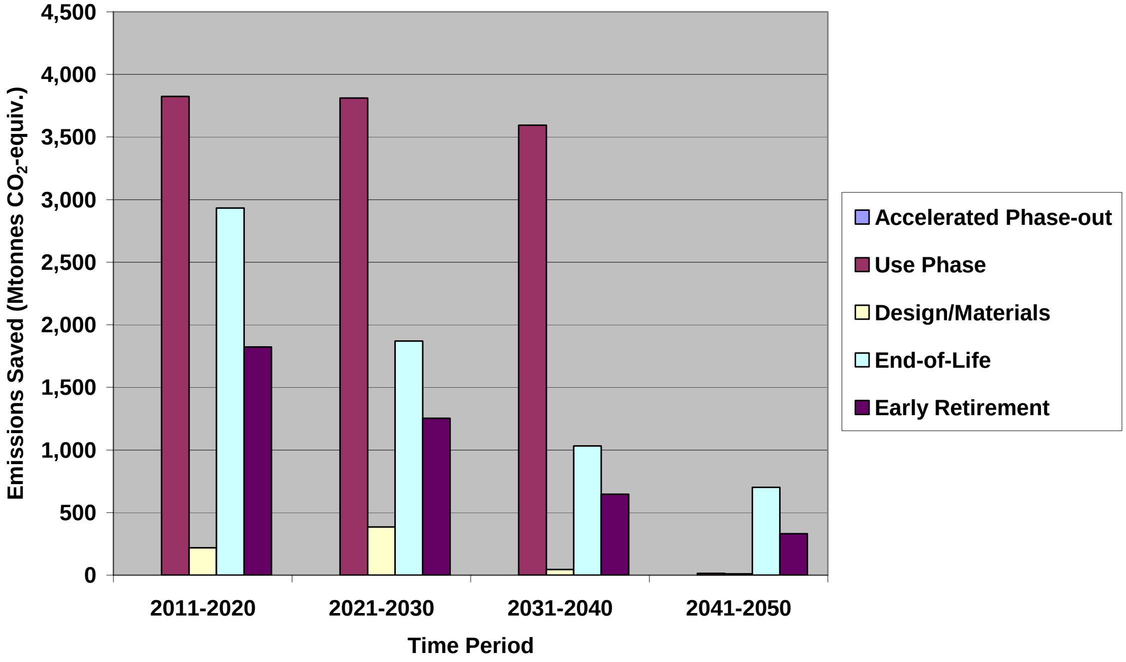


Figure 5.7 – Timing of savings from other practical measures in Mtonnes CO_2-eq - Baseline

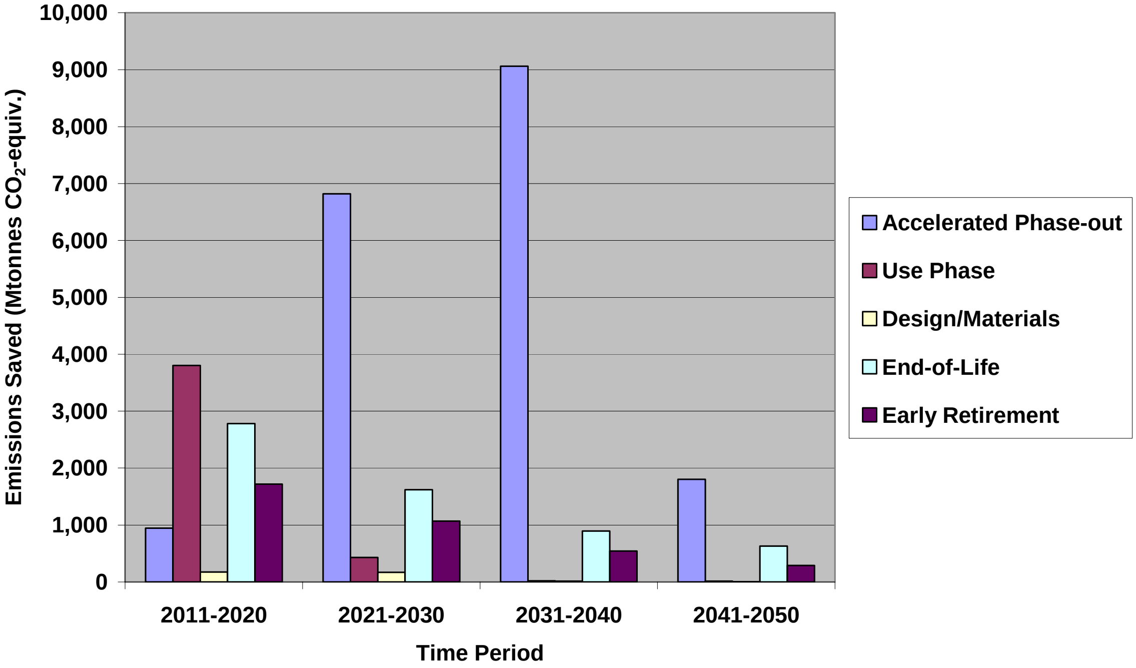


Figure 5.8 – Timing of savings from all measures in Mtonnes CO_2-eq – linear 2016

5.2 Impact on Ozone Recovery

The scenarios presented and discussed in the previous sections are compared here with respect to their effect on the ozone layer. The metric used is the Equivalent Effective Stratospheric Chlorine (EESC) of Daniel et al. (1995)[22]. The EESC index has been used frequently as a measure of the amount of chlorine and bromine available in the stratosphere to destroy ozone (WMO, 2007)[23]. Contributions of very short-lived chlorine- and bromine-containing sources gases and of tropospheric inorganic halogens are generally neglected.

EESC is defined as

$$EESC(t) = f_{CFC-11}\left[\sum_{\substack{Cl-containing\\ halocarbons}} n_i \frac{f_i}{f_{CFC-11}} \rho_{i,entry} + \alpha \sum_{\substack{Br-containing\\ halocarbons}} n_i \frac{f_i}{f_{CFC-11}} \rho_{i,entry}\right]$$

where n is the number of chlorine or bromine atoms in the source gas, f_i/f_{CFC-11} represents the efficiency of the stratospheric halogen release relative to that of CFC-11, denoted by f_{CFC-11} , and $\rho_{i,entry}$ is the tropospheric mixing ratio of source gas i when it entered the stratosphere.

Traditionally, $\rho_{i,entry}$ is calculated assuming a simple time lag Γ (often about 3 years) from the surface observations until the chemical reaches the lower mid-latitude stratosphere, i.e.

$$\rho_{i,entry}(t) = \rho_i(t-\Gamma)$$

where $\rho_i(t)$ is the surface mixing ratio at time t.

The year EESC returns to its 1980 levels is used as a metric used in WMO assessments to compare different scenarios. It generally has been assumed that if all other atmospheric parameters and processes remain constant, ozone depletion relates linearly to EESC above a certain threshold level. This year is chosen because this is the approximate date when mid-latitude and Antarctic ozone depletion has been observed to begin. An exception to this relationship is Antarctic ozone depletion. Springtime depletion became so great around 1990 that there was not enough ozone left in the lower stratosphere for the column ozone amount to continue to follow a linear relationship with EESC. So it is assumed here that no additional Antarctic ozone destruction occurs for EESC values above 1990 levels.

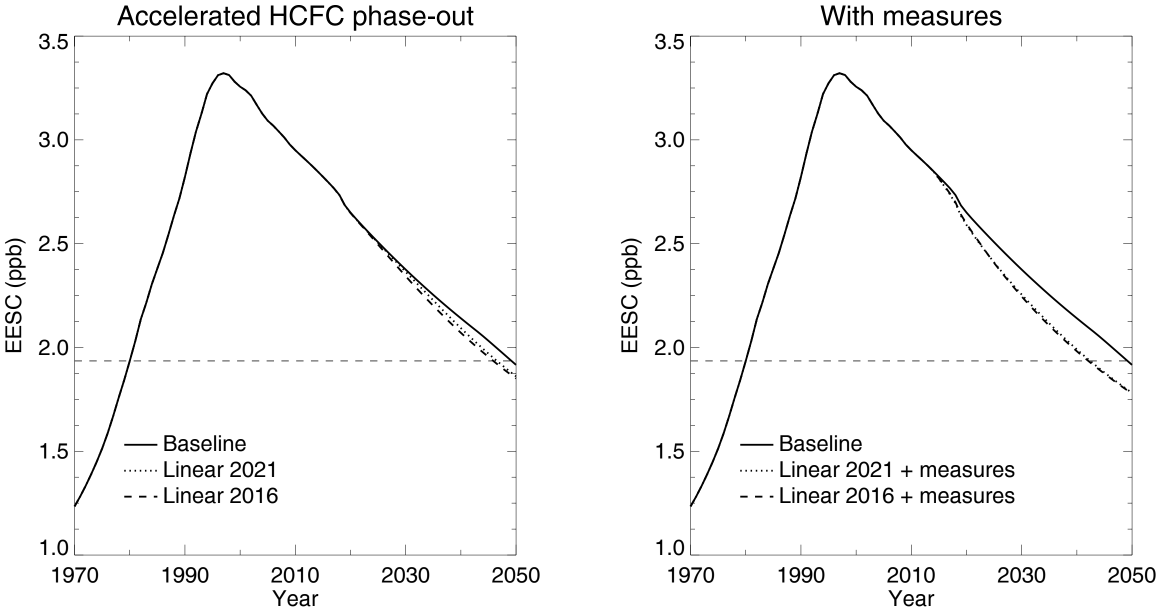
A second metric that has been used to compare scenarios is the integrated EESC value above the 1980 level, integrated from 1980 or the current time until EESC returns to the 1980 level. This metric is meant to represent the cumulative ozone depletion due to ODSs over the specified time frame.

---

[22] ***Daniel J. S. et al (1995)*** On the evaluation of halocarbon radiative forcing and global warming potentials, *Journal of Geophysical Research, 100, 1271-1285*

[23] WMO (World Meteorological Organisation) Scientific Assessment of Ozone Depletion: 2006, Global Ozone Research and Monitoring Project – Report No. 50, Geneva, Switzerland, 2007.

