Inventories and Projections of Ozone Depleting and Synthetic Greenhouse Gases used in Montreal Protocol Industries

2002

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Foreword

Since the adoption of the *Montreal Protocol on Substances that Deplete the Ozone Layer* in 1987, Australia has been recognised as a world leader in eliminating the use of ozone depleting substances (ODS) that increase ultraviolet radiation reaching the Earth's surface. These substances include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons and methyl bromide. CFCs and halons, the most aggressive ODS, were completely phased out by 1995 for all but essential uses. Australia is on-track to phaseout widespread consumption of methyl bromide by the end of 2004 and is progressing an accelerated phase-out of HCFCs well ahead of *Montreal Protocol* requirements with full cooperation between industry and government.

Hydrofluorocarbons (HFCs) and, to a much lesser extent, perfluorocarbons (PFCs) are synthetic greenhouse gases (SGG) that are increasingly being used in areas such as air conditioning and refrigeration, foam blowing and fire protection to replace ODS. These replacement gases do not deplete the ozone layer, although they are potent greenhouse gases.

This Report on emission inventories and projections for ODS and SGG in *Montreal Protocol* industries reflects the Commonwealth Government's ongoing commitment to addressing global environmental issues. It is the first comprehensive survey and estimate of the transition in Australia from ODS to SGG. The Report documents trends in the use of ODS and their replacements, and uses models to estimate current and future emission profiles. Environment Australia and the Australian Greenhouse Office are pleased to present this study and will use the results of this report to develop a better understanding of Australia's environmental performance and input into the further development of ozone protection and greenhouse policies and measures.

This study has already contributed to meeting the challenge being addressed by Australian industry and Government in collaboration to reduce harmful environmental impacts from the use of these potent gases. As a result of the collection of data for this Report, industry and Government have focused on the need for a comprehensive reporting framework to enable robust estimates of emissions. This acknowledgment led directly to successful negotiations between Government and industry to ensure that, while maintaining companies' confidential data and commercial interests, robust and verifiable data is provided to Government to enable these estimates to be prepared. This agreement, a direct result of the efforts in the preparation of this report, ensures that emission estimates on synthetic gases used as replacements for ozone depleting substances will be available from 2003 onwards.

Environment Australia and the Australian Greenhouse Office would like to commend the authors of the report, Burnbank Consulting, as well as acknowledge the contribution of industry and other stakeholders in the preparation of this report.

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ACRONYMS AND ABBREVIATIONS

А	Activity level (either production or consumption)
AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AGAGE	Advanced Global Atmospheric Gases Experiment
CFC	Chlorofluorocarbon
CTC	Carbon tetrachloride
E	Emissions
GC-ECD	Gas chromatography-electron capture detector
GC-MS	Gas chromatography-mass spectrometry
Gg	Gigagram (= 1000 tonnes = 1 kilotonne)
GWP	Global Warming Potential
HAP	Hydrocarbon aerosol propellant
HC	Hydrocarbon
HCB	Hexachlorobutadiene
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
IPCC	Intergovernmental Panel on Climate Change
kt	kilotonne (= 1 gigagram)
kW	kilowatt
LCV	Light commercial vehicle
Mt	megatonne
ODP	Ozone Depleting Potential
OECD	Organisation for Economic Cooperation and Development
PFC	Perfluorocarbon
SNAP Program	US EPA Significant New Alternatives Policy Program
SRES	Special Report on Emissions Scenarios
TEAP	Technology and Economic Assessment Panel
UNEP	United Nations Environment Programme
US EPA	United States Environment Protection Agency

EXECUTIVE SUMMARY

Background

This study was commissioned by Environment Australia and the Australian Greenhouse Office. The objective of the study is to ensure that the Commonwealth has a sound understanding of current use and future trends in supply and emissions of ozone depleting and synthetic gases as they apply to the Montreal Protocol industries in Australia.

The results will be used to develop a more comprehensive National Greenhouse Gas Inventory and to provide for the calculation of projections of greenhouse gas emissions. Historical data on synthetic gas emissions are necessary to enable Australia to choose between 1990 or 1995 as the baseline year for the contribution of synthetic gases to its Kyoto Protocol target. In addition, the results will help develop policies that facilitate the transition from ozone depleting substances to non-ozone depleting substances.

The industries analysed are those affected by both the Montreal Protocol and the Kyoto Protocol, namely:

- refrigeration and airconditioning (including motor vehicle airconditioning)
- foam manufacture
- solvents
- fire protection
- aerosols, including metered dose inhalers.

The substances considered are:

- CFCs and HCFCs
- halons
- methyl chloroform and carbon tetrachloride
- HFCs and PFCs.

Modelling emissions

Models to develop inventories of ozone depleting substances and synthetic greenhouse gases range from the relatively simple – where all that is required are data on imports and exports – to the more complicated that require detailed data on equipment.

The most simple model is the Intergovernmental Panel on Climate Change's (IPCC's) Tier 1 approach outlined in Volume 3 of the IPCC's Revised 1996 Guidelines for National Greenhouse Gas Inventories (IPCC 1997). This approach requires data on production, imports and exports of bulk substances. The net amount used domestically is assumed to be emitted and it is referred to as potential emissions. A slightly more complicated Tier 1 approach includes data on imports and exports of equipment. The quantity of substance contained in imported equipment net of the quantity contained in exported equipment is assumed to be emitted immediately.

More complex models – Tier 2 models as defined by the IPCC – require annual data on sales of gas and equipment, charges of equipment, imports and exports of equipment, along with information on equipment characteristic. An example is the model used by the USA Environment Protection Agency (US EPA). This is referred to as the US EPA's vintaging model.

In Australia, data are not collected and published. The modelling and estimation of emissions presented in this report rely on a variety of approaches that approximate a vintaging model in most

cases (a bottom-up approach). That is, all estimates (with the exception of indicative estimates for metered dose inhalers and fire protection) presented in the report are based on estimated stocks of equipment and not on imports of gases. Data have been assembled from many sources to compile a relatively coherent and consistent inventory of substance use and emissions. The equipment estimates are compared with estimates from atmospheric fluxes. The models used for the main sources of emissions are consistent with the IPCC Tier 2 approach (Tier 2a) and conform with the requirements of the IPCC Good Practice Guidance (IPCCa 2000).

Production, imports, exports and emissions from miscellaneous uses

CFCs

CFCs are still imported for use in metered dose inhalers under an essential use exemption. Ultimately, these substances will be replaced and the main substitutes are likely to be HFC-134a and HFC-227ea. Depending on the mix of substances used, emissions could range from 372 to 830 gigagrams of carbon dioxide equivalents (CO_2 -e) in 2005, and 387 to 863 gigagrams CO_2 -e in 2010.

Halons

Halon consumption is small. There are several essential use exemptions and supply for these uses is controlled through the National Halon Bank. Organisations apart from the National Halon Bank hold around 50 tonnes of halons, much of which is awaiting destruction.

HCFCs

There are substantial imports into Australia of HCFCs. The highest volume substances are HCFC-22 and HCFC-141b. The HCFC blend, R-409A, is the next highest volume import.

HCFC-22 is used in refrigeration and airconditioning, HCFC-141b is used in foam blowing and as a solvent, and R-409A is used as a retrofit interim replacement for CFC-12 and R-500 in low and medium temperature refrigeration. In addition to direct imports of HCFC-22, there are indirect imports contained in equipment, particularly, domestic and small commercial packaged air conditioning.

HFCs

Australia no longer produces any ozone depleting substances and does not produce any HFCs. Fugitive emissions of HFC-23 from HCFC-22 production ceased in 1995.

Imports and consumption of HFCs are largely unknown in Australia. Import data from the Australian Bureau of Statistics show that 2355 tonnes of HFC-134a were imported in 2000. No other data are available, either from the Australian Bureau of Statistics or from the importers of bulk substances.

HFC alternatives to halons are imported into Australia but the quantity is unknown. Assuming growth at the same rate as real gross domestic product and that there is a single HFC species, estimates of emissions based on HFC usage of 150 tonnes in 2000 indicate that emissions could range from 498 to 2083 gigagrams CO₂-e in 2005 and 581 to 2426 gigagrams CO₂-e in 2010. The lower estimates assume all extinguishant is HFC-125 and the upper estimates are based on use of HFC-23. It is improbable that such high levels of emissions will be realised, although uncontrolled use could lead to the development of a significant emissions source.

Consumption of carbon tetrachloride and methyl chloroform is negligible, and stocks of these substances are equally negligible. There are no reliable data on which to base sound estimates of the extent to HFCs might replace technologies that have themselves replaced the use of methyl chloroform as a cleaning solvent. An estimated six megatonnes of CO₂-e could result from using HFCs if HFC-43-

10mee was used in quantities similar to the amount of methyl chloroform consumed in 1990. This level of emissions is unlikely to eventuate, but there is the potential for a large market for HFCs to arise provided that the economics justify attempts to expand the market.

Domestic refrigeration

Domestic refrigeration is a relatively minor source of emissions of ozone depleting substances and synthetic greenhouse gases. Most emissions from this source arise on disposal of equipment.

Where of ozone depleting substances or synthetic greenhouse gases are used in foam blowing, the insulation contains a large stock of substance that will be emitted after disposal. The quantity of gas available from foam is treated as emitted when the equipment is disposed of -a potential emission -a and it is much greater than that available from compressors.

Measures to reduce direct emissions from this source will need to focus on recovery and recycling of refrigerant gas at the time of equipment disposal, and on destroying the gas contained in the insulation.

Motor vehicle airconditioning

Motor vehicle airconditioning is the most significant actual and potential source of emissions of synthetic greenhouse gases in Australia. The estimates indicate that motor vehicles contributed approximately 1.1 megatonnes of CO₂-e emissions in 1999. This is projected to increase to 2.6 megatonnes in 2005 and 3.6 megatonnes in 2010.

In other parts of the world, such as in the United Kingdom and Europe, commercial refrigeration is the largest potential source of emissions, followed by motor vehicle airconditioning (DETR 1999; March Consulting Group 1998). Differences in climate mean that a much larger proportion of the motor vehicle population in Australia is airconditioned than in Europe.

Options for limiting emissions from motor vehicle airconditioning are relatively simple and do not require new technology. Emissions were estimated based on relatively conservative assumptions about the impact of two measures, namely:

- average charge per unit falls from 0.85 kilograms to 0.75 kilograms from 2005
- recycling and recovery for new vehicles is assumed to be 90% from 2005, and for older vehicles recycling and recovery increases from 40% in 1990 to 76% in 2020.

For trucks, buses and light commercial vehicles it is assumed that better practices and improved sealing of systems results in the average emission factor declining from 20% in 2001 to 9% in 2007 and remaining at this level to 2020. The values of 20% to 9% were chosen based on the average values for passenger vehicles derived from Baker (1998 or 1999). This would result in emissions in 2010 of 280 gigagrams CO₂-e compared with 623 gigagrams CO₂-e, a reduction of 55%.

The emission estimates are based on conjectures about average emission factors, which are supplemented by information from individuals that recovery and recycling practices implemented during the phase-out of ozone depleting substances are no longer strictly observed when HFC-134a systems are serviced.

Standards and Codes of Practice that applied during the phase-out of ozone depleting substances should be reinforced with the possibility of legislative backing. Motor vehicle manufacturers should be encouraged to continually improve fittings that minimise leakage from systems. Substantial reductions can be achieved through relatively simple measures.

A requirement to report annual use along with the quantity contained in charged imported equipment

and system characteristics (losses on charging and leakage rates) is an essential component of any program to monitor, estimate, and limit emissions. The marginal cost of reporting would be trivial given that the information sought should be readily available to manufacturers. Reporting by major vehicle importers should also be required.

Domestic and commercial airconditioning

Domestic and commercial airconditioning systems have the potential to become an important source of greenhouse gas emissions as HFCs penetrate the market. At present most domestic systems use HCFC-22, and commercial systems operate on CFC-11, CFC-12, HCFC-22, HCFC-123, and HFC-134a.

It is expected that in the future HFC-134a and HFC blends – R-407C and R-410A – will become the dominant substances in commercial airconditioning. R-407C and R-410A are also expected to displace HCFC-22 in domestic airconditioning equipment, with R-410A being the main substance.

In 2005, domestic airconditioning could contribute 326 gigagrams CO_2 -e emissions, and this could increase to 1227 gigagrams in 2010. Commercial airconditioning has the potential to contribute 192 gigagrams CO_2 -e emissions in 2005, and 814 gigagrams in 2010. This gives a total for airconditioning of 518 gigagrams in 2005 and 2041 gigagrams in 2010.

Recovery and recycling practices combined with installations that are designed to minimise leakage, such as brazed rather than flared joints in pipework, would reduce emissions significantly. Ammonia (R-717) is an alternative that could be used if appropriate means of managing toxicity and flammability can be developed.

Commercial and transport refrigeration

Commercial and transport refrigeration have the potential to become a significant source of emissions of HFCs, with commercial refrigeration far more significant than transport refrigeration in this context, and a major contributor to industrial process emissions. The HFCs that will penetrate the market, having displaced CFCs and ultimately displacing HCFCs, have global warming potentials (GWPs) of between 1,300 for HFC-134a and 3,260 for the HFC blend, R-404A.

Sound substance conservation practices were adopted during the phase-out of CFCs, and it would be straightforward to ensure similar practices are applied in the use of HFCs. Recovery and recycling practices along with manufacturers and contractors placing an emphasis on minimising losses through seals and joints would be effective in significantly reducing emissions both now and in the future.