In Figure 5.9, the EESC corresponding to the Baseline scenario and two other scenarios is shown. The year EESC returns to its 1980 value and the change in integrated EESC are shown in Table 5.1.


Accelerated HCFC phase-out

With measures

Figure 5.9. Global EESC projection for 3 scenarios: 1) Baseline, 2) Accelerated HCFC phase-out with linear decrease from 2016, 3) Accelerated HCFC phase-out with linear decrease from 2016 plus other practical measures.

Scenario		***Change in year (x) when EESC is expected to drop below 1980 value***	***Percent Difference in integrated EESC relative to baseline scenario for the mid-latitude case***	
			$\int_{1980}^{x} EESC\, dt$	$\int_{2007}^{x} EESC\, dt$
Baseline		2049.8		
2012 Freeze	Accelerated HCFC phase-out	-0.4	-0.5%	-1.1%
Linear 2021	Accelerated HCFC phase-out	-2.7	-1.7%	-3.6%
Linear 2016	Accelerated HCFC phase-out	-3.3	-2.6%	-5.6%
Baseline	+ measures	-4.7	-6.4%	-13.8%
2012 Freeze	Acc HCFC phase-out + measures	-5.2	-6.9%	-14.7%
Linear 2021	Acc HCFC phase-out + measures	-6.8	-7.2%	-15.4%
Linear 2016	Acc HCFC phase-out + measures	-7.1	-7.4%	-16.0%

Table 5.1 - Comparison of scenarios: the year when EESC drops below the 1980 value at mid-latitude and integrated EESC differences relative to the baseline scenario. The Baseline scenario presented is based on the baseline scenario (A1) of WMO (2007) with the exception that the production of HCFCs in developed countries is held constant from 2016 to 2040 instead of a linear decrease from 2030 to 2040 as applied in WMO (2007).

For ease of reference, Table 5.1 is also graphically expressed below in Figure 5.10

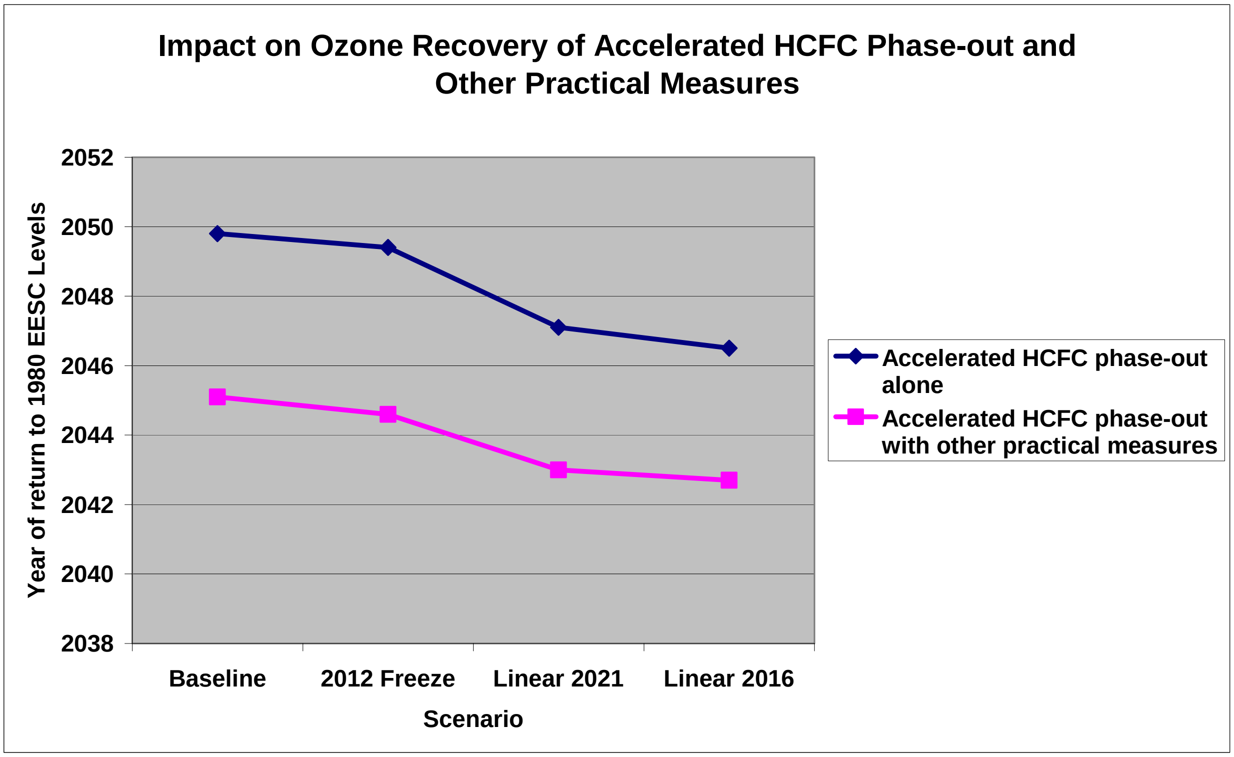


Figure 5.10 Impact on Ozone Recovery of Practical Measures assessed in this Report

6 Conclusions

6.1 Baseline Estimates and Sensitivities

Chapter 2 of this Report outlines the methods and sources used to develop baseline emission estimates in terms of both ozone and climate impacts for the period to 2050. The Chapter provides explanations for choices made, as well as outlines of the treatment given to issues such as the development of feedstock demand. The following primary conclusions are drawn:

- Although at the lower end of the spectrum of growth scenarios between 2005 and 2015 (Growth Factor 1.78), the SROC consumption data provides the most substantive and complete treatment of demand trends at both sectoral and sub-sectoral level.

- While a number of baseline scenarios could be chosen for the use of HCFCs in developing countries after 2015, the preferred option follows precisely the provisions of the existing Montreal Protocol and assumes consistent demand throughout the period from 2015 to 2040. Although this can be viewed as maximising the impact of *'practical measures'* evaluated in Chapter 4, this choice of baseline is justifiable and considered the most appropriate.

- The existing provisions of the Montreal Protocol result in a year-on-year decrease in ozone-related emissions in the period to 2050, although a plateau is reached at just over 50,000 ODP tonnes per year in the period between 2025 and 2040 before the impact of the final phase-out takes effect.

- The ODS-related greenhouse gas emissions similarly plateau in 2025-2040 at an annual emission level of around 900 Mtonnes CO_2-eq which equates to around 3.5% of current annual global GHG emissions.

- Emissions from the refrigeration and air conditioning sector are the single biggest component of the overall totals in both ozone and climate terms, representing 45% and 85% respectively during the plateau period.

- For the baseline scenario, where HFC-23 emissions are left unabated, trends in the use of HCFCs for feedstock cause a significant increase the emissions of ODS-related greenhouse gas emissions in the period from 2025-2039. As a result, these peak at approximately 1.35 billion tonnes in 2039 (i.e. around 5% of current global annual greenhouse gas emissions). In the same year, unabated HFC-23 emissions would be expected to account for just over 450 Mtonnes CO_2-eq which represents around 35% of the total ODS-related emission.

- The climate benefits of an accelerated HCFC phase-out depend not only on the selection of the earlier freeze date and phase-out schedule, but also on the choice of technology to replace HCFCs in insulating foam and refrigeration and air conditioning sectors where indirect emissions from energy are significant. Parties and companies can use LCCP analysis to identify the options offering the greatest net climate benefits.

6.2 Inter-Relationship with the Clean Development Mechanism

Chapter 3 discusses in detail the current status of the Clean Development Mechanism (CDM) and its likely impacts. The chapter also discusses potential options for the removal of the impasse that exists on aspects of the on-going application of the CDM to HFC-23 abatement projects. From these discussions the following conclusions can be drawn.

- HCFC-22 production currently qualifying for CDM support is estimated at 260,000 tonnes, which represents 67-68% of developing country production. Although, these facilities have greater capacity (utilisation rate is currently 70%), increases in production will not qualify for further CDM support under the ‘existing’ facilities provision.

- Two sources of potential market distortion exist under the current arrangements. The first relates to the differing treatment of ‘new’ and ‘existing’ HCFC-22 facilities and the second relates to the fact that some facilities are not eligible for CDM support owing to their location.

- Monies flowing from the sale of CERs could be up to 10 times higher than the costs of mitigation and, under expected future carbon prices, will exceed the sales revenue for the HCFC-22 itself.

- It is unlikely that the price of HCFC-22 would be depressed universally across the refrigeration sector, but individual producers could use their increased financial strength to implement tactical pricing strategies in localised markets to gain share. For ‘other’ HCFC-22 uses, demand is more elastic and the lowering of prices could improve the competitive position of downstream products (e.g. in foams). In extreme cases, it might even be possible that low HCFC-22 prices encourage the re-introduction of the chemical into foam applications in which it has already been replaced or as an aerosol propellant, where it has not been widely used before, or into other applications where environmentally superior technology is widely available.

- The CDM support currently offered to HCFC-22 facilities in developing countries could further accelerate the transfer of production from developed to developing countries, particularly if a provision for ‘new’ facilities is introduced. A method of ‘levelling the playing-field’ between ‘new’ and ‘existing’ plants may therefore be required

- Accelerated HCFC-22 phase-out is not expected to have any significant bearing on HFC-23 emissions in the first contracted period of the CDM and, in the absence also of any measures to control HCFC-22 production for feedstock use, the CDM itself is the only reliable mechanism available to prevent HFC-23 emissions in the short-term.

- The Task Force has not identified any simple ways of solving the potential market distortions created by the CDM, since commitments are already in place for at least the next 7 years. One solution may lie in the development of an inter-governmental agreement of all developing countries hosting or planning to host HCFC-22 production facilities, in which national levies are applied to limit the financial gain of individual manufacturers. Under such a mechanism it could also be possible to include all ‘new’ facilities in order to maintain a level playing-field. Governments involved in any such future agreement could stipulate the uses financed by such levies, even including the possible use of such funds for ozone-related activities.

6.3 The Impact of an Accelerated HCFC Phase-out

Chapter 4 evaluates three scenarios for the accelerated phase-out of HCFCs in developing countries. These are:

(1) Freeze at 2015 with linear phase-down of HCFC use from 2021-2030 (10 year advance);
(2) Freeze at 2015 with linear phase-down of HCFC use from 2016-2025 (15 year advance);

and

(3) Freeze at 2012 with instantaneous phase-out in 2040. (3 year advance in the freeze date).

- The scenario with a 15 year advance in phase-out of HCFCs (Scenario 2) delivers the most potential for ODS emissions abatement. For refrigeration alone, cumulative savings could be 468,000 ODP tonnes to 2050. The least effective ODS emissions abatement scenario arises from freezing at 2012 without an earlier phase-out date (Scenario 3), where cumulative savings over a comparative period are estimated to be about 75,000 ODP tonnes. However, this should not preclude the consideration of an earlier freeze, possibly in combination with other measures.

- ODS savings from accelerating HCFC phase-out measures increase when using higher baseline growth scenarios. With a Growth Factor of 2.5 between 2005 and 2015 (contrasted to SROC value of 1.78), ODS savings arising from a 15-year advance in the phase-out (Scenario 2) increase by 44%.

- Cumulative savings in climate terms from ODS emissions reductions are potentially in excess of 18 billion tonnes CO_2-eq for the period to 2050 when phase-out is advanced by 15 years (Scenario 2). 3.5 billion tonnes CO_2-eq of this is attributable to avoided HFC-23 emissions, assuming that no HFC-23 mitigation strategy is otherwise in place (as is modelled by the baseline scenario).

- Since over 80% of the potential climate-related savings arise from the refrigeration sector, alternatives that result in lower GWP-weighted emissions (e.g. from a low GWP fluid or a less emissive design, or those that deliver sufficient efficiency improvements to offset their impacts) would be necessary to realise a significant proportion of this potential. Regulatory and/or fiscal incentives (e.g. the recent F-Gas regulation in the EU) can assist in creating an appropriate environment for such developments.

- Apart from the uncertainty over the pending availability of suitable low-GWP alternatives, the refrigeration sector carries with it a significant lag based on the servicing tail for existing equipment. This could act as a brake on plans to accelerate the HCFC phase-out unless equipment can be retrofitted or substantial quantities of HCFCs can be recovered, recycled and re-used. As a consequence, the proactive development and introduction of new alternatives needs to be encouraged, particularly if the climate benefits of accelerated HCFC phase-out are to be realised.

- The most appropriate control scenarios are likely to arise out of a consideration of the cumulative ODS emissions saved, the LCCP-based climate benefits that can be derived and the cost of transition. Since these characteristics vary sharply between use sectors, it is unlikely that one phase-down schedule would suit all circumstances. Accordingly, a sector-by-sector approach would be a viable alternative to the chemical-by-chemical approach suggested in some proposed Adjustments. A sector-by-sector approach would however require a further elaboration of the UNEP reporting structure.

- There are several specialist applications of HCFCs for which no technically or economically viable alternatives currently exist. This could impact both developed and developing countries as HCFC phase-out dates approach. Consideration will need to be given as to how such situations should be managed and whether continued use should be allowed in an otherwise accelerated framework through the application of an Essential Uses provision or other mechanism. The permissible criteria for the granting of such essential uses will need further consideration and could, in principle, extend to climate protection where alternatives would impose unacceptable additional climate burdens.

- The underlying impact of production for feedstock uses over time becomes increasingly significant, particularly in the post-2040 period when production for emissive uses will have ceased. This substantial feedstock demand has the potential to differentiate future HCFC production controls from those previously adopted for CFCs.

- The introduction of an earlier transition for HCFCs offers the potential to avoid rapid changes in HCFC production. With growth in feedstock demand for HCFCs continuing to 2050 and beyond, it is certainly possible to ensure at the global level that no additional intermediate capacity is needed to meet HCFC production for emissive uses, even though changes in geographic demand may require some rationalisation, with the closure of some plants and the building of others.

- As an additional consequence, the case for a Basic Domestic Needs provision is offset by the fact that several HCFCs will continue to be needed for feedstock uses.

Nonetheless, BDN provisions may still be valuable to ensure that levels of supply and demand are reviewed, particularly for non-feedstock HCFCs such as HCFC-141b. They may also be required to facilitate the transfer of HCFCs between Article 5 countries.

6.4 The Potential Contribution of Other Practical Measures

Chapter 4 also evaluates the impact on emissions savings of the other practical measures identified in the July 2006 Workshop, both in terms of their magnitude and timing. The following conclusions are drawn:

- The potential impact on emissions savings of the other practical measures in aggregate is equal to or greater than the ozone and climate protection of an accelerated HCFC phase-out alone. However, the ‘linear 2021’ (10-year advance) and the ‘linear 2016’ (15-year advance) remain the single biggest individual components of the scenarios in which they feature. Therefore the option to both accelerate the HCFC phase-out and implement all technically feasible practical measures would yield greater benefits than either action alone.

- The most advanced accelerated HCFC phase-out schedule combined with all other practical measures provides cumulative ozone-related savings of nearly 1.25 million ODP tonnes and in excess of 30 billion tonnes CO_2-eq of potential climate protection

- There is good correlation with the SROC mitigation scenario analysis, although this report provides important new additional information on the further development of savings over time.

- There are important use-phase benefits to be gained in the decade from 2011-2020. The major components of these savings are found in leakage reduction within the commercial refrigeration sector (80,000-90,000 ODP tonnes depending on scenario) and in the management of halon banks (~90,000 ODP tonnes)

- End-of-life measures are consistent and significant contributors to savings in terms of both ozone and climate, with cumulative savings of around 300,000 ODP tonnes and about 6 billion tonnes CO_2-eq. Early retirement of equipment can provide an additional 130,000 ODP tonnes and 3.5-4 billion tonnes CO_2-eq not accounting for energy efficiency benefits that might also accrue. Conversely, design measures and material selection changes do not contribute substantially to emissions savings.

- Decisions on the suite of measures to be adopted can only be optimised at regional level. The relative cost-effectiveness of each measure is a vital component of the decision-making process, but is not considered in this report.

- Evaluations using the approach previously adopted by the Science Assessment Panel to assess the influence of factors on ozone recovery (return to 1980 levels of EESC) show that accelerated HCFC phase-out can advance ozone recovery by up to 3.3 years based on a mid-latitude assessment. When the contribution of all other practical measures is added, the recovery of the ozone layer can be brought forward by as much as 7.1 years.

7 Annexes

7.1 Summary of Findings from the IPCC/TEAP Special Report on Ozone and Climate

The SROC considers ODS replacements and their application in technologies that have either already been demonstrated, or are expected to have significant market potential by 2015, and that could make a significant impact (either positive or negative) on global warming. The effects of total emissions of ODS and their substitutes on the climate system (including the inter-relationship of climate with stratospheric ozone) are assessed as context for understanding how replacement options could affect global warming.

Technical performance, potential assessment methodologies, and indirect emissions related to energy use are considered as well as costs, human health and safety, implications for air quality, and future availability issues. The major application sectors using ODS and their substitutes include refrigeration, air conditioning, foams, aerosols, fire protection, and solvents. Emissions of ODS and their substitutes originate from: manufacture and any unintended by-product releases; intentionally emissive applications; evaporation and leakage from banks contained in equipment and products during use; testing and maintenance; and end of life practices.

The SROC mentions that HCFCs have been used to replace CFCs in several applications as they have shorter lifetimes in the atmosphere and so cause less ozone depletion. It also states that HFCs and PFCs have been identified as potential longer term replacements for ODS because they contain no bromine or chlorine and do not cause any significant ozone depletion. Other alternatives for halocarbon use include ammonia and non-halocarbon organic molecules, for which direct emissions have a very small effect on climate but indirect emissions (linked to energy use) may be important.

The SROC also notes that the estimated emissions of CFC-11 and CFC-12 for 2002 are larger than estimates of production, indicating that a substantial fraction of these emissions are coming from banks of these chemicals built up from past production. Such banks include CFCs contained in foams, air conditioning, refrigeration, and other applications. In contrast, production was, in 2002, greater than emissions for nearly all HCFCs and HFCs, implying that banks of these chemicals are currently building up and could contribute to future emissions and radiative forcing. Continuing atmospheric observations of CFCs and other ODS now enable improved validation of estimates for the lag between production and emission to the atmosphere. This provides new insight into the overall significance of banks and of end-of-life management options which are relevant to future use of HCFCs and HFCs.

Current banks and emissions

The SROC concludes that current emission profiles are largely determined by historic use patterns, resulting in relatively high contributions (now and in the coming decades) from CFCs and HCFCs banked in equipment and foams. Annual emissions of CFCs, HCFCs, HFCs and PFCs in 2002 were stated to be about 2.5 $GtCO_2$-eq yr^{-1}. Refrigeration applications together with stationary air conditioning (SAC) and mobile air conditioning (MAC) contributed the bulk of global direct GHG emissions in 2002. Overall, about 80% of these direct GHG emissions were CFCs and HCFCs.

The banks stored in equipment and foams may leak during the use phase of the products of which they are part, and at the end of the product lifecycle (in cases where they are not recovered and/or destroyed). The bank-turnover varies significantly from application to application: from months (e.g. solvents), several years (refrigeration applications) to over half a century (foam insulation).

Current banks are estimated at about 21 $GtCO_2$-eq (2002), with CFCs, HCFCs, and HFCs contributing about 16, 4, and 1 $GtCO_2$-eq, respectively. The build-up of banks associated with relatively new applications of HFCs will significantly determine future (after 2015) emissions without additional bank management measures to mitigate those emissions.