Under a business-as-usual approach emissions are projected to increase to 957 gigagrams CO₂-e in 2005 and 1,230 gigagrams in 2010. Recovery and recycling practices would be effective in reducing average annual emission factors by reducing losses when equipment is serviced and recovering substances when equipment is scrapped. For example, substances should be recovered if there is a need to evacuate equipment during servicing. This is understood to already be reasonably common in the transport refrigeration sector.

Improved seals and brazed rather than flared joints would further reduce losses. For example, if the only substance that is lost is around 5% leakage per year rather than an average annual emission factor of 20%, over a 10-year life emissions would fall by 75%.

International overview

Internationally, the phase-out of CFCs has been successful. There remain issues as to whether HCFC phase-out will proceed as smoothly because there is no apparent decline in sales and HCFC-141b sales are continuing to grow.

HFC substitutes are not widely available, particularly for foam blowing, and substitution of HFCs in some applications requires new technologies. For example, compressors for use with R-410A need to be designed for that purpose. As equipment is scrapped and new units are purchased, market penetration of HFCs will increase with a consequent reduction in sales of HCFCs. This trend is not expected to be observed for several years.

Analyses of market penetration of HFCs in the United Kingdom, USA and mainland Europe, and the IPCC Special Report on Emission Scenarios, demonstrate that they are likely to become a major contributor to greenhouse gas emissions.

In the absence of policies designed to limit emissions with an emphasis on the importance of continuation of good practices adopted during the phase-out of ozone depleting substances, emissions of HFCs are projected to more than double in most developed countries from 2000 and 2010.

Comparison of estimates from alternative sources

Emissions have been estimated using several approaches – the IPCC Special Report on Emission Scenarios (2000b) (chapter 9), atmospheric fluxes (chapter 10), and the activity and equipment-based estimates. The atmospheric flux emissions include three gas species only, namely HFC-125, HFC-134a and HFC-152a. The estimates are shown in Table ES-1 for 2000 (in the case of fluxes the value is for 1998–99) and for 2010.

Significant species that are not included and are used in high proportions in HFC blends are HFC-32 (GWP 650) and HFC-143a (GWP 3800). HFC-143a is used in the blends R-404A and R-507, and HFC-32 is used in the blends R-407C and R-410A. All four of these blends are assumed to be used in significant quantities in the future. There are also a number of existing uses and, therefore, emission sources. Approximate emissions from equipment of HFC-143a added to the flux estimate is included in Table ES-1.

Estimation method	Emissions in	Emissions in
	2000	2010
	(Gg CO2-e)	(Gg CO2-e)
Activity/equipment	2085	6924
IPCC Special Report on Emission Scenarios	3577	6821
Atmospheric fluxes	841-1311	
Atmospheric flux plus equipment estimate of HFC-143a (approximation)	1159–1629	
95% confidence interval (minimum)	667-1651	
95% confidence interval (maximum)	1182-2076	

Table ES-1. Estimated emissions derived using different approaches

Source: See chapter 10

The estimate based on the IPCC Special Report on Emission Scenarios (SRES estimate) is much larger in 2000 than both the equipment estimate and flux estimate. By 2010, the SRES estimate and equipment estimate are much closer. This suggests that the rate of adoption of HFCs in Australia is slower than elsewhere or that emission factors are lower. Emission factors in most cases are derived from overseas studies, consequently slower adoption is the more likely explanation.

The uncertainty in the flux estimates for individual species expressed as coefficients of variation (standard deviation as a percentage of the mean) range from 24% to 46%, depending on the correlating species. Assuming independent approximately normal distributions for the flux observations, the uncertainty in the total expressed as coefficients of variation range from 29% for the minimum to 17% for the maximum. This implies 95% confidence intervals of \pm 58% and \pm 34%. The correlating species for

the minimum is CFC-12 and the correlating species for the maximum is dichloromethane (CH₂Cl₂).

Given the high level of uncertainty in the estimates, differences in the equipment estimates and the flux estimates (with HFC-143a included) are not unreasonably large. In the early stages of use of substances, equipment estimates based on average annual emission factors that include venting on servicing and equipment disposal are expected to be higher than flux estimates.

Flux estimates have a different time profile and measure the amount of substance that is present in the atmosphere. As the use of a substance becomes mature, the estimates are likely to converge initially and then the flux estimates should periodically exceed the equipment estimates. Flux estimates will capture emissions at the time when equipment is vented (on servicing or disposal) whereas equipment estimates distribute these emissions over time.

Emissions of HFCs in 2000 are:

- unlikely to be less than 667 gigarams CO₂-e
- unlikely to be greater than 2085 gigarams CO₂-e.

In 2010, emissions from the uses analysed in detail in this report are unlikely to exceed 6924 gigagrams of CO_2 -e.

Policy issues and management strategies

The policy issues concern the need to take some corrective action in relation to the collection and reporting of data, as well as the requirement to implement strategies that will ensure emissions of HFCs are minimised.

Data collection

Establishing a data collection and reporting regime is fundamental to the implementation of appropriate strategies and monitoring of performance. The regime must include:

- mandatory reporting of bulk imports of all HFCs disaggregated by species
- mandatory reporting of all imports of equipment containing HCFCs and HFCs with the species contained identified along with the total quantity of species contained. This should include motor vehicles, domestic and commercial refrigerators, domestic and commercial airconditioners, fire extinguishers (if any), and aerosols.

1 INTRODUCTION

In 2000, Environment Australia in association with the Australian Greenhouse Office engaged Burnbank Consulting to develop inventories of ozone depleting substances and synthetic greenhouse gases. The Terms of Reference stated that the objective of the project is to ensure that the Commonwealth has a sound understanding of current use and future trends in supply and emissions of ozone depleting and synthetic gases as they apply to the Montreal Protocol industries in Australia.

The information reported from this study is an essential input into the development of ozone protection and greenhouse policies and measures. The results will be used to develop a more comprehensive National Greenhouse Gas Inventory and to provide for the calculation of projections of greenhouse gas emissions. Historical data on synthetic gas emissions are necessary to enable Australia to choose between 1990 or 1995 as the baseline year in determining the contribution of synthetic gases to its Kyoto Protocol target. In addition, the results will assist in the development of policies to facilitate the transition from ozone depleting substances to non-ozone depleting substances.

1.1 APPROACH TO THE PROJECT

In deciding on the approach to the project, given the detailed and complex nature of the research, substantial reliance was placed on an expectation that industry would cooperate in providing data, information and comments. Many industry participants were approached and the project was explained along with the importance of obtaining industry input to assist with the development of inventories, understanding of future developments in technologies and the impact on gases used, and the consequences for industry of changes in the management of synthetic greenhouse gases. Further, it was considered that industry input would be valuable in the formulation of any policies to address the management and use of these substances. Cooperation and assistance from industry was limited. This was due partly to the diversity of industry sectors and activities that are responsible for the use of ozone depleting substances and synthetic greenhouse gases.

Literature on overseas experience was reviewed and individuals with an understanding of the industries were consulted. Data on motor vehicles and imports of relevant equipment were purchased from the Australian Bureau of Statistics, and data on imports of gases, to the extent that these are recorded, were obtained from Australian Bureau of Statistics data and the data held by Environment Australia. Other data were obtained from a variety of sources. Data sources are clearly identified in each of the chapters. The majority of emission sources is equipment consequently estimates and projections are based on equipment stocks. Indicative estimates for metered dose inhalers and fire protection are based on historical import data. Projections using gas imports could not be derived because data on imports for other than HFC-134 are not available. Nonetheless, the report is comprehensive and covers in excess of 90% of the uses and potential uses of both ozone depleting substances and synthetic greenhouse gases.

1.2 STRUCTURE OF THE REPORT

The report is structured as follows:

- Chapter 2 provides an overview of relevant ozone depleting substances and synthetic greenhouse gases.
- Chapter 3 summarises various approaches to modelling emissions.
- Chapter 4 examines imports, production and consumption of ozone depleting substances and synthetic greenhouse gases. Emissions from production are discussed along with potential emissions from aerosols, fire extinguishant and solvents.
- Chapter 5 is concerned with domestic refrigeration.
- Chapter 6 provides detailed analysis of emissions from motor vehicles.
- Chapter 7 analyses domestic and commercial airconditioning.
- Chapter 8 deals with commercial, industrial and transport refrigeration. Data availability limits the extent of the analysis of industrial refrigeration and, to a lesser extent, commercial refrigeration.
- Chapter 9 provides an overview of international developments in the phase-out of ozone depleting substances and the adoption of synthetic greenhouse gases.
- Chapter 10 details the results of research on and measurement of atmospheric fluxes in Australia.
- Chapter 11 summarises the results and provides a comparison of emission estimates derived using different approaches.
- Chapter 12 concludes the report with a discussion of policy issues and instruments.

2 OZONE DEPLETING SUBSTANCES AND SYNTHETIC GREENHOUSE GASES—THE SUBSTANCES AND USES

2.1 OZONE DEPLETING SUBSTANCES

2.1.1 CFC-11 (R-11): Trichlorofluoromethane (CCl₃F)

CFC-11 was used in aerosols (as a solvent), solvent applications, foam blowing and commercial airconditioning (chillers). Limited aerosol use is governed by an essential use exemption granted under the provisions of the *Ozone Protection Act 1989* as part of the phase-out of ozone depleting substances. Continuing use in chillers is largely reliant on recovered and recycled stocks although it is understood that a significant quantity of new material is still available. However, availability of CFC-11 is becoming more restricted and prices are increasing. As this becomes more pronounced, existing chillers will either be retrofitted to operate on an alternative substance or the chillers will be replaced with systems using HFCs or blends.

Prior to the phase-out, CFC-11 was used as a foam-blowing agent. It has been entirely replaced in this use by HCFCs (the main transitional substance is HCFC-141b) and non-ozone depleting blowing agents (cyclopentane and isopentane).

2.1.2 CFC-12 (R-12): Dichlorodifluoromethane (CCl₂F₂)

CFC-12 was used as an aerosol propellant, refrigerant in motor vehicle airconditioning systems, transport refrigerant, and refrigerant in domestic refrigerators and commercial-industrial refrigeration and airconditioning. As with CFC-11, limited use as a propellant continues under an essential use exemption. Use in domestic refrigeration and motor vehicle airconditioning ceased in 1994. HFC-134a (R-134a) – tetrafluoroethane – has completely replaced CFC-12 in these applications.

There remain some vehicles in the vehicle fleet that were manufactured in 1994 or earlier with airconditioning systems operating on CFC-12. Servicing of these systems is becoming increasingly difficult due to restrictions on the availability of CFC-12. Most of these vehicles will either be retrofitted to operate on HFC-134a or the systems will leak all of the CFC-12 and the vehicle will not be serviced before it is eventually retired.

Part of the domestic refrigerator population contains CFC-12. These refrigerators will continue to operate until they are scrapped and the majority of the remaining CFC-12 will be vented to the atmosphere at or some time after scrapping. Action is being taken in some areas to assess the viability of recovering gas from old domestic refrigerators but trials are in the early stages.

The extent to which CFC-12 is maintained in some commercial and industrial refrigeration equipment and transport refrigeration is unknown. It is suspected that some systems still operate but the remaining life of the equipment is likely to be short.

CFC-12 was used as part of the blend in a refrigerant known as R-500. This is an azeotropic blend of CFC-12 (73.8%) and HFC-152a (26.2%) and was used in large airconditioning systems. An **azeotrope** is a blend in which all of the components vaporise at a constant temperature. Vapour and liquid composition are the same. A **zeotrope** differs from an azeotrope in that the components vaporise differentially over a range of temperatures leading to a change in the boiling point of the fluid. This is referred to as the **temperature glide**. This means that the composition of the vapour and liquid is not

the same, with the boiling point increasing as the more volatile component vaporises. Blend composition is designed and controlled to ensure that refrigerant performance is not undermined by preferential vaporisation.

2.1.3 CFC-13 (R-13): Chlorotrifluoromethane (CCIF₃)

CFC-13 is a low temperature refrigerant. Use in Australia was not substantial.

2.1.4 CFC-113 (R-113): Trichlorotrifluoroethane (C₂Cl₃F₃)

CFC-113 was used as a solvent and cleaning agent for electronic components, metal parts, dry cleaning, and laboratory analysis. In addition, it was used as a refrigerant in a small number of water chillers. Prior to the phase-out of CFCs, the largest use was as a solvent which has now disappeared. Solvent uses are direct emissive uses and it is likely that there would be negligible emissions if any quantities of CFC-113 were available.

2.1.5 CFC-114 (R-114): Dichlorotetrafluoroethane (C₂Cl₂F₄)

CFC-114 was used in airconditioning where there are high ambient temperatures, such as in smelting plants, crane cabins in foundries or smelters and naval vessels. Small quantities continue to be used in Australia. There was also minor use as a solvent in aerosol preparations.

2.1.6 CFC-115 (R-115): Chloropentafluoroethane (C₂CIF₅)

CFC-115 was used with HCFC-22 as a component of the azeotropic refrigerant blend, R-502 (CFC-115 (51%) and HCFC-22 (49%)). R-502 was used in commercial freezers and refrigerated transport and was the first major product to disappear from sale. This equipment has a relatively long life and there are still some systems in supermarkets and transport that continue to operate using R-502.

HCFC-22 is freely available but CFC-115 is not. Access to supplies of CFC-115 at a reasonable price, combined with the need to produce a carefully controlled blend, suggests that the lifetime of any remaining systems is likely to be short. Most systems have been converted to HFCs (R-404A, R-507) or HCFC-22, with a small number being converted to R-408A (HCFC).

2.1.7 HCFC-22 (R-22): Chlorodifluoromethane (CHCIF₂)

HCFC-22 is a transitional ozone depleting substance with a small ozone depleting potential (ODP) of 0.055. HCFC-22 has been in common use for many years, unlike some other substances that were introduced specifically as transitional substances to fill the void left by the elimination of CFCs.

The main application of HCFC-22 in terms of the numbers of equipment is in domestic airconditioning units and small commercial airconditioning units. Larger quantities are accounted for through use in some commercial refrigeration units such as open reach-in freezers commonly found in supermarkets. Rapid development of small scale airconditioners that are suitable for domestic use is substantially attributable to the availability of HCFC-22. A small number of larger systems (chillers) operate with HCFC-22, but this is not common. Limited quantities of HCFC-22 are used in foam applications, in some cases as part of a blend with HCFC-142b.

2.1.8 HCFC-123 (R-123): Dichlorotrifluoroethane (C₂HCl₂F₃)

HCFC-123 replaced CFC-11 in centrifugal (low pressure) water chillers (commercial airconditioning), and was also used to retrofit centrifugal chillers operating with CFC-11. Initial concerns about occupational safety and health restricted its use. Following assessment of the safety and health issues,

HCFC-123 was cleared for use in refrigeration and airconditioning, but safety concerns have impeded application in foam blowing where it was considered a possible substitute for CFC-11. Under the US Environment Protection Agency (US EPA) Significant New Alternatives Policy (SNAP) program it is noted as acceptable as a blowing agent. It has the lowest ODP of the HCFCs.

2.1.9 HCFC-124 (R-124): Chlorotetrafluoroethane (C₂HCIF₄)

HCFC-124 is used in centrifugal chillers and as part of zeotropic blend drop-in replacements for CFC-12 and R-502 in refrigeration. R-401A, R-409A and R-414A are zeotropic blends that contain HCFC-124 as do several of the blends classified against R-416A (for example, FR-12, DI-24, DI-36). Consumption of the zeotropic blends has been negligible in Australia with the exception of FR-12, which was imported for a relatively short period primarily as a retrofit option for motor vehicle airconditioners. The motor vehicle industry's preference for single component fluids limited market acceptance of FR-12. HCFC-124 is effective as a replacement for CFC-114 and CFC-12 in some larger refrigeration systems.

Minor uses are as a flooding agent for fire suppression and as a replacement for CFC-12 carrier gas in sterilant mixtures of ethylene oxide.

2.1.10 HCFC-141b (R-141b): Dichlorofluoroethane (C₂H₃Cl₂F)

HCFC-141b is commonly used as a foam blowing agent for polyurethane foam insulation replacing CFC-11 and as a replacement for CFC-113 in solvent applications. It has been found to be an efficient transitional replacement for CFC-11 with substantial growth in use since 1992 when it was restricted to experimental quantities pending Program on Alternative Fluorocarbons Toxicity testing.

The use of HCFC-141b as a solvent has been restricted by some materials incompatibility. It reacts with polystyrene, polymethylacrylate and acrylonitrile-butadiene-styrene. Despite its aggressiveness with some materials it is known to be used as a solvent. Price is a further impediment to widespread use as a solvent.

2.1.11 HCFC-142b (R-142b): Chlorodifluoroethane (C₂H₃CIF₂)

HCFC-142b is used as a blend with HCFC-22 for foam blowing (40% HCFC-142b and 60% HCFC-22) and has been applied in small quantities as a propellant in aerosol applications. In Australia, imports of the blend commenced in 1996 with all of the substance used in foam blowing. HCFC-142b can be used alone or in combination with other substances. Australian imports of HCFC-142b have fluctuated since 1992.

2.2 BLENDS—ZEOTROPIC AND AZEOTROPIC

Management of the phase-out of CFCs and the impending phase-out of HCFCs has seen the development of blends of substances, both zeotropic and azeotropic. This proliferation of blends complicates the market by making comparisons and choices more difficult. It also makes it more complex to analyse issues that depend on speciation because the quantity of the relevant substance to be analysed needs to be isolated from the other substances.

When investigating the contribution of HFCs or other blend components (PFCs and hydrocarbons) to global warming, the HCFCs need to be removed despite the fact that they have global warming potentials (GWPs). As with any substance under an international agreements that will eliminate it from use, HCFC emissions are not included in the greenhouse accounting framework.

This leaves us with two possible values of GWP for a blend:

- the overall GWP, which includes all substances in the blend
- the relevant GWP, which includes the GWP attributable to HFCs and other substances that are not excluded under other international agreements HCFCs are excluded from this value.

This issue does not arise if the analysis is undertaken for individual species but it is not clear whether some analyses might mistakenly use a GWP that includes HCFC components of blends. Table 1 shows the various zeotropic blends (400 series refrigerants) and Table 2 shows the several azeotropic blends. The relevant GWP is derived through weighting the blend by composition. For example, for R-401A, the relevant GWP is 0.13 multiplied by 140 – the GWP of HFC-152a which forms 13% of the blend by weight.

The phase-out schedule for CFCs and HCFCs is summarised in Table 3.

R-No.	Substances	Composition by	GWP	Relevant
		weight (approx)	(100 years)	GWP
401A	HCFC-22/HFC-152a/HCFC-124	53:13:34	1082	18
402A	HCFC-22/HFC-125/HC-290	38:60:2	2326	1680
403A	HCFC-22/PFC-218/HC-290	75:20:5	2675	1400
403B	HCFC-22/PFC-218/HC-290	56:39:5	3682	2730
404A	HFC-143a/HFC-125/HFC-134a	52:44:4	3260	3260
406A	HCFC-22/HC-600a/HCFC-142b	55:4:41	1755	0
407C	HFC-32/HFC-125/HFC-134a	23:25:52	1526	1526
408A	HCFC-22/HFC-143a/HFC-125	47:46:7	2743	1944
409A	HCFC-22/HCFC-142b/HCFC-124	60:15:25	1440	NA
410A	HFC-32/HFC-125	50:50	1725	1725
412A	HCFC-22/HCFC-142b/PFC-218	70:25:5	2040	350
413A	HFC-134a/PFC-218/HC-600a	88:9:3	1930	1930
414A	HCFC-22/HCFC-124/HCFC-142b/HC-	51:28.5:16.5:4	1329	0
	600a			
415A	HCFC-22/HFC-23/HFC-152a	80:5:15	1966	606

Table 1. Various R-400 series refrigerants

Source: Based on Pedersen (1998; p.62) excluding relevant GWP

Table 2. Var	ious R-500	series	refrigerants
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R-No.	Substances	Composition by weight (approx)	GWP (100 years)	Relevant GWP
502	CFC-115/HCFC-22	51:49	5576	NA
507	HFC-143a/HFC-125	50:50	3300	3300
508A	HFC-23/PFC-116	39:61	10175	10175
508B	HFC-23/PFC-116	46:54	10350	10350
509A	HCFC-22/PFC-218	44:56	4668	3920

Source: Pedersen (1998; p.62) excluding relevant GWP

Table 3. Summary of Montreal Protocol control measures

Ozone Depleting Substances	Developed Countries	Developing Countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995 ^a	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
Carbon tetrachloride	Phased out end of 1995 ^a	Total phase out by 2010
Methyl chloroform	Phased out end of 1995 ^a	Total phase out by 2015
Hydrochlorofluorocarbons	Freeze from beginning of 1996 ^b	Freeze in 2016 at 2015 base level
(HCFCs)	35% reduction by 2004	Total phase out by 2040
	65% reduction by 2010	
	90% reduction by 2015	
	Total phase out by 2020 ^c	
Hydrobromofluorocarbons		
(HBFCs)	Phased out end of 1995	Phased out end of 1995
Methyl bromide	Freeze in 1995 at 1991 base level ^d	Freeze in 2002 at average 1995-
	25% reduction by 1999	1998 base level
	50% reduction by 2001	20% reduction by 2005 ^e
	70% reduction by 2003	Total phase out by 2015
	Total phase out by 2005	-

^a With the exception of a very small number of internationally agreed essential uses that are considered critical to human health and/or laboratory and analytical procedures.

^b Based on 1989 HCFC consumption with an extra allowance (ODP weighted) equal to 2.8% of 1989 CFC consumption.

^c Up to 0.5% of base level consumption can be used until 2030 for servicing existing equipment.

d All reductions include an exemption for pre-shipment and quarantine uses.

Review in 2003 to decide on interim further reductions beyond 2005.

Source: Environment Australia

2.3 SYNTHETIC GREENHOUSE GASES

2.3.1 HFC-23 (R-23): Trifluoromethane (CHF₃)

HFC-23 is a by-product emission from the manufacture of HCFC-22, a source of emissions that will be eliminated once HCFCs are phased-out. It is used in very-low temperature refrigeration (R-415A), and as a blend component in fire suppression and plasma etching and cleaning in semiconductor manufacturing. HFC-23 is a component of the azeotropic blends R-508A and B with perfluoroethane (PFC-116). Both HFC-23 and PFC-116 have very high GWPs, and the blends have GWPs ranging from 10175 to 10350. HFC-23 has a GWP of 11700, the highest GWP of the HFCs.

2.3.2 HFC-32 (R-32): Difluoromethane (CH₂F₂)

HFC-32 is a component of several refrigerants. It is a component of the zeotropic blends R-407C and R-410A, both of which are HFC blend refrigerants. It is expected that use of R-407C and R-410A will increase over time as they replace HCFC-22 in airconditioning applications. HFC-32 has a GWP of 650.

2.3.3 HFC-43-10mee: Decafluoropentane (C₅H₂F₁₀)

HFC-43-10mee is a relatively new substance and it is used as cleaning solvent. It has the potential to increase in use if it displaces all CFC-113 uses and expands into other solvent applications. HFC-43-10mee has a GWP of 1300.

2.3.4 HFC-125 (R-125): Pentafluoroethane (C₂HF₅)

HFC-125 is a blend component of several refrigerants and a fire suppressant. It is a component of the

zeotropic blends, R-402A, R-404A (a HFC blend refrigerant), R-407C (a HFC blend refrigerant), R-408A, and R-410A (a HFC blend refrigerant). It is also a component of the HFC azeotropic blend, R-507. The use of HFC-125 is expected to continue to increase due to its use in blends that are likely to increase in use in refrigeration (R-404A) and airconditioning (R-407C and R-410A). It has a GWP of 2800.

2.3.5 HFC-134a (R-134a): Tetrafluoroethane (C₂H₂F₄)

HFC-134a is the highest volume HFC currently in use. It is widely used in domestic refrigeration and motor vehicle airconditioning. It is a component in R-404A, R-407C and R-413A (a blend that includes a perfluorocarbon component). HFC-134a uses are expanding to comprise aerosol preparations (including metered dose inhalers) and foam blowing. It is expected that use will continue to grow. HFC-134a has a GWP of 1300.

2.3.6 HFC-143a (R-143a): Trifluoroethane (C₂H₃F₃)

HFC-143a is a refrigerant that is commonly used in refrigerant blends. It is a component of the zeotropic blends R-404A (HFC) and R-408A (HCFC), and the azeotropic blend R-507 (HFC). R-404A is now used widely in commercial refrigeration as is R-507. R-408A is an interim HCFC substitute for R-502.

2.3.7 HFC-152a (R-152a): Difluororoethane (C₂H₄F₂)

HFC-152a is a component of the refrigerant blends R-401A (HCFC) and R-415A (HCFC).

2.3.8 HFC-227ea(R-227ea): Heptafluoropropane (C₃HF₇)

HFC-227ea is used as a fire suppressant and has been approved for use as a propellant in metered dose inhalers. It is imported into Australia for use as a fire extiguishant.

2.3.9 HFC-236fa (R-236fa): Hexafluoropropane (C₃H₂F₆)

HFC-236fa is used as a fire suppressant and as a refrigerant.

2.3.10 HFC-245fa (R-245fa): Pentafluoropropane (C₃H₃F₅)

HFC-245fa is a foam blowing agent and refrigerant. It has been investigated as a potential long-term replacement for HCFC-141b in foam blowing and is expected to be used in this application in the next few years.

2.3.11 HFC-365mfc (R-365mfc): Pentafluorobutane ($C_4H_5F_5$)

HFC-365mfc is a refrigerant and foam blowing agent. As with HFC-245fa, it is expected to be used in the future as a foam blowing agent.

2.4 HYDROFLUOROETHERS (HFES)

The phase-out of ozone depleting substances combined with the global warming impacts of HFCs has focused attention on the development of other substances. HFEs are a class of substances that have been investigated for several years. HFE-7100 (GWP 500) is a cleaning solvent and heat transfer fluid, and HFE-7200 (GWP 100) is a cleaning solvent. These substances appear to have shorter atmospheric lifetimes and lower GWPs than the HFC alternatives.

2.5 SUMMARY

Values of GWP of the HFCs and HFEs are shown in Table 4.

Substance	GWP (100 years)
HFC-23	11700
HFC-32	650
HFC-43-10mee	1300
HFC-125	2800
HFC-134a	1300
HFC-143a	3800
HFC-152a	140
HFC-227ea	2900
HFC-236fa	6300
HFC-245fa	790
HFC-365mfc	910*
HFE-7100	500
HFE-7200	100

Table 4. Global warming potential of HFCs

* World Meteorological Organisation estimate (1998)

3 METHODOLOGIES FOR ESTIMATING EMISSIONS OF CFCS, HCFCS AND HFCS

3.1 IPCC METHODOLOGIES

Methodologies for estimating emissions of CFCs, HCFCs and HFCs are conceptually straightforward; implementation of the methodologies is not. The simplest and least accurate approach is the default methodology proposed by the IPCC in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997; Chapter 2). This methodology (classified as the Tier 1 methodology) assumes that all gases will be emitted eventually and derives potential emissions rather than actual emissions. The methodology refers to HFCs and PFCs but is equally applicable to CFCs and HCFCs.