2015 Business-As-Usual projections

In the SROC, sector chapters developed Business-As-Usual (BAU) projections for the use and emissions of CFCs, HCFCs, halons, HFCs and some PFCs (where these are used as replacements for ozone-depleting substances) through to the year 2015. These projections have assumed that all existing measures continue including the Montreal Protocol phase-out and relevant national regulations. The usual practices and emission rates are kept unchanged up to 2015. End-of-life recovery efficiency is assumed not to increase. Emissions in the post-2015 period are not considered except in the case of foams, where the long-lived nature of the products and related banks necessitates a BAU emissions assessment to the year 2100.

The SROC mentions that refrigeration applications together with stationary (SAC) and mobile air conditioning (MAC) contribute the bulk (77% in 2015 BAU) of global direct GHG emissions in line with the higher emission rates associated with refrigerant banks. The largest part of GHG emissions from foams are expected to occur after 2015 because most releases occur at end-of-life. HFC-23 by-product emissions account for 14% of all direct GHG emissions (2015 BAU). The projected threefold increase in HFC emissions is the result of increased application of HFCs in the refrigeration, SAC and MAC sectors, and due to by-product emissions of HFC-23 from increased HCFC-22 production. HCFC-22 production is projected to increase by about 40% over the 2002 to 2015 period.

2015 Mitigation Scenario projections

Mitigation options are identified and described in the respective sector chapters of the SROC. On an aggregated level, overall sector emission reduction potentials are determined for 2015 as compared to the BAU scenario. The estimates are based on a Mitigation Scenario that assumes global application of best practices in use, recovery and destruction of ODS and ODS-substitutes.

Through global application of best practices and recovery methods about 1.2 $GtCO_2$-eq yr^{-1} of direct GHG emissions can be avoided by 2015, as compared with the BAU scenario. About 60% of this potential is in HFC emission reductions, while HCFCs and CFCs contribute about 30%

and 10% emissions reductions respectively. Almost 75% of the emission reduction potential can be found in the refrigeration, stationary air conditioning and mobile air conditioning sectors; and about 25% can be found in the destruction of HFC-23 by-product emissions from HCFC-22 production. This mitigation measure represents about 40% of the HFC emission reduction potential, which is significant and is addressed further in this Report.

In general, the SROC mentions the technical options available to reduce direct GHG emissions:

- improved containment of substances;
- reduced charge of substances in equipment and products;
- end-of-life recovery and recycling or destruction of substances;
- increased use of alternative substances with a lower or zero global warming potential; and
- not-in-kind technologies.

Reductions of indirect GHG emissions are stated to be possible by improving the energy efficiency of products and processes (and by reducing the specific GHG emissions of the energy system). In determining which technology option has the highest GHG emission reduction potential, both direct and indirect emissions have to be assessed. Comparison of technology options is mentioned not to be a straight-forward exercise as even within one technological application significant variations in direct and indirect emissions may occur.

Refrigeration and Air Conditioning

The SROC mentions that refrigerants have by far the largest contribution to direct emissions of GHG. Within the SROC the refrigeration sector is divided in the following sub-sectors: domestic refrigeration, commercial refrigeration, industrial refrigeration and food processing and cold storage, and transport refrigeration. The sectors of Residential and Commercial Air Conditioning and Heating (‘Stationary Air Conditioning (SAC)’) and Mobile Air Conditioning (MAC) are presented in separate sections in the SROC.

The five general options to reduce direct GHG emissions for the refrigeration sector are specified as follows in the SROC:

- Improved containment – leak-tight systems;
- Recovery, recycling, and destruction of refrigerants during servicing and at the end of life of the equipment;
- Application of reduced charge systems:
- lower refrigerant charge per unit of cooling capacity,
- reduced refrigeration capacity demand;
- Use of alternative refrigerants with a lower or zero global warming potential
- (e.g. hydrocarbons, carbon dioxide, ammonia, etc.) ; and
- Not-in-kind technologies.

These options equally apply for the SAC and MAC sectors.

The SROC also deals extensively with foams, medical aerosols, fire protection and solvents, and provides detailed estimates on halocarbon production by-products and fugitive emissions.

Foams

The adoption of responsible use criteria in HFC selection has successfully reduced the consumption of HFCs in the foam sector by nearly 50% over that predicted in 1999. Nonetheless, there are several areas in which further substitution may be possible over the next five to ten years, for example:

- Wider hydrocarbon use in polyurethane spray foam;
- Wider CO_2 use in extruded polystyrene (XPS);
- Wider hydrocarbon use in appliance foams; and
- Changes in the attitude of insurers to HCs in panels.

SROC states that the baseline assumption is a freeze at 2015 consumption levels for both HCFCs and HFCs. It is assumed that HCFCs are phased-out linearly between 2030 and 2040. Bearing in mind that technology developments are likely to continue in the foams sector, reliance on HFCs is not expected beyond 2030 and linear decline is assumed after 2020. The assumptions can further be summarized as:

- A linear decrease in use of HFCs between 2010 and 2015 leading to 50% reduction by 2015;
- The adoption of production emission reduction strategies from 2005 for all block foams and from 2008 in other foam sub-sectors; and
- The extension of existing end-of-life measures to all appliances and steel-faced panels by 2010 together with a 20% recovery rate from other building-based foams from 2010.

Medical Aerosols

Annual growth in the global market in inhaled asthma /COPD medication through to 2015 is projected to be approximately 1.5-3% per year. A large proportion of CFCs is being replaced by HFCs (approximately 90% HFC-134a and 10% HFC-227ea) and all MDI use in the developed world will be HFC by 2010. Dry powder inhalers also provide inhaled asthma/COPD medication. From peak annual CFC use of over 15,000 metric tonnes in 1987-2000, CFC use in MDIs has fallen to an estimated 8,000 tonnes, with HFC of 3,000-4,000 tonnes in the period 2001-2004, and by 2015 HFC use is estimated to rise to 13,000-15,000 metric tonnes. No major technical breakthroughs in device technology are expected in the short term.

Fire Protection

There are two categories of applications that can require halon or an alternative: fixed systems and portable extinguishers. Halon-1301 dominated the market in fixed systems prior to the Montreal Protocol, and its remaining bank was about 45 ktonnes in the year 2000. Halon-1211 was primarily used in portable extinguishers and the bank in the year 2000 was estimated at about 154 ktonnes. On average, emission rates for fixed systems are about 2±1% per year; and for portable extinguishers about twice that, i.e., 4±2% per year of the bank (installed base including stocks for recharge). Halon is no longer necessary in most (>95%) new installations that would have used halons in pre-Montreal Protocol times. The remaining new installations still using halons are principally in commercial aircraft and some military applications where an effective alternative to halons has yet to be found.

Further detailed estimates of banks are given in the SROC.

Solvents

By 1999, it is estimated that 90 percent of the ODS solvent use had been reduced through conservation and substitution with not-in-kind technologies (no-clean flux, aqueous or semi-aqueous cleaning, and hydrocarbon solvents). The remaining 10 percent of solvent use is shared by several organic solvent alternatives. The only HCFC solvents currently used are HCFC-141b and HCFC-225ca/cb. Most HCFC-141b use is for foam blowing; solvent applications represented less than 10 percent of its global use in 2002. Use of HCFC-141b is banned in the European Union and is rapidly declining in other developed countries. In developing countries, use of HCFC-141b is still increasing especially in China, India and Brazil, as economic growth rates are high. HCFC-225ca/cb use is directed to niche applications and, because of its ODP and phase-out schedule, is being gradually replaced by HFC, HFE and not-in-kind alternatives.

Emission reduction options in solvent applications fall into two categories:

- Improved containment in existing uses; and
- Alternative fluids and technologies.

Production By-products and Fugitive Emissions

The SROC mentions that emissions of ODS, HFCs and PFCs also occur during the production of fluorocarbons either as undesired by-products or as losses of useful material as fugitive emissions. Fugitive losses are stated to be small, generally at less than 1 percent of total production. The most significant of the by-products is HFC-23 (fluoroform) which is generated during the manufacture of HCFC-22. While the Montreal Protocol will eventually phase out the direct use of HCFC-22, its use as a feedstock is permitted to continue indefinitely because it does not involve the release of HCFC-22 to the atmosphere. Global feedstock demand has been increasing and is expected to continue to grow beyond 2015. HCFC-22 production is growing rapidly in developing countries, especially China and India.

It is also mentioned that HFC-23 generation ranges from 1.4 to 4 percent of total HCFC-22 production, depending on production management and process circumstances. HFC-23 is the most potent (GWP of 14,310) and persistent (atmospheric life 270 years) of the HFCs. Global emissions of HFC-23 increased by an estimated 12% between 1990 and 1995, due to a similar increase in global production of HCFC-22. However, due to the widespread implementation of process optimization and thermal destruction in developed countries, this trend has not continued and since 1995 the rate of HFC-23 emissions has become smaller than the increase in production.

It is technically feasible through capture and destruction to reduce future emissions of HFC-23 from HCFC-22 by over 90% (or a factor of 10). However, the SROC mentions that emissions of

HFC-23 could grow by as much as 60% between now and 2015, from about 15 ktonnes yr^{-1} to 23 ktonnes yr^{-1} due to anticipated growth in HCFC-22 production. The upper bound of HFC-23 emissions is on the order of 3 to 4 percent of HCFC-22 production but the actual quantity of HFC-23 produced depends in part on how the process is operated at each facility.

Techniques and procedures to reduce the generation of HFC-23 through process optimization can reduce average emissions to 2 percent or less of production. However, actual achievements vary for each facility and it is not possible to eliminate HFC-23 emission by this means. Capture and destruction of HFC-23 by thermal oxidation is a highly effective option to reduce emissions. Destruction efficiency can be greater than 99.0 percent, but the impact of ‘down-time’ of thermal oxidation units on emissions needs to be taken into account.

7.2 Summary of findings from the ODS Supplement to the SROC

As noted earlier, the TEAP Supplementary Report (ODS Supplement) was developed in response to requests by the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer to provide a supplementary report that elaborates clearly the ozone depletion implications of the issues raised in the IPCC TEAP Special Report. In particular, the supplementary report should estimate current and projected levels of ozone-depleting substances contained and emitted from banks, expressed as ODP tonnes; project atmospheric concentrations of ozone-depleting substances under the "Mitigation" and “Business-as-Usual” scenarios that appear in the SROC, and their associated impact on the ozone layer. Furthermore, it should estimate costs of mitigation measures described in the report in terms of cost per ODP tonne.

The SROC describes the banks and emissions in all relevant sectors in kg CO_2-eq, this being the typical way emissions are considered for determining global warming impacts. The ODS Supplement more specifically presents the impacts on the ozone layer from emissions reductions, expressed in ODP tonnes.

Both Reports noted that there are sources of uncertainty arising from the lack information on use-patterns of ODS in Article 5 Parties. The ODS Supplement states that if the sectoral use is not understood, it is impossible to establish whether emissions are prompt (less than 1 year) or spread over a longer period.

The ODS Supplement mentions that, for the major banked substances, the emissions of ODS banked in fire protection, refrigeration and air conditioning equipment during the use-phase tend to be greater than for foams. This reflects the more dynamic nature of the use-phase for such equipment and the need for routine servicing. In all cases, however, the management of the decommissioning process at end-of-life is a key determinant in ultimate emission levels.

The ODS Supplement sets out the key elements of the Business-As-Usual (BAU) scenario used in the SROC and highlights key differences by sector and by region. The assessment elaborates the observation that current ODS recovery rates vary significantly by sector and that, within a given sector, recovery rates tend to be significantly lower in Article 5 Parties than in non-Article 5 Parties.

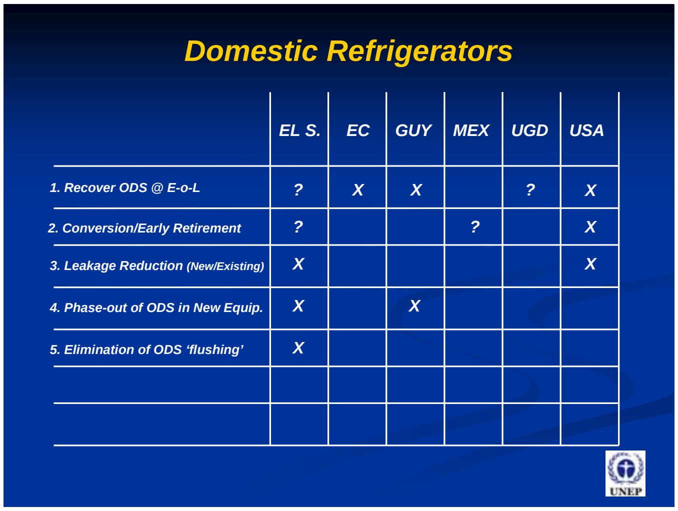
The assessment reveals that, in ODP tonnage terms, 70% (1,820 ODP ktonnes) of all banked ODS (i.e., CFCs and HCFCs, excluding halons) were located in non-Article 5 Parties in 2002. With on-going emissions of ODS in the period until 2015, all banks are expected to decrease. However, due to more rapid emissions from refrigeration and air conditioning equipment and more higher emitting foams in Article 5 Parties, the proportion of the global bank in non-Article 5 Parties is expected to increase in ODP terms by 2015 (75% or about 1,660 ODP ktonnes).

In the ODS Supplement the Mitigation Scenario, as presented in the SROC, is further analysed. Where it focused on the greatest technically feasible reduction of global warming impacts (i.e., reduction of CO_2-eq emissions) by 2015, the analysis in the ODS Supplement is related to the reduction of ODS emissions. In the refrigeration and air conditioning sector, several potential measures are expected to be introduced progressively in the period to 2015 that would have an impact on emission patterns, even after phasing out the use of ODS. This also relates to specific servicing practices, such as recharging for leakage, particularly in Article 5 Parties, where CFC-based equipment is still abundant. If measures are implemented in the last stage of the ODS phase-out process, their main impact would be on the level of future HFC emissions in preference to ODS. The main mitigation strategies likely to have effect on ODS emissions in the mid-term (e.g., as of 2008) are those associated with end-of-life measures in refrigeration and (mobile and stationary) air conditioning, where recovery and destruction would have a significant impact on the level of emissions released from the banks.

Based on the estimates available at the time of writing the ODS Supplement, the best estimate of when the Equivalent Effective Stratospheric Chlorine (EESC) is projected to return to the 1980 levels was the year 2046, taking into consideration the bank and emission estimates used in the SROC. When also taking into account the on-going emissions from servicing of refrigeration and AC equipment, which are additional to emissions from the banks, the return of the EESC to 1980 levels might be delayed by another two years at maximum (2048). Destruction of all banks in refrigeration and AC equipment as of 2008 (at end of life) would theoretically lead to a return of the EESC to 1980 levels around the year 2046.

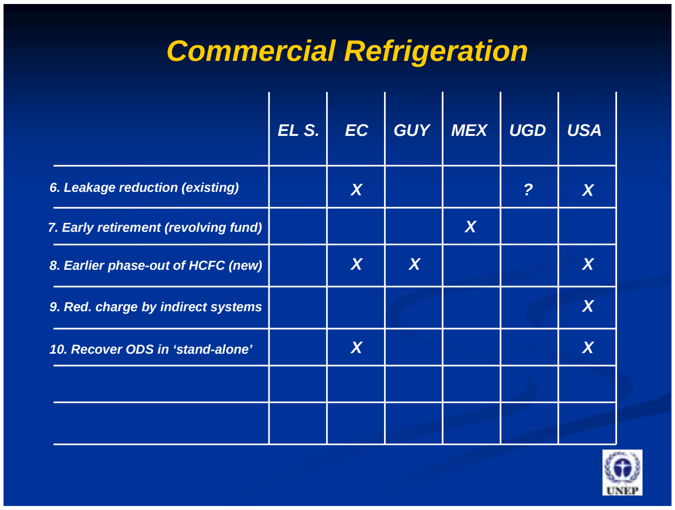
The ODS Supplement provided some examples of mitigation costs and pointed out limitations in the use of this information. However, the ODS Supplement also highlighted that the likelihood of a mitigation measure being considered cost-effective will depend substantially on whether the value of ODS recovery is considered independently of the value of greenhouse gas emission abatement. If these values are combined, a mitigation measure is more likely to be considered cost-effective in local circumstances, where an individual analysis of the value of ODS recovery might have dictated otherwise. The ODS Supplement report states that, in Article 5 Parties, the implication of collection and recovery costs are likely to be greater than in non-Article 5 Parties owing to the lack of infrastructure to implement these measures. Indeed, end-of-life management options are more limited in Article 5 Parties than in non-Article 5 countries and the degree of re-use is generally much higher.

7.3 Sub-Division of the Simplified List of Proposed Practical Measures by Sector



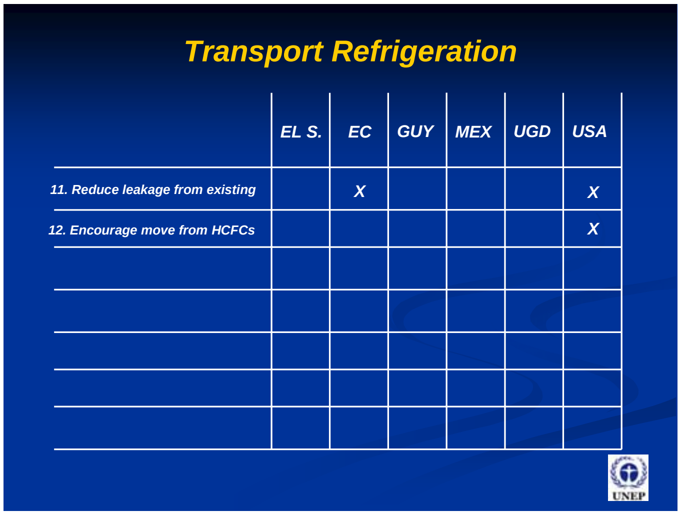
Domestic Refrigerators

	EL S.	EC	GUY	MEX	UGD	USA
1. Recover ODS @ E-o-L	?	X	X		?	X
2. Conversion/Early Retirement	?			?		X
3. Leakage Reduction (New/Existing)	X					X
4. Phase-out of ODS in New Equip.	X		X			
5. Elimination of ODS 'flushing'	X					



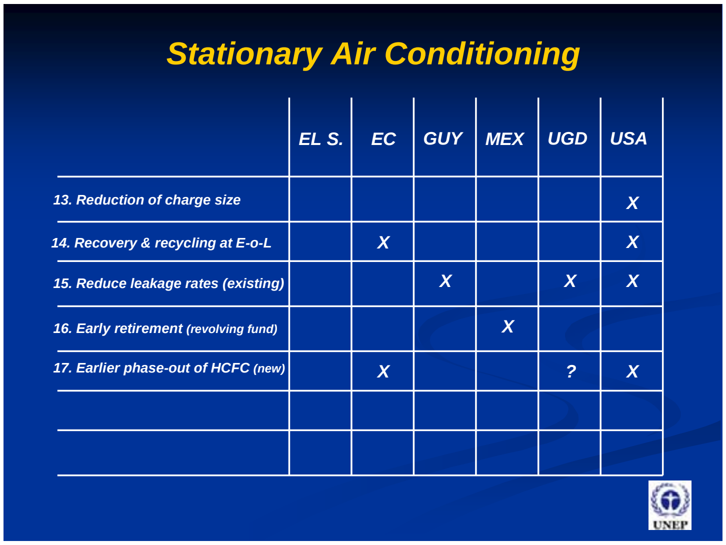
Commercial Refrigeration

	EL S.	EC	GUY	MEX	UGD	USA
6. Leakage reduction (existing)		X			?	X
7. Early retirement (revolving fund)				X		
8. Earlier phase-out of HCFC (new)		X	X			X
9. Red. charge by indirect systems						X
10. Recover ODS in 'stand-alone'		X				X