Expressed simply:

Potential emissions = Production of substance + Imports of substance -Exports of substance - Destruction of substance

Under the Tier 1a approach no account is taken of gas that is contained in fully charged imported equipment. Tier 1b includes production, imports, exports, and destruction of bulk substances along with imports and exports of products containing these substances. Including products in Tier 1b makes the approach more data intensive. The estimate is still an estimate of potential emissions because no account is taken of the characteristics of the products. Leakage rates and losses on disposal are not included in the calculations. This means that there is no time profile of emissions and recovery of substances is not included in the estimates.

Tier 2 is a more advanced methodology and provides more accurate estimates and time profiles of emissions. Implementation of this methodology is data intensive and requires data on product characteristics that are relevant to emissions (charges, losses on charging, losses in operation, losses on servicing, servicing practices, recovery of substances, residual charges on disposal and fate of substances on disposal, numbers of products, and product lives).

The IPCC Good Practice Guidance (IPCC 2000a; p. 3.79) note that, '*Good practice* is to use the Tier 2 actual method for all sub-source categories within this source category', the source category being substitutes for ozone depleting substances. Further, the IPCC (2000a; p. 3.83) comment that, 'It is good practice that actual and potential estimates are not to be included in the same time series, and that inventory agencies recalculate historical emissions with the actual method, if they change approaches.'

Increased model complexity could give the impression that the estimates are less uncertain than is the case. Avoiding internal inconsistencies within the model structure requires more complexity, irrespective of the ultimate level of uncertainty. For example, if it is assumed that products are retired according to a schedule derived from average ages, then it is inconsistent to assume that the disposal charge will be the same for all units. Alternatively, the internal inconsistency can be removed by assuming a 'one-hoss-shay' equipment attribute (all products function without change up to a specified age and die at the retirement age; for example, a light bulb). Few products are in this category and the emissions profile would be distorted by this assumption. Nonetheless it is worth bearing in mind that, 'real emission data for a given year will never be exactly known, irrespective of the refinement of the estimation methods' (IPCC 1997; p. 2.51).

3.2 US EPA VINTAGING MODEL

Examples of more complex models include the US EPA vintaging model (1999). The model tracks the use and emissions of various compounds for the annual 'vintages' of equipment that enter service or are disposed in each end use. The model is characterised as a bottom-up model and is consistent with the IPCC Tier 2 approach. Information is collected regarding annual sales of equipment that use ozone depleting substances and their substitutes (synthetic greenhouse gases) and the amount of the chemical required by each unit of equipment. Emissions for each end use are estimated by applying annual leakage rates and release profiles. By aggregating the data for more than 40 different end uses, the model produces estimates and projections of annual use and emissions of each compound through to the year 2030 (US EPA 1999; Appendix C). The model was developed to track ozone depleting substances, consequently the base year used is 1985. The model has been developed and applied over a long period of time with a long history of data collection and refinement. It is a data-intensive model.

3.3 GAS AND EQUIPMENT SALES DATA METHOD

An alternative modelling approach has been suggested by Schaeffer, Forte and Clodic (u.d.). The model is based on sales of substances and equipment containing substances. No assumptions are needed in respect of emission factors for different types of equipment or uses. Schaeffer *et al.* comment that the estimation method uses data on current and historical sales of gas (or equipment) to directly calculate the share of gas consumption that replaces gas released to the atmosphere in the region being studied. The general form of the equation is:

Emissions = Annual sales of new gas – Total charge of new equipment + Original total charge of retiring equipment – Gas destroyed –

Gas stockpiled + Gas drawn from stockpiles

where:

Annual sales are the annual sales of gas for filling or refilling equipment, both in bulk and in equipment.

New gas means newly produced gas. Recycled gas is not new gas.

- Total charge of new equipment means the sum of the full charges of all new equipment that is sold in a year, including both equipment that is filled in the factory before shipment and equipment that is filled after installation. It does not include charging emissions.
- Original total charge of retiring equipment means the sum of the original full charges of all the equipment that is retired in a year, including both equipment that was filled in the factory before shipment and equipment that was filled after installation. It does not include charging emissions, and it does not exclude gas lost to the atmosphere after the equipment was installed.
- New and retiring equipment both include imported equipment and exclude imported equipment.

The model is based on the idea that an industry's demand for new gas comes from four sources:

- 1. the need to replace emissions from the current equipment stock
- net changes in the size of the operating gas bank, that is, in the total charge of the equipment stock (which may come from changes in the number of individual pieces of equipment and/or changes in the charge size of equipment)
- 3. the need to replace destroyed gas
- 4. stockpiling of gas.

Schaeffer *et al.* (u.d.) note that while the sales-based approach can yield a good estimate of current emissions, it is not designed to predict future emissions. There are also two interrelated factors that may complicate the application of the sales-based approach – the import or export of recycled material into or out of a country or sector, and the retrofit of equipment to use a new gas. These are accounted for by including two additional terms in the equation – recycled gas exported to other sectors or countries is subtracted, and recycled gas imported from other sectors or countries is added. The sales-based method is consistent with the IPCC Tier 2 approach (Tier 2b as defined in IPCC (2000a; p. 3.81)).

3.4 SUMMARY

The models from the most simple, the IPCC's Tier 1 approach, to the more complicated such as the US EPA's vintaging model all have one thing in common – they cannot be applied without any data. The IPCC's Tier 1 approach requires data on imports and exports. These are not collected and published in Australia. The other models, Tier 2 models as defined by the IPCC, require data on sales of gas and equipment, charges of equipment, imports and exports of equipment, along with information on equipment characteristics for the detailed models. None of these data are available in Australia.

The modelling and estimation of emissions presented in this report rely on a variety of approaches that approximate a vintaging model in most cases (a bottom-up approach). Data have been assembled from many sources, and fragments of information have been used in order to compile a relatively coherent and consistent inventory of substance use and emissions. The models used for the main sources of emissions are consistent with the IPCC Tier 2 approach (Tier 2a) and conform with the requirements of the IPCC Good Practice Guidance (IPCC 2000a).

4 PRODUCTION, IMPORTS AND CONSUMPTION OF CFCs, HCFCs AND HFCs

4.1 CFC AND HCFC PRODUCTION AND FUGITIVE EMISSIONS OF HFC-23

Australia does not produce any ozone depleting substances or synthetic greenhouse gases. All of these substances are imported either in bulk form or contained in equipment and products. Until 1995, CFC-11, CFC-12 and HCFC-22 were produced by one company – Pacific Chemical Industries – at a plant located in Sydney. Carbon tetrachloride was a significant input into the production process for CFC-11 and CFC-12, and substantial imports of this substance were accounted for by this use. Production of HCFC-22 gives rise to emissions of HFC-23 as a by-product from the production process.

It is straightforward to estimate emissions of HFC-23 from HCFC-22 production because there is an established, empirical relationship between the amount of HCFC-22 produced and the by-product and fugitive emissions of HFC-23. Mass ratio analyses put emissions at 2% to 4% of the HCFC produced (US EPA 1999; p. 3–26). However, more sophisticated techniques are now used by the US EPA. These are based upon measurements of critical feed components at individual HCFC-22 production plants.

As is consistent with the Revised IPCC Guidelines (IPCC 1997; p. 2.42) recommendations, 4% is used to derive HFC-23 emissions estimates. Closure of the Australian plant means that this source of emissions has been eliminated. Detailed information that could be used to further refine the estimates is not available, but given that the plant was old it is considered that 4% is appropriate being at the upper limit of the mass ratio analysis. Emissions are calculated as follows:

 $E_{\rm HFC-23} = A_{\rm HCFC-22} \times 0.04$

where:

E_{HFC-23} is emissions of HFC-23 (tonnes) A_{HCFC-22} is the amount of HCFC-22 produced (tonnes) 0.04 is the constant mass ratio (or proportion)

Emission estimates are shown in Table 5.

Year	HCFC-22 production	HFC-23 emissions	CO ₂ -equivalent emissions
	(tonnes)	tonnes	(Gg) (GWP = 11700)
1990	2407*	96.3	1,127
1991	2407*	96.3	1,127
1992	2252	90.1	1,054
1993	3091	123.6	1,447
1994	1734	69.4	811.5
1995	1536	61.4	718.8

Table 5. By-product and fugitive emissions of HFC-23 from the production of HCFC-22

Notes: * 1990 and 1991 HCFC-22 production assumed to be the same as in 1989.

1992 to 1995 HCFC-22 production data provided by Environment Australia.

HFC-23 emissions estimated from HCFC production data.

Emissions of HFC-23 peaked in 1993 at around 1447 gigagrams CO_2 -e declining to 718.8 gigagrams CO_2 -e in 1995, the final year of plant operation. Within the National Greenhouse Gas Inventory these emissions are classified as industrial process emissions, and elimination of this source through the plant closure has the effect of significantly reducing industrial process emissions irrespective of whether 1990 or 1995 is chosen as the base year. Lack of data have so far prevented the inclusion of this source in the national inventory.

In addition to production of HCFC-22, Australia produced CFC-11 and CFC-12 up until 1995. Production declined significantly from 1991 to 1995, the final year of operation of the plant.

4.2 IMPORTS AND CONSUMPTION OF CFCs, HCFCs AND SYNTHETIC GREENHOUSE GASES

Bulk imports are the primary source of CFCs, HFCs, and HCFCs. They are used in original equipment manufactured domestically and for servicing both imported and domestically manufactured equipment. Recovered substances are a minor source overall, but, as CFCs and HCFCs become more scarce, recovered gases will be the sole source for equipment servicing. Equipment and uses that still rely upon CFCs, with the exception of essential use exemptions, must rely exclusively on recovered substances if the equipment is to remain in operation without retrofitting. Total imports in 1999 were higher than in 1997, after allowing for essential use exemptions. The exemption permitting these imports relates to medical applications, namely, for use in metered dose inhalers. The requirement for a medically safe solvent and propellant for metered does inhalers means that this use will continue until such time as a substitute or substitutes penetrate the market. HFC-134a is a potential substitute as is HFC-227ea, both of which have been approved for use overseas and in Australia. Some reduction in use could result from the development of new technologies, such as dry powder inhalers.

Substantial quantities of CFCs were used in refrigeration, airconditioning, foam blowing, and solvent applications in 1990. Estimated consumption in 1986, the base year for the phase-out under the Montreal Protocol, was in excess of 14000 tonnes (Environment Australia 1996). Note that these data refer to new substances (imports plus production minus exports) and do not take into account consumption of recovered and recycled CFCs. Imports of equipment containing stage-1 scheduled substances were restricted from 1989 (Schedule 4 of the Act) with dates varying from 1 January 1989 to the date of commencement of the Act (16 March 1989) to 31 December 1989, dependent on the application of the substance. Imports of equipment containing the main CFCs ceased to be an issue from 1990 onwards.

Imports of HCFCs are confidential. HCFCs are transitional substances that have facilitated the rapid phase-out of CFCs. Reflecting this, imports increased substantially from 1990 to 1999. The highest volume HCFC is HCFC-22, followed by HCFC-141b. Unlike other HCFCs, HCFC-22 is not solely a transitional substance, although there are several applications where it is now used in place of CFCs. It has been primarily used in residential airconditioning for many years.

HCFC-22 is a component of the transitional HCFC zeotropic blends – R-402A (38%), R-406A (55%), R-408A (47%), R-409A (60%) and R-409B (65%). R-402A and R-408A include HFC components and in the case of R-402A, a hydrocarbon component, that all need to be accounted for in estimating emissions of synthetic gases. R-406A includes a hydrocarbon component that also needs to be accounted for in the estimation of emissions. Relevant global warming potential values are listed in Table 1 for various R-series refrigerants. HCFC-22 consumption has remained relatively stable from 1990 to 1999, although there was a sharp decline in consumption in 1994 and 1995, the reason for which is not obvious. It could be due to an anomaly in the data collection regime or scarcity as a result of limited production in the two years prior to closure of Pacific Chemical Industries' manufacturing plant.

HCFC-141b consumption increased from 1992 to 1999. HCFC-141b is the main transitional substance substitute for CFC-11 in foam blowing and it is also used as a solvent. The phase-out of CFC-113 and methyl chloroform along with use in foam blowing explains the rapid expansion in the use of HCFC-141b.

Consumption of HCFC-123 was relatively stable from 1995 to 1999. HCFC-123 replaced CFC-11 in chillers, with between 30% and 50% of chillers moving to this substance. HCFC-123 was also used in retrofitting some CFC-11 chillers and it is likely that this will continue. A factor that might have inhibited uptake was that there were initial occupational health and safety concerns with at least one major manufacturer deciding not to use the substance. Toxicity testing cleared it for use in refrigeration and airconditioning, but safety concerns have impeded application in foam blowing where it was considered a possible substitute for CFC-11. It is noted as acceptable as a blowing agent under the US EPA SNAP program.

R-409A is the highest volume zeotropic blend and it is the main transitional substance used in retrofitting commercial refrigeration equipment. R-401A and R-402A were initially and briefly used but these were quickly displaced by R-408A and R-409A. The pattern of consumption of these two blends suggests that use is declining as they are replaced by the HFC blends, R-404A and R-507.

The only HFC import data available to this study are shown in Table 6 for HFC-134a. Imports have increased from 721.6 tonnes in 1998 to 2354.8 tonnes in 2000. All bulk gas importers were approached on several occasions for import data to enable a complete dataset of imports of HFCs and HFC blends to be provided. No data were received from the major bulk gas importers, all of which are subsidiaries of large chemical manufacturing companies or distributors located in Europe or the USA.