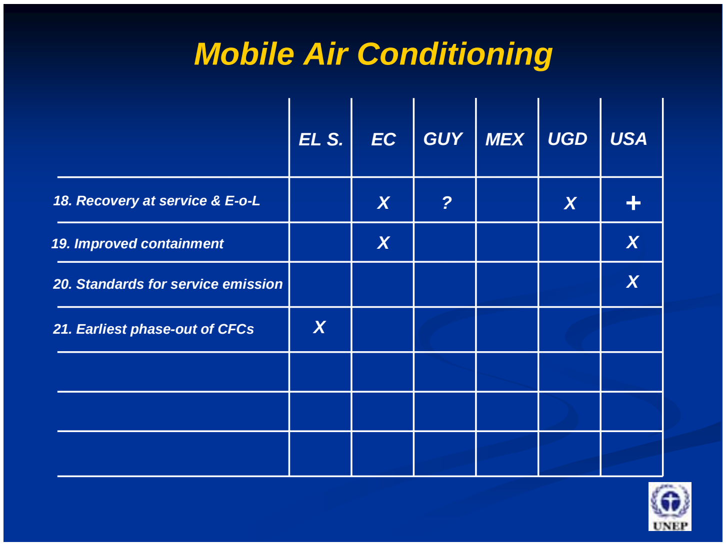
Transport Refrigeration

	EL S.	EC	GUY	MEX	UGD	USA
11. Reduce leakage from existing		X				X
12. Encourage move from HCFCs						X



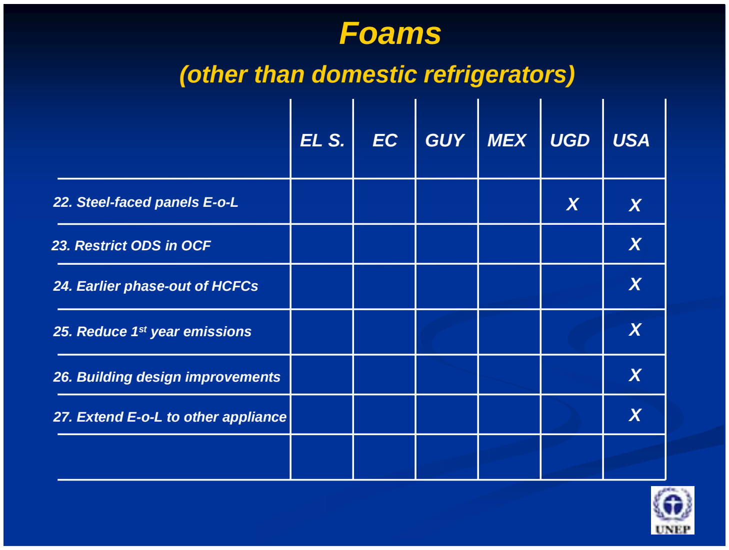
Stationary Air Conditioning

	EL S.	EC	GUY	MEX	UGD	USA
13. Reduction of charge size						X
14. Recovery & recycling at E-o-L		X				X
15. Reduce leakage rates (existing)			X		X	X
16. Early retirement (revolving fund)				X		
17. Earlier phase-out of HCFC (new)		X			?	X



Mobile Air Conditioning

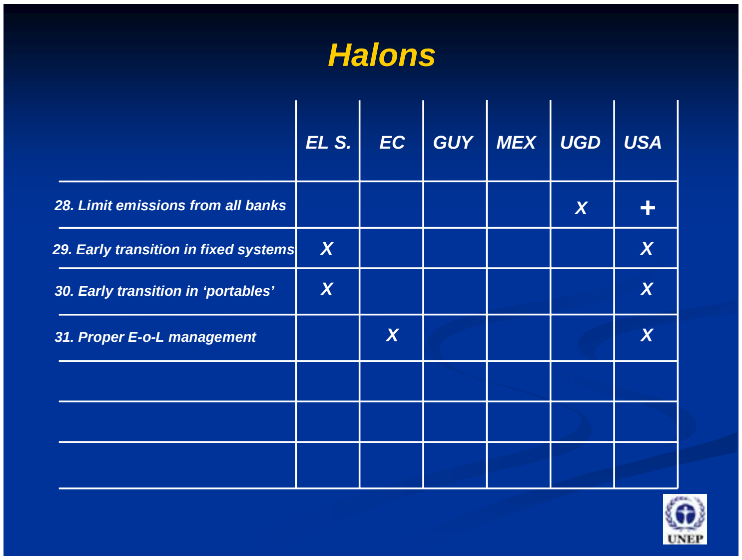
	EL S.	EC	GUY	MEX	UGD	USA
18. Recovery at service & E-o-L		X	?		X	+
19. Improved containment		X				X
20. Standards for service emission						X
21. Earliest phase-out of CFCs	X					



Foams

(other than domestic refrigerators)

	EL S.	EC	GUY	MEX	UGD	USA
22. Steel-faced panels E-o-L					X	X
23. Restrict ODS in OCF						X
24. Earlier phase-out of HCFCs						X
25. Reduce 1st year emissions						X
26. Building design improvements						X
27. Extend E-o-L to other appliance						X



Halons

	EL S.	EC	GUY	MEX	UGD	USA
28. Limit emissions from all banks					X	+
29. Early transition in fixed systems	X					X
30. Early transition in 'portables'	X					X
31. Proper E-o-L management		X				X

7.4 Physical properties and toxicity data of HCFC-225ca and HCFC-225cb

The addition reaction of tetrafluoroethylene and HCFC-21 ($CHCl_2F$) can produce an almost equimolar (45/55) mixture of HCFC-225ca and HCFC-225cb. The mixture as produced is usually used without further separation for most of cleaning solvent applications of HCFC-225, because the two isomers exhibit almost the same physical properties as shown in Table 7.1.

		CFC-113	**HCFC-225ca**	**HCFC-225cb**	**AK-225**
Chemical formula		$CClF_2CCl_2F$	$CF_3CF_2CHCl_2$	$CClF_2CF_2CHClF$	HCFC-225ca +HCFC-225cb
Molecular weight		187.38	202.94	202.94	202.94
Boiling point	[°C]	47.56	51.10	56.10	54
Vapor pressure(25°C)	[kPa]	44.8	38.1	32.0	37.8
Density - Liquid (25)	[kg/m^3]	1561	1551	1554	1553
Specific heat - Liquid (25°C)	[kJ/(kg•K)]	0.96	1.03	1.08	1.00
Thermal conductivity (25°C)	[mW/(m•K)]	75.1	71.7	72.8	72.0
Viscosity - Liquid (25°C)	[mPa•s]	0.65	0.58	0.60	0.59
Surface tension	[mN/m]	17.2	15.5	16.6	16.0
Kauri-Butanol value	-	31	-	-	31
Combustibility (range of explosion)	-	None	None	None	None
ODP	(CFC-11=1)	0.8	0.025	0.033	0.03
GWP (ITH=100year)	(CO_2=1)	5000	120	586	370
Atmospheric life time	[years]	79	2.7	7.9	-

Table 7.1 – Physical properties of CFC-113 and HCFC-225 alternatives

However, the two isomers shows different toxicity especially on repeated oral and repeated inhalation toxicity as shown in Table 2, and HCFC-225cb is clearly less toxic. Therefore, if necessary, HCFC-225cb could be separated from the isomeric mixture by the refined distillation.

	HCFC-225ca	***HCFC-225cb***
	Acute Toxicity (Single Dose Toxicity)	
Oral (Rats)	LD50 > 5,000mg/kg	LD50 : 5,000mg/kg
Inhalation (Rats)	LC50 : 37,000ppm	LC50 : 36,800ppm
Percutaneous <via skin>	LD50 > 2,000 mg/kg	LD50 > 2,000 mg/kg
	Repeated-dose Oral Toxicity	
28-Day (Rats)	NOEL < 8mg/kg *Increase in liver weights and hepato-cellular hypertrophy were seen at 8mg/kg or more.*	NOEL <200mg/kg *Increase in liver weights and hepato-cellular hypertrophy were seen at 1,000mg/kg*
	Repeated Inhalation Toxicity	
28-Day (Rats)	NOAEL : 0.6mg/L (ca.72ppm) *Increase in liver weights and hepato-cellular hypetrophy were seen at 1.8mg/L or more.*	NOAEL> 5.4mg/L (ca.650ppm) *No toxicological changes were seen at 5.4mg/L*
28-Day (Marmosets)	*Decrease in lipid in blood, higher GOT, GPT, LDH and ALP, and increase in the amount of cytochrome P450 were seen at 1,000ppm.*	*No toxicological changes were seen at 5,000ppm.*

LD50 : 50% lethal dose
LC50 : 50% lethal concentration
NOEL : No observed effect level
NOAEL : No observed adverse effect level

Table 7.2 – Toxicity data for HCFC-225 isomers

7.5 Existing schedules relating to Basic Domestic Needs

SCHEDULES FOR NON-ARTICLE 5 PARTIES (PARTIES OTHER THAN DEVELOPING COUNTRIES OPERATING UNDER ARTICLE 5)

Annex A, Group I; Annex B, Groups I, II, III; Annex C, Group II
Production and consumption to be phased out by the end of 1995, but for possible essential-use exemptions granted from year to year by Meetings of the Parties.
For meeting the basic domestic needs (BDN) of Article 5 Parties, the following quantities were permitted.

Annex A, Group I (CFCs)

- Until the end of 2002: annual average of its production to meet the BDN for the period of 1995 to 1997 inclusive (base).
- Until the end of 2004: 80 per cent of the base.
- Until the end of 2006: 50 per cent of the base.
- Until the end of 2009: 15 per cent of the base.
- From 1 January 2010: zero.

Annex B, Group I (other CFCs)

- Until the end of 2002: 15 per cent of production in 1989.
- Until the end of 2006: 80 per cent of the (base) production for meeting the BDN during 1998–2000.
- Until the end of 2009: 15 per cent of the base.
- From 1 January 2010: zero.

Annex B, Groups II and III (carbon tetrachloride and methyl chloroform)

15 per cent of the production in 1989.

Annex C, Group II (HBFCs)

None.

Annex A, Group II (halons)

Production and consumption to be phased out by the end of 1993 but for possible essential-use exemptions. The additional production permitted to meet the basic domestic needs (BDN) was:

- Until the end of 2001: 15 per cent of the production in 1986.
- Until the end of 2004: annual average of production to meet the BDN in 1995–1997 (base).
- Until the end of 2009: 50 per cent of the base.
- From 1 January 2010: zero.