Table 6. Imports of HFC-134a from 1998 to 2000					
Year	HFC-134a imports (tonnes)				
1998	721.6				
1999	1700.0				
2000	2354.8				

Source: Australian Bureau of Statistics import data

Only two companies provided data and these data are not presented in the report. The industry commented, however, that it has a high degree of confidence in the import data reported by the Australian Bureau of Statistics (used in Table 6).

The National Greenhouse Strategy released in 1998 foreshadowed the development of environmental management strategies for synthetic gases, noting that the strategy for HFCs will address the use of HFCs in non-refillable containers (p. 85). The Customs (Prohibited Imports) Regulations 1956 were amended with effect from 1 July 2000 and these prohibited the importation of non-refillable containers containing HFCs designed for use in the maintenance of refrigerative units (including airconditioning units). According to industry, there was an increase in imports of HFC-134a for one year as a result of companies importing non-refillable containers of HFCs prior to the imposition of the ban. This suggests that part of the increase in HFC-134a imports from 1999 to 2000 is attributable to stockpiling of non-refillable containers in anticipation of the prohibition from 1 July 2000. The significant growth in imports shown in Table 6 cannot be interpreted as indicative of a long-term trend. This would

require a much larger dataset and projections of demand based on the stock of equipment and the estimated growth in demand for equipment. All projections included in this report are based on equipment estimates.

4.2.1 Aerosols

Imports and consumption of CFC-11 and CFC-12 are subject to an essential use exemption for use in aerosol preparations of metered dose inhalers. Two HFCs—HFC-134a (GWP 1300) and HFC-227ea (GWP 2900)—have been approved for use in metered does inhalers. To estimate the potential impact on emissions of replacing CFC-11 and CFC-12, a range was derived assuming all of the ozone depleting substances are replaced either by HFC-134a or HFC-227ea from 2002. Projections of emissions are based on the assumption that use will grow at the same rate as population. Implicit in this assumption is that there will be no change in the incidence of the relevant diseases in the population and that the distribution across the population remains constant. The estimates are shown in Table 7. If CFCs were to be replaced by HFC-134a, emissions in 2005 would be 372 gigagrams of CO₂-e and 387 gigagrams of CO₂-e in 2010. If the replacement substance is HFC-227ea, emissions would be 830 gigagrams in 2005 and 863 gigagrams in 2010.

Year	Substance used	ential (Gg CO2-e)	
	(tonnes)	HFC-134a	HFC-227ea
2000	274		
2001	276		
2002	279	363	809
2005	286	372	830
2010	298	387	863
2015	308	400	892
2020	317	412	920

Tahle	7.	Potential	emissions	from	aerosols
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4.3 IMPORTS AND CONSUMPTION OF HALONS, CARBON TETRACHLORIDE AND METHYL CHLOROFORM

Imports and consumption of halons, carbon tetrachloride and methyl chloroform are shown in Table 8 and Table 9 respectively. Halons were the first ozone depleting substances to be phased out. Some halon remains in specialist fire applications. Most of the carbon tetrachloride consumed was as a feedstock in the production of HCFC-22 and this use ceased when Pacific Chemical Industries closed the manufacturing plant in 1995.

Substantial quantities of methyl chloroform were consumed in solvent applications. Once the requirement to phase-out methyl chloroform was established it was displaced rapidly by alternative cleaning methods and the use of HCFC-141b. However, methyl chloroform is still used far more than is HCFC-141b as a solvent.

Table 8. Imports of halons, carbon tetrachloride and methyl chloroform, 1990 to 1999

Substance	1990 ¹	1991 ¹	1992	1993	1994	1995	1996	1997	1998	1999
Halon-1211	163.7	110.9	39.32	0	0	0	0	0	6.5	1.91
Halon-1301	16.7	11.3	38.91	0	0	0	0	0	0	1.2
Halon-2402	0	0	0	0	0	0	0	0	0	0
Total halon	180.4	122.2	78.23	0	0	0	0	0	6.5	3.11
Carbon tetrachlorid	11160	11160	10441	10423	5127.78	3070.89	0.3934	0.469	0.22	0.0074
Methyl chloroform	6608.5	4680	5086	3626	2272.61	846.44	0.1458	0.104	0.0478	0.051

^{1.} All data for 1990 are estimates; carbon tetrachloride for 1991 is an estimate.

Table 9. Consumption² of halons, carbon tetrachloride and methyl chloroform, 1990 to 1999

Substance	1990 ¹	1991 ¹	1992	1993	1994	1995	1996	1997	1998	1999
Halon-1211	163.7	110.9	13.52	0	0	0	0	0	6.5	1.91
Halon-1301	16.7	11.3	38.91	0	0	0	0	0	0	1.2
Halon-2402	0	0	0	0	0	0	0	0	0	0
Total halon	180.4	122.2	52.43	0	0	0	0	0	6.5	3.11
Carbon tetrachlorid	11160	11160	10441	10423	5127.78	3070.89	0.3934	0.469	0.22	0.0074
Methyl chloroform	6608.5	4680	5086.00	3585.85	2272.61	846.44	0.1458	0.104	0.0478	0.051

^{1.} All data for 1990 are estimates; carbon tetrachloride for 1991 is an estimate.

^{2.} The difference between imports and consumption is destruction of substance.

4.3.1 Halons

Stocks of halon still remain in holdings of the National Halon Bank and in equipment—halon-1211 is used in portable fire extinguishers and halon-1301 is used in fixed installations. Halon-1211 amounts remaining in equipment tend to be in aircraft (portable applications) and halon-1301 is used in ships (fixed installations).

Sustainable Solutions (1998) reported that total holdings of halon-1211 were 643 tonnes, and the estimated use requirements to the year 2030 would be 0.5 tonnes per year. Estimated total holdings of halon-1301 were 668 tonnes in 1998, with an annual requirement to 2030 of a 'guesstimate' of seven tonnes (ibid. p. 30–31). By June 1998, the National Halon Bank had collected 1228 tonnes of halon-1211 and 537 tonnes of halon-1301 (ibid. p. 10). Of the amounted collected, 437 tonnes of halon-1211 were destroyed (ibid. p. 12). Further quantities have been destroyed since 1998, amounting to an estimated total of 1002 tonnes. In late 2000, the National Halon Bank held stocks of 140 tonnes of halon-1211 of which 70 tonnes is being held for essential use applications and the excess is awaiting destruction. Halon-1211 is still being collected from the community and industry at an estimated rate of about 30 tonnes per year.

The National Halon Bank has collected an estimated 565 tonnes of halon-1301 from around Australia since 1992 (this is lower than the estimate cited by Sustainable Solutions). The National Halon Bank's policy with respect to halon-1301 is not to destroy it, but instead to hold stocks for future re-use in essential applications. No destruction of halon-1301 at the National Halon Bank has taken place. The stock of 565 tonnes of halon-1301 is currently being processed for re-use.

DASCEM estimates that halon-1301 is still being collected, mainly from industry, at a rate of about four to five tonnes per annum, with 92% of the banked halon-1301 coming from Government and large commercial companies. The Commonwealth Government and its agencies have deposited in excess of 50% of all halon-1301 at the National Halon Bank. To the extent that information is available, data on stocks of halons by sector are shown in Table 10 and Table 11.

Table 10. Halon-1211 stocks

Sector	Stocks purified (tonnes)	Stocks contained in equipment (tonnes)
Defence	30 tonnes (awaiting destruction)	8
	10 tonnes of purified stocks in	
	store	
Australian Antarctic bases	not applicable	2.275
Ansett	not applicable	0.23-0.35
Qantas	not available	not available
Impulse	not applicable	0.1 (estimated)
Other aircraft	not applicable	15 (estimated)
Fire Control Companies	1.12	not available
Shipping	not available (mainly halon-	not available (mainly halon-1301)
	1301)	

Table 11. Halon-1301 stocks

Sector	Stocks purified (tonnes)	Stocks contained in equipment (tonnes)
Defence	20.45	25.814
Australian Antarctic bases	1.645	2.009
Ansett	1.71	0.23 - 0.35
Qantas	not available	not available
Impulse	not available	not available
Other aircraft	2.53 (purity unknown)	not available
Fire Control Companies	1.5-2.0	not available
Shipping	not available	11.912

The Australian Halon Management Strategy (Environment Australia 2000; p. 10) states that based on the inventory carried out in 1998 (Sustainable Solutions 1998), approximately 70 tonnes of halon-1211 and approximately 250 tonnes of halon-1301 have been set aside as an essential use reserve. This stock will be retained at the National Halon Bank and will be made available to end-users as required. This study did not elicit any information that would suggest demand for either halon would increase.

State and Territory environment agencies provided information on control and essential use within their jurisdiction as listed below.

Australian Capital Territory

Outside the defence and aviation sectors there are no halon systems classified as being essential use in the ACT. Data provided indicated that total quantities collected in the ACT up to August 2000 are 26.2 tonnes of halon-1211 and 18.4 tonnes of halon 1301.

New South Wales

In NSW approval for the last land-based essential use halon system outside the defence, aviation and shipping sectors expired in 1995. There are no essential use permits for halon outside these sectors.

Northern Territory

In the Northern Territory, the only area of essential halon use outside the aviation, shipping and
defence sectors was for fire control systems in offshore petroleum drilling platforms. The mining sector has entirely phased out the use of halon-1211 and halon-1301, and is using alternative fire suppressants. After consultation with the Northern Territory Environmental Protection Agency, it was established that approximately 3.5 tonnes of halon-1301 are still installed in offshore petroleum facilities in Northern Territory waters. A total of 1.5 tonnes of halon-1211 and 2.5 tonnes of halon-1301 were decommissioned and left the Territory during the 1999–2000 financial year to be stored in the DASCEM National Halon Bank.

Queensland

In Queensland, there are no essential use permits for halon use outside the aviation, shipping and defence sectors.

South Australia

South Australia has no essential use permits outside the defence, aviation and shipping sectors. During 1999–2000, 2.2 tonnes of halon-1211 and 0.3 tonnes of halon-1301 were collected in South Australia. Total quantities collected to the end of June 2000 were 119.6 tonnes of halon-1211 and 59.4 tonnes of halon-1301.

Tasmania

At the time of Sustainable Solutions' 1998 report, Tasmania did not currently enforce the decommissioning of fixed halon flooding systems, and there was no requirement to provide details of fixed flooding systems to the Tasmanian Environment Protection Authority.

The Tasmanian Department of Primary Industries, Water and Environment suggested that the only permits for essential use halon outside the defence, aviation and shipping sectors had been given to three fire protection specialist companies. These are: Parmic Pty Ltd, which holds no stocks of halon; Fire Fighting Enterprises, which holds all halon stocks at Kidde Graviner's facility in Victoria; and Wormald Pty Ltd, which holds all the halon it uses at the company's central facility.

Victoria

In 1998 there was only one essential use halon permit in operation outside the defence, aviation and shipping sectors in Victoria (Sustainable Solutions 1998). This permit was for 192 kilograms of halon-1211 that was installed in explosion suppression equipment in a petrochemical plant. The continuation of this permit was at that time under review and appeared unlikely to be extended beyond early 1999. The Victorian Environmental Protection Agency was unable to provide information on the current status of this permit.

Western Australia

In Western Australia, existing halon flooding systems do not have to be decommissioned and can remain in indefinite use, with conversion of these systems to be determined by market forces. However, owners of halon fixed flooding systems were required to notify the Western Australian Environmental Protection Agency as to the type of halon system, its location and the volume of installed halon by June 1994. A copy of this list of halon systems registered with the Western Australian Environmental Protection Agency was obtained, however, not all companies that have decommissioned their halon systems have notified the Agency. A total of 82.82 tonnes of halon were listed as being installed in fixed flooding systems in Western Australia. However, these data are unreliable, as many of these systems may have been decommissioned in the period of time since the register was compiled. In addition, the register does not distinguish between different halon types.

4.3.2 HFC alternatives to halons

The main HFC alternatives to halons are HFC-23 (GWP 11700), HFC-125 (GWP 2800), HFC-227ea (GWP 2900), and HFC-236fa (GWP 6300). Perfluoropropane (GWP 7000), perfluorobutane (GWP 7000) and perflurohexane (GWP 7400) are PFCs that are used in fire suppression. Transitional HCFCs in use are HCFC-123, HCFC-124 and several HCFC blends produced by North American Fire, imports and consumption of which are shown in Table 10 and Table 11.

HFC-23, HFC-125, HFC-227ea and HFC-236fa are understood to be used in Australia. HFC-23 is promoted as a total flooding agent substitute for halon-1301. The other HFC substances are marketed as fire extinguishing agents that can be substituted for either halon-1211 or halon-1301 depending on the application. Very small quantities of PFC extinguishants have been imported into Australia. It is unlikely that amounts of any significance will be imported in the future, particularly given that 3M have been involved in a substantial research effort over several years to develop more environmentally benign alternatives with a focus on hydrofluoroethers (HFEs).

Replacement of halons has not resulted in an equivalent quantity of HCFCs and HFCs being used in fire extinguishing equipment. It is conjectured that 150 to 200 tonnes per year of HCFCs and HFCs are used and that HFC usage is probably around 100 tonnes. Potential emissions can be derived assuming that HFCs eventually displace all HCFCs, that base usage in 2000 is 150 tonnes, and that use increases at the same rate as growth in real gross domestic product. The CO₂-e emissions are derived assuming that all fire extinguishant is a single species and the results are shown in Table 12.

Year	Total fire extinguishant	Emissions (Gg CO ₂ -e) assuming all fire extinguishant is:					
	(tonnes)	HFC-23	HFC-125	HFC-227ea	HFC-236fa		
2000	150	1755	420	435	945		
2005	178	2083	498	516	1121		
2010	207	2426	581	601	1307		
2015	240	2808	672	696	1512		
2020	273	3192	764	791	1719		

Table 12. Potential emissions from fire extinguishant use

Source: Estimated using real gross domestic product growth rates provided by the Australian Greenhouse Office

The results are no more than indicative upper limits. For example, if all the extinguishant used in the year 2000 was HFC-23, CO₂-e emissions would be 1755 gigagrams. However, if use was exclusively HFC-125, emissions would total to only 420 gigagrams in the year 2000. By 2010, these emissions would increase to 2426 gigagrams and 581 gigagrams respectively. Clearly a single fire extinguishant will not be used because different applications require different extinguishants. A mix of extinguishants will be used and some of these will be HFCs. What the results in Table 12 demonstrate is that there is the potential for substantial emissions of greenhouse gases from an area of use of HFCs that, initially, might be considered as likely to be relatively minor. It is emphasised that these data have not been substantiated. Nonetheless, they provide a starting point for discussions with industry that will result in more reliable data.

4.3.3 Carbon tetrachloride

Imports and consumption of carbon tetrachloride are shown in Table 8 and Table 9 above. Carbon tetrachloride is currently listed as a Schedule 7 Drug or Poison by the National Drug and Poisons Scheduling Committee. Under the Montreal Protocol all importing and production of carbon tetrachloride was required to cease by 1 January 1996, apart from needs classified as being essential use. Nominations for continuing essential uses of carbon tetrachloride (for example, medical research or pharmaceutical purposes) can only be made by the Australian Government.

Carbon tetrachloride was used as feedstock for the production of CFC-11, CFC-12 and HCFC-22 up until the end of 1995. It is also known to have been used as a solvent in clothing drycleaning, but it is no longer used in this industry.

All suppliers listed under the National Industrial Chemicals Notification and Assessment Scheme were contacted and they did not report holding stocks of carbon tetrachloride.

Carbon tetrachloride is used as a solvent and sterilising agent in pharmaceutical laboratories. Based on advice from companies, approximately 21 litres of carbon tetrachloride are held by pharmaceutical companies.

Almost every pharmaceutical company and research facility contacted mentioned that they had phased out or were intending to phase out use of carbon tetrachloride on occupational health and safety grounds because of its carcinogenic nature.

4.3.4 Methyl chloroform

Imports and consumption of methyl chloroform are shown in Table 8 and Table 9 above. Methyl chloroform (also known as 1,1,1-trichloroethane) is currently listed as a Schedule 5 Drug or Poison by the National Drug and Poisons Scheduling Committee. Under the Montreal Protocol, all importing and production of methyl chloroform was required to cease by 1 January 1996, apart from needs classified as being essential use.

Prior to that date, methyl chloroform was used in aerosols and as a solvent in other applications. It is now mainly used in solubility reactions and as a cleaning and sterilising agent. As with all of the substances that have been phased-out, nominations for continuing essential uses (for example, medical research or pharmaceutical purposes) can only be made by the Australian Government. Suppliers did not report holding stocks of methyl chloroform.

Advice from pharmaceutical companies and research facilities indicated that around 11.4 litres are held by these organisations.

Most pharmaceutical companies and research facilities contacted stated that they had phased out or were intending to phase out use of methyl chloroform due to its carcinogenic nature. From the data and responses collected, it would appear that occupational health and safety issues have also been a strong impetus for the phase out of this chemical from use in pharmaceutical laboratories.

4.3.5 Alternatives to methyl chloroform

The rapid displacement of methyl chloroform has been noted along with the fact that alternative cleaning methods have displaced many of the solvent cleaning applications. There are several substances in addition to HCFC-141b that are or could be used in solvent cleaning applications, ignoring cleaning in semiconductor applications. These include chlorobromomethane, n-propyl bromide, hexachlorobutadiene, HFC-43-10mee (GWP 1300), and the hydrofluoroethers (HFEs), HFE-7100 (GWP 500) and HFE-7200 (GWP 100).

The National Industrial Chemicals Notification and Assessment Scheme called for information on chlorobromomethane, n-propyl bromide, and hexachlorobutadiene (HCB) in the Chemical Gazette of 3 October 2000. Only three responses were received indicating that small quantities of chlorobromomethane and n-propyl bromide were imported in 1999 and 2000, and there were no imports of HCB. It is uncertain whether this information is complete. During this study it was suggested that chlorobromomethane and n-propyl bromide were being imported for use as solvents, either blended with another substance or alone, and in quantities greater than those noted by National

Industrial Chemicals Notification and Assessment Scheme. No substantiation of this information was provided and the veracity of the claim remains untested.

The Customs Codes and import data provide a possible indication of imports, although not all substances are explicitly specified. If the customs code for chlorobromomethane is 2903499064 then imports are as follows:

- 1996–97 328 kilograms
- 1997–98 5262 kilograms
- 1998–99 107 kilograms
- 1999–00 3 kilograms

As with chlorobromomethane, n-propyl bromide is not specifically identified. If the Code is 2903300066 then imports were:

- 1996–97 1624.235 tonnes
- 1997–98 1576.807 tonnes

No further imports for this Code are recorded. If these imports are n-propyl bromide, imports of this magnitude for solvent use could be understood in the context of rapid displacement of methyl chloroform, a substance that was used in very large quantities. More than 200 tonnes of HCFC-141b are used in the cleaning solvents sector. However, more than 4500 tonnes of methyl chloroform being used in 1991 (including as aerosol solvents) and so there is a large quantity of substance that has been displaced by other technologies or other solvents.

Changes in cleaning applications that used solvents are attributable to the fact that large quantities of controlled substances that were subject to phase-out schedules were used. Examination of these quantities suggests that the potential for use of uncontrolled substances could be significant. HFCs, for example, are not controlled substances and if developments facilitated more widespread use as a solvent this would result in a substantial contribution to greenhouse gas emissions. There is no guarantee that increased use of HFCs will not eventuate, particularly in an environment where information is scarce and there is no established reporting and monitoring system. For example, if the use of HFC-43-10mee¹ increased to that of methyl chloroform in 1991, emissions could be more than six megatonnes of CO₂-e per annum. It is not suggested that this is likely to occur, because the cost would be prohibitive. Nonetheless, it provides an indication of the maximum amount of emissions that are theoretically possible from unconstrained use of solvents.

Historical data on the use of methyl chloroform and other solvents (such as CFC-113) provides some guidance on the potential market for alternative solvents both in aerosols and for cleaning. It is clear that a large amount of substance could be sold in this sector in the absence of any controls on use. If a substance could be marketed as safe and effective and approved for use elsewhere, increased demand would lead to larger volumes being manufactured with a consequent reduction in price. This could displace some of the non-fluorochemical technologies that were adopted following the phase-out of CFCs. There is a strong incentive to expand the market for substances that are not controlled.

4.4 CONCLUSION

HCFC-22 production as a source of fugitive emissions of HFC-23 ceased in 1995. Australia no longer produces any ozone depleting substances and does not produce any HFCs. CFCs are still imported for use in metered dose inhalers under an essential use exemption. Ultimately, these substances will be

¹ HFC-43-10mee is an acceptable aerosol solvent and an acceptable substitute for metals cleaning under the US Environment Protection Agency's Significant New Alternatives Policy program

replaced and the main substitutes are likely to be HFC-134a and HFC-227ea. Dependent on the mix of substances used, emissions could range from 372 to 830 gigagrams CO_2 -e in 2005, and 387 to 863 gigagrams CO_2 -e in 2010.

There are substantial imports of HCFCs, with the highest volume substances being HCFC-22 and HCFC-141b. The HCFC blend, R-409A, is the next highest volume import. HCFC-22 is used in refrigeration and airconditioning, HCFC-141b is used in foam blowing and as solvent, and R-409A is used as a retrofit interim replacement for CFC-12 and R-500 in low and medium temperature refrigeration. In addition to direct imports of HCFC-22, there are indirect imports contained in equipment, particularly, domestic and small commercial packaged airconditioning.

Halon consumption is small. There are several essential use exemptions and supply for these uses is controlled through the National Halon Bank. Holdings by organisations apart from the National Halon Bank are around 50 tonnes, much of which is awaiting destruction. HFC alternatives are imported into Australia but the quantity is unknown. Estimates based on HFC usage of 150 tonnes in 2000^2 indicate that emissions could range from 498 to 2083 gigagrams CO₂-e in 2005 and 581 to 2426 gigagrams CO₂-e in 2010. The lower bound assumes all extinguishant is HFC-125 and the upper bound is based on use of HFC-23. It is improbable that such high levels of emissions will be realised, although uncontrolled use could lead to the development of a significant emissions source.

Consumption of carbon tetrachloride and methyl chloroform is negligible, as is the amount of stocks held. It was suggested that there was a stockpile of methyl chloroform in South Australia but no further information was obtained. The extent to which HFC use could replace use of methyl chloroform as a cleaning solvent or its replacement technologies is unknown, and there are no reliable data on which to base sound estimates of this. However, emissions could be as high as six megatonnes CO_2 -e if HFC-43-10mee was used in similar quantities to methyl chloroform in 1991. This level of emissions is unlikely to eventuate, but there is the potential for a large market for HFCs to arise provided that the economics justify attempts to expand the market.

The amounts of HFCs imported and exported are largely unknown. Australian Bureau of Statistics import data show that 2355 tonnes of HFC-134a were imported in 2000. No other data are available, either from the Australian Bureau of Statistics or from the importers of bulk substances.

 $^{^{2}}$ assuming growth at the same rate as real gross domestic product and a single HFC species

5 DOMESTIC REFRIGERATION

Australia's domestic refrigeration industry has changed substantially over the last 30 years. There were nine local manufacturers in the early 1970s, and only two in 2000 – Email and Fisher & Paykel.

Fisher & Paykel commenced production in a new plant in 1990 in Cleveland, Brisbane. Located in Orange, New South Wales, Email is the sole remaining producer from the 1970s having acquired many of the other producers with the final acquisition being the whitegoods³ division of Southcorp in 1999. Some of the more traditional Australian brand names such as Kelvinator are now imported from Korea and serviced by Email.

Despite the consolidation of the industry, domestic production has continued to increase (see Table 14).

5.1 MODELLING EMISSIONS

Emissions of ozone depleting substances and synthetic greenhouse gases from domestic refrigeration arise from charging, leakage and disposal. There is minimal servicing of domestic refrigerators.

Modelling of emissions requires information on:

- production
- imports
- exports
- sales
- losses on charging
- refrigerator charges
- the leakage rate from domestically produced and imported refrigerators
- the average life of refrigerators
- the number of refrigerators retired each year and the residual charge of these refrigerators
- the stocks of refrigerators.

5.1.1 Estimation of refrigerator numbers

The Australian Bureau of Statistics publish production data and import data can be purchased for the payment of a consultancy fee.

Production over time period, t, is denoted as Y_t . Imports are denoted M_t . Exports are denoted by the symbol, X_t . Sales for period, t, are denoted V_t , where V refers to the number of units of a particular vintage. Stocks at time t are denoted by the symbol S_t . Retirement rates are derived from sales and stocks, and are denoted R_t .

The data items, symbols and data sources are shown in Table 13.

³ whitegoods is the generic term used for refrigerators, stoves, washing machines

Data item	Data source
Production (Y)	Australian Bureau of Statistics Catalogue 1301.0 (various
	years) for the years 1965–66 to 1996–97; estimated for other
	years
Imports (M)	Australian Bureau of Statistics for the years 1989 to 1999;
	estimated for other years
Sales (V – number for each	Derived from production and imports
vintage)	
Stocks (S)	Derived from sales and assumptions on average lives of
	equipment
Retirements (R)	Derived from data on sales and assumptions on average
	lives of equipment
Characteristics (charges, losses on	Industry advice; assumption
charging, leakage rates)	· · ·

Table 13. Data and data sources on domestic refrigerators

Equipment sales at time, t, should equal production plus imports minus exports. Assuming that exports are negligible, then:

Sales = Production + Imports

 $V_t = Y_t + M_t$

Starting at a time period such that all stocks in time periods earlier than t are retired by the first year at which emissions are estimated, the relevant stock at time period t is:

 $S_t = V_t$

That is, assuming no retirements, the relevant stock is equal to sales. For each period, stocks can be estimated from sales in the current and earlier relevant periods minus retirements.

To complete the model and estimate retirements, it is necessary to make an assumption concerning the average life of domestic refrigerators. AGO (1999) assumes that all units of a particular vintage remain in service for one third of the average service life, with a linear retirement rate in following years until all units have been scrapped. The linear retirement assumption means that 50% of the vintage survive to the average service life, and the last appliance in the vintage retires at five thirds of the average service life. This model was developed by the Lawrence Berkeley Laboratories and has been applied in other studies (AGO 1999; p. 90).

Assuming an average service life of 15 years (less than that assumed in AGO 1999) the model implies that the first retirements of each vintage occur in year six after the purchase, and continue until the last units are retired in year 25. That is, 5% of the units of a specific vintage are retired each year from year six giving rise to disposal emissions. For example, units from the 1989–90 vintage all remain in-service up to 1994–95, with the first retirements in that year.