Annex C, Group I (HCFCs)

Consumption frozen at the base level (1989 HCFC consumption +2.8 per cent of 1989 CFC consumption) in 1996; 35 per cent reduction from 1 January 2004; 65 per cent reduction from 1 January 2010; 90 per cent reduction from 1 January 2015; 99.5 per cent reduction from 1 January 2020 and consumption restricted to servicing; and 100 per cent phase-out from 1 January 2030. Production frozen at the base level (1989 HCFC production +2.8 per cent of the 1989 HCFC production) from 1 January 2004; 15 per cent additional production allowed to meet the BDN.

Annex C, Group III (bromochloromethane)

Production and consumption phase-out from 1 January 2002. No exemptions.

Annex E (methyl bromide)

Production and consumption frozen at the base level of 1991 until the end of 1998; 25 per cent reduction until the end of 2000; 50 per cent until the end of 2002; 70 per cent until the end of 2004; complete phase-out from 1 January 2005 with possible critical-use exemptions. Production to meet the BDN is as follows:

- Until the end of 2001: 15 per cent of the base level production.
- Until the end of 2004: 80 per cent of production in 1995–1998 to meet the BDN.
- From 1 January 2005: zero.

SCHEDULES FOR ARTICLE 5 PARTIES (DEVELOPING COUNTRIES)

Annex A, Group I (CFCs)

Production and consumption frozen at the level of average during 1995–1997 (base) from 1 July 1999; 50 per cent reduction from 1 January 2005; 85 per cent reduction from 1 January 2007; and 100 per cent phase-out from 1 January 2010 with possible essential-use exemptions; 10 per cent base level production permitted to meet BDN until the end of 2009.

Annex A, Group II (halons)

Production and consumption frozen at the average 1995–1997 level (base) from 1 January 2002; 50 per cent reduction from 1 January 2005; 100 per cent phase-out from 2010 with possible essential-use exemptions; 10 per cent of base production allowed to meet BDN until the end of 2009.

Annex B, Group I (other CFCs)

Production and consumption reduction of 20 per cent from the level of 1998–2000 (base) from 1 January 2003; 85 per cent reduction from 1 January 2007; 100 per cent phase-out from 1

January 2010 with possible essential-use exemptions; 10 per cent of base level production allowed to meet the BDN until the end of 2009.

Annex B, Group II (carbon tetrachloride)

Production and consumption reduction of 85 per cent from 1 January 2005 from the level of 1998–2000 (base); 100 per cent phase-out by 2010 with possible essential-use exemptions; 10 per cent additional production allowed to meet the BDN until the end of 2009.

Annex B, Group III (methyl chloroform)

Freeze of production and consumption at the 1998–2000 level (base) from 1 January 2003; 30 per cent reduction from 1 January 2005; 70 per cent reduction from 1 January 2010; 100 per cent phase-out from 1 January 2015 with possible essential-use exemptions; 10 per cent additional production allowed to meet the BDN until the end of 2009.

Annex C, Group I (HCFCs)

Freeze of production and consumption from 1 January 2016 at 2015 level; phase-out of consumption from 1 January 2040; 15 per cent of base level allowed until the end of 2039.

Annex C, Group II (HBFCs)
Phase-out of production and consumption from 1 January 1996 with possible essential-use exemptions.

Annex C, Group III (bromochloromethane)
Phase-out of production and consumption from 1 January 2002 with possible essential-use exemptions.

Annex E (methyl bromide)
Freeze of production and consumption at 1995–1998 level (base) from 1 January 2002; 20 per cent reduction from 1 January 2005; 100 per cent phase-out from 1 January 2015 with possible essential-use exemptions; amounts used for quarantine and pre-shipment applications exempted at all stages.

7.6 The Potential Contribution of Other Practical Measures

SUMMARY OF SAVINGS - BASELINE

			Ozone (ODP tonnes)					Climate (Mt CO2-equiv)				
			2011-2020	2021-2030	2031-2040	2041-2050	*Total*	2011-2020	2021-2030	2031-2040	2041-2050	*Total*
Baseline	HCFC		0	0	0	0	*0*	0.00	0.00	0.00	0.00	*0.00*
	HFC-23		0	0	0	0	*0*	0.00	0.00	0.00	0.00	*0.00*
	Sub-total		*0*	*0*	*0*	*0*	*0*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
	Use Phase	Domestic	3421	845	194	45	*4505*	36.26	8.96	2.06	0.48	*47.75*
		Commercial	90710	88350	84463	0	*263523*	2547.56	2767.60	2610.66	0.00	*7925.81*
		Transport	294	20	0	0	*314*	6.72	0.64	0.00	0.00	*7.36*
		Stationary A/C	8100	7967	7730	0	*23796*	295.14	250.47	238.33	0.00	*783.93*
		Mobile A/C	4894	49	0	0	*4943*	96.89	1.51	0.00	0.00	*98.40*
		Foams	1056	1091	982	0	*3128*	7.06	7.29	6.56	0.00	*20.91*
		Halons	93003	31735	23809	18961	*167508*	62.24	22.07	16.63	13.27	*114.21*
	Sub-total		*201478*	*130057*	*117177*	*19006*	*467718*	*3051.86*	*3058.54*	*2874.23*	*13.74*	*8998.38*
	Design	Commercial	5884	9446	273	2	*15605*	181.88	291.97	8.45	0.06	*482.35*
		Stationary A/C	843	2734	922	237	*4736*	26.04	84.51	28.49	7.33	*146.37*
		Mobile A/C	857	459	213	52	*1580*	9.08	7.20	6.49	1.59	*24.37*
		Foams	106	215	313	313	*946*	0.71	1.43	2.09	2.09	*6.32*
	Sub-total		*7689*	*12853*	*1721*	*603*	*22867*	*217.71*	*385.12*	*45.53*	*11.07*	*659.42*
	End-of-Life	Domestic	19460	4808	1104	256	*25629*	206.28	50.97	11.70	2.72	*271.66*
		Commercial	62343	39985	17905	9376	*129609*	1836.00	1177.56	527.30	276.11	*3816.99*
		Transport	458	202	71	31	*762*	10.14	4.47	1.57	0.68	*16.86*
		Stationary A/C	13832	11774	8048	6688	*40342*	458.66	390.40	266.86	221.77	*1337.70*
		Mobile A/C	16281	6674	2329	1015	*26300*	345.83	141.77	49.48	21.56	*558.64*
		Foams	13380	15466	24639	28573	*82058*	76.55	105.49	175.94	177.96	*535.94*
		Halons	0	0	0	0	*0*	0.00	0.00	0.00	0.00	*0.00*
	Sub-total		*125755*	*78909*	*54096*	*45939*	*304700*	*2933.47*	*1870.66*	*1032.85*	*700.81*	*6537.79*
	Early Retirement	Domestic	1460	361	83	19	*1922*	15.47	3.82	0.88	0.20	*20.37*
		Commercial	46757	29989	13429	5625	*95800*	1377.00	883.17	395.48	165.67	*2821.32*
		Stationary A/C	12968	11038	7545	5016	*36567*	429.99	366.00	250.18	166.33	*1212.51*
	Sub-total		*61185*	*41387*	*21057*	*10661*	*134289*	*1822.47*	*1253.00*	*646.54*	*332.20*	*4054.20*
	Total		***396107***	***263207***	***194051***	***76209***	***929574***	***8025.50***	***6567.32***	***4599.16***	***1057.82***	***20249.79***
	HCFC-22 production avoided		99104	96337	92193	0						
	HCFC-22 real tonnes		1801886	1751577	1676228	0						
	HFC-23 avoided							773.55	751.95	719.60	0.00	2245.11
	Emission Rate	3%										
	GWP	14310										

SUMMARY OF SAVINGS - 2012 FREEZE

			Ozone (ODP tonnes)					Climate (Mt CO2-equiv)				
			2011-2020	2021-2030	2031-2040	2041-2050	*Total*	2011-2020	2021-2030	2031-2040	2041-2050	*Total*
2012 Freeze	HCFC		15885	29623	30319	1425	*77252*	468.77	896.73	924.06	39.62	*2329.19*
	HFC-23		0	0	0	0	*0*	194.86	248.25	214.45	0.00	*657.56*
	Sub-total		*15885*	*29623*	*30319*	*1425*	*77252*	*663.64*	*1144.98*	*1138.51*	*39.62*	*2986.75*
	Use Phase	Domestic	3421	845	194	45	*4505*	36.26	8.96	2.06	0.48	*47.75*
		Commercial	83282	75465	72144	0	*230890*	2304.11	2363.96	2229.90	0.00	*6897.97*
		Transport	310	203	198	0	*710*	7.25	6.36	6.10	0.00	*19.71*
		Stationary A/C	19489	18522	17972	0	*55982*	712.22	582.35	554.12	0.00	*1848.69*
		Mobile A/C	4894	112	107	0	*5113*	96.89	3.47	3.30	0.00	*103.66*
		Foams	996	998	898	0	*2892*	6.65	6.66	5.99	0.00	*19.30*
		Halons	93003	31735	23809	18961	*167508*	62.24	22.07	16.63	13.27	*114.21*
	Sub-total		*205395*	*127879*	*115321*	*19006*	*467601*	*3225.63*	*2993.82*	*2818.11*	*13.74*	*9051.30*
	Design	Commercial	5603	9724	388	3	*15718*	173.19	300.56	12.00	0.08	*485.84*
		Stationary A/C	795	2559	862	222	*4437*	24.57	79.11	26.63	6.85	*137.16*
		Mobile A/C	857	459	213	52	*1580*	9.08	7.20	6.49	1.59	*24.37*
		Foams	100	199	313	313	*925*	0.66	1.33	2.09	2.09	*6.18*
	Sub-total		*7355*	*12941*	*1776*	*589*	*22660*	*207.51*	*388.20*	*47.22*	*10.61*	*653.54*
	End-of-Life	Domestic	19460	4808	1104	256	*25629*	206.28	50.97	11.70	2.72	*271.66*
		Commercial	61512	37889	16859	8828	*125088*	1794.86	1105.58	491.92	257.58	*3649.94*
		Transport	459	217	79	35	*790*	12.22	5.78	2.12	0.92	*21.04*
		Stationary A/C	13774	11594	7913	6576	*39857*	457.95	385.46	263.08	218.63	*1325.13*
		Mobile A/C	16281	6678	2332	1016	*26308*	349.93	143.53	50.13	21.85	*565.44*
		Foams	13380	15466	24639	28573	*82058*	76.55	105.49	175.94	177.96	*535.94*
		Halons	0	0	0	0	*0*	0.00	0.00	0.00	0.00	*0.00*
	Sub-total		*124866*	*76653*	*52926*	*45284*	*299729*	*2897.79*	*1796.81*	*994.88*	*679.66*	*6369.14*
	Early Retirement	Domestic	1460	361	83	19	*1922*	15.47	3.82	0.88	0.20	*20.37*
		Commercial	46134	28417	12644	5297	*92492*	1346.14	829.18	368.94	154.55	*2698.81*
		Stationary A/C	12913	10869	7418	4932	*36133*	429.33	361.37	246.64	163.97	*1201.31*
	Sub-total		*60507*	*39647*	*20145*	*10248*	*130546*	*1790.94*	*1194.38*	*616.46*	*318.73*	*3920.50*
	Total		***414008***	***286743***	***220487***	***76551***	***997788***	***8785.51***	***7518.18***	***5615.17***	***1062.36***	***22981.23***
	HCFC-22 production avoided		103081	94189	90313	0						
	HCFC-22 real tonnes		1874196	1712523	1642059	0						
	HFC-23 avoided							804.59	735.19	704.94	0.00	2244.71
	Emission Rate	3%										
	GWP	14310										

SUMMARY OF SAVINGS - LINEAR FROM 2021

			Ozone (ODP tonnes)					Climate (Mt CO2-equiv)				
			2011-2020	2021-2030	2031-2040	2041-2050	*Total*	2011-2020	2021-2030	2031-2040	2041-2050	*Total*
Linear - 2021	HCFC		9073	73369	220722	54991	*358155*	273.39	2181.92	6795.63	1745.65	*10996.59*
	HFC-23		0	0	0	0	*0*	21.24	1035.87	1655.84	0.00	*2712.95*
	Sub-total		*9073*	*73369*	*220722*	*54991*	*358155*	*294.63*	*3217.80*	*8451.46*	*1745.65*	*13709.54*
	Use Phase	Domestic	3421	845	194	45	*4505*	36.26	8.96	2.06	0.48	*47.75*
		Commercial	87000	38384	1	0	*125384*	2426.29	1212.15	0.03	0.00	*3638.47*
		Transport	321	95	0	0	*416*	7.60	3.02	0.00	0.00	*10.62*
		Stationary A/C	20249	8573	0	0	*28823*	737.85	272.81	0.00	0.00	*1010.66*
		Mobile A/C	4894	49	0	0	*4943*	96.89	1.51	0.00	0.00	*98.40*
		Foams	1056	491	0	0	*1547*	7.06	3.28	0.00	0.00	*10.34*
		Halons	93003	31735	23806	18958	*167503*	62.24	22.07	16.58	13.22	*114.11*
	Sub-total		*209943*	*80172*	*24001*	*19003*	*333120*	*3374.18*	*1523.80*	*18.67*	*13.70*	*4930.35*
	Design	Commercial	5288	7530	156	1	*12975*	163.44	232.74	4.82	0.03	*401.04*
		Stationary A/C	843	2480	764	196	*4283*	26.04	76.65	23.62	6.07	*132.38*
		Mobile A/C	857	358	6	0	*1221*	9.08	4.10	0.08	0.00	*13.27*
		Foams	106	155	155	155	*570*	0.71	1.03	1.03	1.03	*3.81*
	Sub-total		*7093*	*10523*	*1080*	*352*	*19048*	*199.27*	*314.53*	*29.56*	*7.14*	*550.50*
	End-of-Life	Domestic	19460	4808	1104	256	*25629*	206.28	50.97	11.70	2.72	*271.66*
		Commercial	62086	38167	16665	8726	*125644*	1731.91	1064.68	464.89	243.43	*3504.90*
		Transport	460	218	78	34	*790*	11.11	5.25	1.89	0.82	*19.07*
		Stationary A/C	13832	11613	7852	6525	*39822*	488.52	410.14	277.30	230.44	*1406.40*
		Mobile A/C	16281	6674	2329	1015	*26300*	345.83	141.77	49.48	21.56	*558.64*
		Foams	13380	15466	24639	28573	*82058*	76.55	105.49	175.94	177.96	*535.94*
		Halons	0	0	0	0	*0*	0.00	0.00	0.00	0.00	*0.00*
	Sub-total		*125500*	*76946*	*52667*	*45130*	*300243*	*2860.21*	*1778.29*	*981.19*	*676.93*	*6296.62*
	Early Retirement	Domestic	1460	361	83	19	*1922*	15.47	3.82	0.88	0.20	*20.37*
		Commercial	46564	28625	12499	5236	*92924*	1298.93	798.51	348.66	146.06	*2592.16*
		Stationary A/C	12968	10887	7361	4894	*36110*	457.99	384.51	259.97	172.83	*1275.29*
	Sub-total		*60992*	*39873*	*19943*	*10149*	*130956*	*1772.39*	*1186.84*	*609.51*	*319.09*	*3887.83*
	Total		***412601***	***280882***	***318413***	***129626***	***1141522***	***8500.69***	***8021.25***	***10090.38***	***2762.52***	***29374.84***
	HCFC-22 production avoided		107569	47053	1	0						
	HCFC-22 real tonnes		1955808	855500	16	0						
	HFC-23 avoided							839.63	367.27	0.01	0.00	1206.90
	Emission Rate	3%										
	GWP	14310										

SUMMARY OF SAVINGS - LINEAR FROM 2016

			Ozone (ODP tonnes)					Climate (Mt CO2-equiv)				
			2011-2020	2021-2030	2031-2040	2041-2050	*Total*	2011-2020	2021-2030	2031-2040	2041-2050	*Total*
Linear - 2016	HCFC		21919	171921	241945	57437	*493221*	638.72	5116.71	7406.31	1801.74	*14963.49*
	HFC-23		0	0	0	0	*0*	305.01	1701.78	1655.84	0.00	*3662.62*
	Sub-total		*21919*	*171921*	*241945*	*57437*	*493221*	*943.74*	*6818.49*	*9062.15*	*1801.74*	*18626.11*
	Use Phase	Domestic	3421	845	194	45	*4505*	36.26	8.96	2.06	0.48	*47.75*
		Commercial	79382	8208	1	0	*87590*	2179.01	261.57	0.03	0.00	*2440.61*
		Transport	294	20	0	0	*314*	6.72	0.64	0.00	0.00	*7.36*
		Stationary A/C	17806	1814	0	0	*19620*	656.47	58.52	0.00	0.00	*714.99*
		Mobile A/C	4879	10	0	0	*4890*	96.44	0.32	0.00	0.00	*96.77*
		Foams	892	109	0	0	*1002*	5.96	0.73	0.00	0.00	*6.69*
		Halons	93003	31734	23805	18957	*167500*	62.24	22.05	16.57	13.21	*114.07*
	Sub-total		*199678*	*42740*	*24000*	*19002*	*285421*	*3043.10*	*352.79*	*18.65*	*13.69*	*3428.24*
	Design	Commercial	4691	3807	39	0	*8538*	145.01	117.67	1.21	0.01	*263.90*
		Stationary A/C	709	1541	421	108	*2780*	21.90	47.64	13.03	3.35	*85.92*
		Mobile A/C	850	344	5	0	*1198*	9.01	3.76	0.06	0.00	*12.82*
		Foams	89	100	100	100	*390*	0.60	0.67	0.67	0.67	*2.60*
	Sub-total		*6339*	*5792*	*565*	*209*	*12905*	*176.52*	*169.73*	*14.96*	*4.03*	*365.24*
	End-of-Life	Domestic	19460	4808	1104	256	*25629*	206.28	50.97	11.70	2.72	*271.66*
		Commercial	61829	34728	14687	7691	*118935*	1638.70	920.43	389.27	203.84	*3152.24*
		Transport	458	202	71	31	*762*	10.14	4.47	1.57	0.68	*16.86*
		Stationary A/C	13760	10918	7286	6055	*38019*	504.16	400.03	266.97	221.86	*1393.03*
		Mobile A/C	16279	6660	2323	1012	*26274*	344.47	140.93	49.15	21.42	*555.97*
		Foams	13380	15466	24639	28573	*82058*	76.55	105.49	175.94	177.96	*535.94*
		Halons	0	0	0	0	*0*	0.00	0.00	0.00	0.00	*0.00*
	Sub-total		*125167*	*72782*	*50110*	*43618*	*291678*	*2780.31*	*1622.31*	*894.60*	*628.48*	*5925.70*
	Early Retirement	Domestic	1460	361	83	19	*1922*	15.47	3.82	0.88	0.20	*20.37*
		Commercial	46371	26046	11016	4614	*88048*	1229.02	690.32	291.96	122.30	*2333.60*
		Stationary A/C	12900	10235	6831	4541	*34508*	472.65	375.02	250.29	166.40	*1264.36*
	Sub-total		*60731*	*36642*	*17929*	*9175*	*124478*	*1717.15*	*1069.17*	*543.12*	*288.90*	*3618.34*
	Total		***413834***	***329877***	***334550***	***129441***	***1207702***	***8660.81***	***10032.49***	***10533.49***	***2736.83***	***31963.62***
	HCFC-22 production avoided		97482	10042	1	0						
	HCFC-22 real tonnes		1772401	182573	16	0						
	HFC-23 avoided							760.89	78.38	0.01	0.00	839.28
	Emission Rate	3%										
	GWP	14310										