Using the retirement assumption, then in year, t+5, the first year of retirements, the following outcomes apply:

$$\begin{split} & Production = Y_{t+5} \\ & Imports = M_{t+5} \\ & Sales = Y_{t+5} + M_{t+5} = V_{t+5} \\ & Retirements = R_{t+5} = 0.05V_t \text{ (that is 5% of vintage } V_t \text{ are retired)} \\ & Stocks = S_{t+5} = S_{t+4} + V_{t+5} - R_t = V_t + V_{t+1} + V_{t+2} + V_{t+3} + V_{t+4} + V_{t+5} - 0.05V_t \end{split}$$

The dataset necessary to estimate emissions has been constructed from actual and estimated data. Initial estimates of emissions were calculated for 1989–90. These estimates included units that had

been purchased since 1965–66 because the last units of the 1965–66 vintage are disposed of in 1989–90. Hence 1965–66 is called the starting year for that particular calculation.

Production data for the years from 1997–98 are estimated from the following equation derived from an autoregressive structure:

 $Y_t = 1.0118 Y_{t-1}$

Import data for 1965–66 to 1987–88, and 2000–01 to 2020 are estimated from the following equation derived from a log-linear structure:

 M_t = 1.0443 M_{t-1}

Production is assumed to grow at 1.18% per year, and imports are assumed to grow at 4.43% per year. The data are shown in Table 14.

Year	Production ('000)	Imports ('000)	Sales ('000)	Retirements ('000)	Stock ('000)
1990	346	194	540	363	6295
1991	363	194	557	373	6478
1992	372	187	559	381	6656
1993	393	186	579	393	6842
1994	460	210	670	404	7109
1995	408	217	625	414	7320
1996	414	233	647	426	7541
1997	398	267	665	436	7770
1998	403	296	699	449	8020
1999	407	374	781	464	8338
2000	412	391	803	479	8662
2005	437	485	922	566	10383
2010	464	602	1066	678	12262
2015	492	748	1240	799	14350
2020	521	929	1450	941	16746

Table 14. Production, imports, sales, retirements and stocks of domestic refrigerators

An alternative to constructing a complete data series from 1965–66 is to use time series data from other studies. Sales and stocks data have been updated where possible by Energy Efficient Strategies (1999), using data collected by GfK and AGO (1999). These data are somewhat problematic and have not been used in this study. Analysis of the stocks and assumed lives of equipment (17 years) yield retirements that are less than expected. In addition, sales data are available for five years only.

5.1.2 Estimating emissions and the bank of gas

Emissions arise from charging losses (C), leakage (L), and disposal (D).

Charging losses are determined from production. Leakage emissions are derived from stocks of equipment, and disposal losses are estimated from retirements. The bank of gas contained in equipment is estimated from equipment stocks.

It is assumed that up to and including 1993–94, all compressors were charged with CFC-12. From 1994–95, it is assumed that HFC-134a is used (see Table 15). This means that all sales and stocks up to and including 1993–94 contained CFC-12, with all sales thereafter containing HFC-134a.

Table 15. Refrigerant gas, average charge and assumed period of use

Refrigerant gas	Average charge (grams)	Period of use
CFC-12	175	Up to 1993-94
HFC-134a	145	From 1994-95

Source: Industry advice.

The assumptions of the retirement model have implications for estimating both in-service and disposal emissions, and the bank of gas contained in the stock, and complicate the emissions model as follows:

- If it is assumed that the average leakage rate applies to the residual charge rather than the initial charge, the leakage estimates need to take into account the age profile of the stock, otherwise emissions will be overestimated. The situation where lifetime losses from leakage are so large as to seriously impair the function needs to be avoided. Consider an assumption of 2% leakage of the initial charge per year. After 25 years this implies that only 50% of the charge remains and it is unlikely that the refrigerator would function adequately with a loss of this magnitude. If the assumption is 2% leakage of the residual charge per year, after 25 years, 62% of the initial charge remains. Again this is unlikely to be sufficient for the refrigerator to function adequately.
- The structure of the model means that at the maximum the retirements each year are comprised of proportions of 20 vintages, each of which have different residual charges and different disposal emissions potential. This needs to be taken into account.
- Different vintages of the stock will contain different amounts of gas which in turn has an impact on estimation of the bank of substances contained in equipment.

Using the definitions of variables, the model can be described in a detailed form. Starting from year t, sales are V_t , and are equal to stocks S_t . There are no retirements until year t + 5, so in year t, R_t is equal to zero. Now V_t is equal to $Y_t + M_t$. Let:

C be the average charge of equipment (grams)

ec be the proportion of C emitted when equipment is charged (assumed constant)

e1 be the proportion of C emitted in each year (assumed constant)

 e_d be the proportion of C emitted on disposal (e_d is a function of e_l and equipment age).

It is assumed that servicing of domestic refrigerators is negligible.

```
Starting at time, t,:
```

Production = Y_t Stocks = Sales = V_t Retirements = $R_t = 0$ Bank of gas = $(1 - e_l)CV_t$

and the following emissions occur:

 $E_t = e_c C Y_t + e_l C V t$

Implicitly this assumes that all units are charged, or that they are imported and enter service at the beginning of the period, and that vintage V_t leaks in period t. Note that charging emissions arise from domestic production, and in-service emissions (leakage) arise from domestic production and imports.

At time, t + 1, sales equal V_{t+1} , and stocks (S_{t+1}) are $V_t + V_{t+1}$. Emissions are:

 $E_{t+1} = e_c C Y_{t+1} + e_l C (V_t + V_{t+1})$

In period, t + 5, the period at which the first retirements and disposal emissions occur:

$$\begin{split} & \text{Production} = Y_{t+5} \\ & \text{Sales} = V_{t+5} \\ & \text{Retirements} = R_{t+5} = 0.05V_t \\ & \text{Stocks} = S_{t+5} = 0.95V_t + V_{t+1} + V_{t+2} + V_{t+3} + V_{t+4} + V_{t+5} \\ & \text{Bank of gas} = (1 - e_l)CV_{t+5} + (1 - 2e_l)CV_{t+4} + (1 - 3e_l)CV_{t+3} + (1 - 4e_l)CV_{t+2} + (1 - 5e_l)CV_{t+1} + (1 - 6e_l)C0.95V_t \end{split}$$

and emissions are:

$$E_{t+5} = e_c C Y_{t+5} + e_l C [(V_t - 0.05V_t) + V_{t+1} + V_{t+2} + V_{t+3} + V_{t+4} + V_{t+5}] + e_{dt} C 0.05V_t$$

where R_t , R_{t+1} , R_{t+2} , R_{t+3} and R_{t+4} all equal zero.

As noted, e₁ is a constant proportion of C, the original charge, rather than a proportion applied to each end of period residual charge (to do otherwise would overly complicate an already complicated model) then:

Charge on disposal = C - $5e_1C$ and $e_d = 1 - 5e_1$

At time, t + 6, emissions are:

$$E_{t+6} = e_c C Y_{t+6} + e_l C [(V_t - 0.05V_t - 0.05V_t) + (V_{t+1} - 0.05V_{t+1}) + V_{t+2} + V_{t+3} + V_{t+4} + V_{t+5} + V_{t+6}) + e_d C (0.05V_t + 0.05V_{t+1})]$$

where $R_{t+6} = 0.05V_t + 0.05V_{t+1}$.

The pattern of emissions and retirements continue up to time, t + 24, when the last units of vintage V_t are retired.

The general formula for emissions with a full set of vintages represented is:

$$\begin{split} E_{t+24} &= e_c C Y_{t+24} + e_l C [0.05 V_{t+1} + 0.10 V_{t+2} + 0.15 V_{t+3} + 0.20 V_{t+4} + 0.25 V_{t+5} + 0.30 V_{t+6} + \\ &\quad 0.35 V_{t+7} + 0.40 V_{t+8} + 0.45 V_{t+9} + 0.50 V_{t+10} + 0.55 V_{t+11} + 0.60 V_{t+12} + 0.65 V_{t+13} + 0.70 V_{t+14} \\ &\quad + 0.75 V_{t+15} + 0.80 V_{t+16} + 0.85 V_{t+17} + 0.90 V_{t+18} + 0.95 V_{t+19} + V_{t+20} + V_{t+21} + V_{t+22} + V_{t+23} \\ &\quad + V_{t+24}] + e_d C (0.05 V_t + 0.05 V_{t+1} + 0.05 V_{t+2} + \dots 0.05 V_{t+19}) \\ &= E_c + E_l + e_d C (V_t + V_{t+1} \dots V_{t+19}) \end{split}$$

Estimation of the quantity that leaks each year can be simplified as can estimation of the bank of substances. The assumption that the leakage rate is a constant proportion of the initial charge means that all units leak the same quantity of gas each year. Therefore, annual leakage is equal to a proportion, e_i (the constant leakage rate), of the total original charge of the stock of equipment. That is:

Leakage = $L_t = e_l CS_t$

where C is the average initial charge of equipment, S_t is the stock of equipment at time t, and CS_t is the total original charge of the equipment.

Similarly, the bank equals the total amount of substance originally contained in equipment minus the amount emitted from leakage and disposal. Therefore:

$$B_t = CV_t - L_t - D_t$$

where L_t and D_t are leakage and disposal emissions respectively at time t.

More generally where a full complement of vintages is represented at year 25 (the year when the last units of V_1 are retired in year 26 the vintages represented will be V_2 , V_3 , V_{26}):

$$B_{25} = C \sum_{t=1}^{t=25} V_t - \sum_{t=1}^{t=25} L_t - \sum_{t=1}^{t=25} D_t$$

In year n, the bank is:

$$B_n = C \sum_{t=1}^{t=n} V_t - \sum_{t=1}^{t=n} L_t - \sum_{t=1}^{t=n} D_t$$

Refrigerant gas is not the only source of emissions from domestic refrigeration. Insulation foam is another source of emissions. To complete the model it is assumed that 5% of the blowing agent is lost when the foam is blown and that 95% is retained in the foam cells and is emitted on disposal. Blowing losses are relevant to domestic production and disposal emissions arise from both imported and domestically produced refrigerators.

5.1.3 Emissions from domestic refrigeration

Refrigerant gas

The model has been used to estimate emissions from domestic refrigeration and the bank of gas contained in equipment. Assumptions are summarised in Table 16.

1	
Variable	Assumption
Average charge (C)	CFC-12: 175 grams; HFC-134a: 145 grams
Loss on charging (e_c)	0.5% of C
Leakage (e ₁)	1% per year of C
Disposal emissions	Residual of C after accounting for leakage
Average life	15 years
Age of first units retired in each vintage	5 years (retired in year 6)
Age of last units to be retired in each	25 years
vintage	
Average quantity of gas in foam	800 grams
Average amount emitted on blowing	5% = 40 grams

Table 16. Variables and assumptions used in the model

Emissions and the bank of refrigerant gas are shown in Table 17. These data do not include emissions from foams.

As shown in Table 17 and Figure 1, annual emissions of CFC-12 peaked in 1999 at 78.9 tonnes and declined from then until all CFC-12 is expected to be exhausted just before 2020. Emissions of HFC-134a are estimated to grow strongly until 2020 as the total stock of refrigerators reaches the point where all CFC-12 containing units are retired and replaced by equipment containing HFC-134a. From 2020, HFC-134a emissions will grow at the same rate as the assumed growth in sales as the growth in the stock of equipment containing HFC-134a stabilises with all CFC-12 units replaced. In 2020, emissions of HFC-134a are estimated at 142.8 tonnes under business-as-usual assumptions.

Year	CFC-12 (tonnes)					HFC-134a (tonnes)				
	Leakage	Disposal	Charging	Total	Bank	Leakage	Disposal	Charging	Total	Bank
				emissions					emissions	
1990	11.0	54.7	0.3	66.0	1013.5	0.0	0.0	0.0	0.0	0.0
1991	11.3	56.3	0.3	67.9	1043.4	0.0	0.0	0.0	0.0	0.0
1992	11.6	57.5	0.3	69.4	1072.1	0.0	0.0	0.0	0.0	0.0
1993	12.0	59.4	0.3	71.7	1102.1	0.0	0.0	0.0	0.0	0.0
1994	12.4	61.0	0.4	73.9	1145.9	0.0	0.0	0.0	0.0	0.0
1995	11.7	62.6	0.0	74.3	1071.5	0.9	0.0	0.3	1.2	89.7
1996	11.0	64.4	0.0	75.4	996.2	1.8	0.0	0.3	2.1	181.7
1997	10.2	66.0	0.0	76.2	920.0	2.8	0.0	0.3	3.1	275.3
1998	9.4	67.9	0.0	77.3	842.6	3.8	0.0	0.3	4.1	372.8
1999	8.6	70.3	0.0	78.9	763.7	5.0	0.0	0.3	5.3	481.1
2000	7.8	67.4	0.0	75.2	688.5	6.1	4.3	0.3	10.7	587.2
2005	4.4	51.7	0.0	56.0	369.8	11.4	28.3	0.3	40.1	1082.1
2010	1.8	35.0	0.0	36.8	148.4	16.3	56.3	0.3	72.8	1515.3
2015	0.3	16.1	0.0	16.4	25.2	20.5	87.1	0.4	108.0	1894.9
2020	0.0	0.0	0.0	0.0	0.0	24.3	118.1	0.4	142.8	2235.0

Table 17. CFC-12 and HFC-134a emissions from domestic refrigeration





Foams

Prior to the decision to eliminate the use of ozone depleting substances, the insulation foam in domestic refrigerators was blown with CFC-11. Following the phase-out of CFC-11 manufacturers moved to the use of HCFC-141b as an interim measure and later most switched to pentane (cyclopentane and isopentane). In Australia, it is assumed that producers switched to HCFC-141b from 1992, with one producer continuing to use HCFC-141b until 1999 when the plant was closed. Other domestic production is assumed to move to cyclopentane and isopentane from 1995, and all imported product is assumed to contain HCFC-141b from 1992 to 1994, and cyclopentane and isopentane thereafter. Estimation of emissions and potential emissions uses the same assumptions on average lives and retirement rates as detailed earlier. Additional assumptions are specified in Table 18.

Table 18. Assumptions used in the foam model

Variable	Assumption
Quantity of gas lost on blowing	40 grams
Average quantity contained in insulation	800 grams
Actual or potential emission on disposal	800 grams
Year when CFC-11 use ceased	1991
Year when HCFC-141b use commenced	1992
Year when imports and 70% of domestic production commenced use of	1995
pentane	
Year when 30% of domestic production ceased use of HCFC-141b	1999

Potential emissions refer to the amount of substance that is contained within the foam when the appliance is retired. The qualifier 'potential' is used in recognition of the fact that the emissions might not arise immediately on disposal, but the substance will be released eventually to the atmosphere.

The estimates presented in Table 19 indicate that emissions from foam blowing are relatively trivial but that there is a substantial bank of CFC-11 contained in foam that will result in emissions at some future time. Compared with the emissions of refrigerant gas, the potential emissions are much larger.

Over the period from 1990 to 2020, the disposal of domestic refrigerators will make available a total of approximately 7245 tonnes of CFC-11 to be released to the atmosphere. By contrast, over the same period, leakage and disposal emissions of CFC-12 from domestic refrigerators are estimated to total around 1330 tonnes.

The potential for emissions of HCFC-141b is substantially less than for CFC-11. Total potential emissions from 1992 to 2020 of HCFC-141b contained in foam is estimated at about 1970 tonnes. The lower estimate reflects the that HCFC-141b is assumed to have been used from 1992 to 1995 for all imports and domestic production, and until 1999 for 30% of domestic production.

Year	CFC	CFC-11 emissions (tonnes)			HCFC-141b emissions (tonnes)		
	Blowing	Disposal (P)	Total	Blowing	Disposal (P)	Total	
1990	13.8	290.1	303.9	0.0	0.0	0.0	
1991	13.1	298.5	311.6	0.0	0.0	0.0	
1992	0.0	304.8	304.8	11.9	0.0	11.9	
1993	0.0	314.7	314.7	12.6	0.0	12.6	
1994	0.0	322.8	322.8	14.7	0.0	14.7	
1995	0.0	331.1	331.1	4.9	0.0	4.9	
1996	0.0	340.4	340.4	5.0	0.0	5.0	
1997	0.0	348.8	348.8	4.8	22.4	27.1	
1998	0.0	358.9	358.9	4.8	45.5	50.4	
1999	0.0	371.0	371.0	4.9	72.3	77.2	
2000	0.0	358.2	358.2	0.0	77.2	77.2	
2005	0.0	284.4	284.4	0.0	96.7	96.7	
2010	0.0	199.3	199.3	0.0	96.7	96.7	
2015	0.0	94.6	64.6	0.0	96.7	96.7	
2020	0.0	0.0	0.0	0.0	14.5	14.5	

Table 19. Actual and potential emissions of CFC-11 and HCFC-141b from foams used in domestic refrigeration



Figure 2. Actual and potential emissions of CFC-11 and HCFC-141b from domestic refrigerator insulation

5.2 CONCLUSION

Domestic refrigeration is a relatively minor source of emissions of ozone depleting substances and synthetic greenhouse gases. Most emissions from this source arise on disposal of equipment. Where ozone depleting substances or synthetic greenhouse gases are used in foam blowing, the insulation contains a large stock of substance that will be emitted after disposal. The quantity of gas available from foam is far in excess of that available from compressors. Measures to reduce direct emissions from this source will need to focus on recovery and recycling of refrigerant gas on equipment disposal, and destruction of gas contained in the insulation.

6 MOTOR VEHICLE AIRCONDITIONING

There are four manufacturers of motor vehicles in Australia – Ford, Toyota, General Motors Holden, and Mitsubishi. Ford, Toyota and General Motors have plants in Victoria, and Mitsubishi and General Motors operate plants in South Australia. A fifth manufacturer, Nissan Australia, operated in Victoria in 1990 but this plant has since closed.

Airconditioning units used in motor vehicles produced in Australia are charged in Australia. The units are imported. Up to 1994, units were charged with the ozone depleting substance CFC-12, and since 1995 the synthetic greenhouse gas HFC-134a has been used. Retrofits of older vehicles use HFC-134a and, less commonly, FR-12 (R-416A), a blend of HCFC-124 (59%), HFC-134a (39.5%) and butane (1.5%).

Emissions from motor vehicle airconditioning arise from charging of units, leakage, losses on servicing, and losses on disposal. Servicing losses include losses from venting or purging the system, and from recharging. Work practices have improved over the years where units are evacuated and the residual gas is recovered but it is likely that the practice of venting residual charges continues, especially with newer units using HFC-134a. Scarcity of CFC-12 is likely to be an important factor in more responsible management of residual gas contained in CFC units that remain in service. Unlike domestic refrigerators, motor vehicle air conditioning is serviced frequently during the vehicle lifetime, consequently emissions from recharging and the fate of residual gas are potentially important issues to be accounted for in emissions modelling.

6.1 MODELLING EMISSIONS

Modelling emissions from motor vehicle airconditioning requires information on:

- production
- motor vehicle population classified by age
- proportion of vehicles in each age class with airconditioning
- charge of airconditioning units
- loss on charging
- leakage rate
- loss on recharging
- average quantity purged (released) on recharging
- average quantity recovered on recharging
- average residual charge on retirement (or scrappage)
- number of vehicles retrofitted from CFC-12 to HFC-134a

The Australian Bureau of Statistics publishes data on motor vehicle production, the total population of registered vehicles in each census year, and time series data on the total motor vehicle population (ABS various years; 1997; 1999). Although publication of total population data is irregular, data have been published for 1998 and 1999. Each of these data sources can be used to estimate motor vehicle populations for the inventory years by age class.

Further details about data sources are listed in Table 20.

Table 20. D	ata and data	sources for	motor vehicles
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Data item	Data source
Production	ABS (various years) for 1965-66 to 1996-97;
	estimated for 1997-98 to 2019-2020
Motor vehicle population by age	ABS (1997; 1999) for census years 1971, 1976,
	1979, 1982, 1985, 1988, 1991, 1993, 1995, 1998
	and 1999; estimated for intervening years and
	for 2000 to 2020
Proportion of vehicles in each age class	Industry advice and assumption
with airconditioning	
Number of vehicles retrofitted from	Industry advice and assumption
CFC-12 to HFC-134a	
Characteristics (charge, losses on charging,	Assumption
leakage, recharging losses, etc)	

6.2 MOTOR VEHICLE PRODUCTION, MOTOR VEHICLES WITH AIRCONDITIONING AND THE NUMBER OF VEHICLES IN EACH AGE CLASS

Motor vehicle production in Australia has been relatively static since 1965–66 when 293660 passenger vehicles (cars and station wagons) were produced; some 304000 vehicles were produced in 1996–97. Production data are used to estimate the quantity of gas used in charging motor vehicle air conditioning units each year and the quantity lost on charging. It is assumed that the declining trend in domestic production over more than 30 years from 1965–66 will be maintained with local production contracting each year to 2020. Estimation of the annual change from 1965–66 to 1996–97 yields an annual reduction in production of 0.53% per year.

The number of registered motor vehicles in each census year and their year of manufacture (referred to as the age class or vintage) can be derived from census data. Import and production data are not required. This data set is important because there has been a substantial change in the proportion of new vehicles with airconditioning since the 1970s, when airconditioning was an expensive optional extra for the majority of motor vehicle purchasers. By the late 1990s airconditioning had become standard. It is assumed that all vehicles manufactured up to and including 1994 contained CFC-12, and all vehicles manufactured from 1995 contained HFC-134a.

Motor vehicle populations published by the Australian Bureau of Statistics for census years are classified in terms of age based on year of manufacture: from 0-years to 10-years, and vehicles older than 11-years are grouped. For example, the 1971 census data on vehicles in the 0-years category means that these vehicles were manufactured in 1971, 1-years category were manufactured in 1970, and those in the 11-years and over category were manufactured in 1960 or earlier. These data are used to derive the proportion of motor vehicles in each age class and the rate of change of the number of vehicles in each age class from census year to census year.

The method used to derive the number of vehicles for each age class uses data on total motor vehicles and is as follows. Starting in 1971, the annual change from 1971 to 1976 for each age class was estimated by a simple compound growth rate, g, that is:

 $g_0 = (S_{760}/S_{710})^{(1/5)} - 1$

where:

S₇₁₀ is the stock of vehicles of 0-years in 1971 S₇₆₀ is the stock of vehicles of 0-years in 1976 These estimates were used to determine the number of vehicles in each age class for intervening years. This enabled a data set to be constructed for every year from 1971 to 1998 with the total population classified into 12 categories from 0-years to 11-years and over. A more disaggregated age classification for 1999 was derived using a similar numerical solution using the more detailed data purchased from the Australian Bureau of Statistics. The objective was to develop a schedule of the proportion of vehicles in each year total for each age class. The final schedule from 1999 comprises 30 estimated proportions that are then applied to the estimated total vehicle populations from 2000 to 2020.

Table 21 shows the number of vehicles by age class based on year of manufacture from 1971 to 1976.

Year of		Es	timated numbe	er of vehicles		
manufacture	1971	1972	1973	1974	1975	1976
1976						406643
1975					399390	624826
1974				392266	603773	649872
1973			385269	583429	615939	593079
1972		378397	563770	583778	562397	507767
1971	371648	544774	553297	533301	488382	497582
1970 and earlier	4735192	4452412	4157964	3869290	3612153	3341688
Total	5106840	5375583	5660300	5962065	6282034	6621457

Table 21. Estimated age distribution of motor vehicles for 1971 (census) to 1976 (census)

Source: Estimated from Australian Bureau of Statistics Motor Vehicle Census data.

Estimating a schedule of proportions to determine the number of vehicles in each age class based on the census data generates results that appear inconsistent. Results for some age classes give a larger population in that age class several years after the original census when some retirements would be expected to have already taken place. In part, the result can be explained by the fact that all vehicles manufactured in a particular year are not purchased and registered in that year. There could be a two or three year lag between the year of manufacture and the year of first registration. Some volatility in the numbers across initial overlapping years would be expected where, for example, the population of vehicles manufactured in 1996 on the register in 1999 could be larger than for 1998, 1997 and 1996. The issue is whether some level of inconsistency can be tolerated. Provided the age pattern is a reasonable approximation derived from the available data, the profile can be considered acceptable. Further refinement of the data to eliminate the inconsistencies was not considered justifiable in that manipulation of the data was unlikely to provide further information. Total emissions will not vary but the time profile of emissions will change slightly with different age profiles.

The final step in determining the schedule of age class proportions was to terminate the schedule at 30 years and older. Vehicles that are 30 years and older, in some cases much older, clearly form a part of the total registered population. The full age class schedule applied to estimates of the passenger motor vehicle population is shown in Table 22.

Age class	ge class Proportion of total in		Proportion of total in
(years)	each age class	(years)	each age class
0	0.05	15	0.04
1	0.07	16	0.03
2	0.06	17	0.03
3	0.05	18	0.03
4	0.05	19	0.02
5	0.05	20	0.02
6	0.05	21	0.02
7	0.04	22	0.01
8	0.04	23	0.01
9	0.05	24	0.01
10	0.05	25	0.01
11	0.04	26	0.01
12	0.03	27	0.00
13	0.04	28	0.01
14	0.05	29	0.02

Table 22. Age class schedule applied to the motor vehicle population

Source: Estimated from Australian Bureau of Statistics Motor Vehicle Census data.

The next step is to estimate the proportion of the motor vehicle population with airconditioning. This is achieved through making assumptions on the proportion of vehicles for each age class that are airconditioned. The proportions for passenger motor vehicles are shown in Table 23. The estimated proportion of the total motor vehicle population with airconditioning is shown in Figure 3.

with airconditioning	Table 23. Assumed proportion of vehicles manufactured
	with airconditioning

Year	Proportion of new vehicles
	with airconditioning
1998 to 2020	1
1997	0.95
1996	0.95
1995	0.95
1994	0.95
1993	0.95
1992	0.92
1991	0.9
1990	0.9
1989	0.85
1988	0.8
1987	0.75
1986	0.7
1985	0.65
1984	0.6
1983	0.55
1982	0.55
1981	0.5
1980	0.5
1979 and earlier	0.15

Source: Assumptions and advice

For example, it is assumed that all vehicles in the population manufactured in 1998 or later are airconditioned, and that 15% of all vehicles in the population that is manufactured in 1979 or earlier are airconditioned. Assumptions on the proportion of vehicles manufactured with airconditioning at particular times are essential to enable the motor vehicle population with CFC-12, and the population with HFC-134a to be estimated for all relevant years.



Figure 3. Estimated proportion of the total motor vehicle population with airconditioning

Many vehicles with CFC-12 systems were retrofitted to HFC-134a systems and this information is used to determine the overall population of vehicles with HFC-134a systems for each relevant year. Unavoidable complexity is introduced to the model by the fact that some systems were retrofitted because this needs to be accounted for in retirements or scrappage of vehicles. In order to simplify, it is assumed that retirements of the original CFC vintages are from vehicles that have not been retrofitted.

It is assumed that in 1996, 1% of the CFC-12 vehicle population were retrofitted, 5% were retrofitted in 1997, and 10% in 1998, 1999 and 2000. Further, it is assumed that this rate of retrofits continues until 2004 when CFC-12 systems will be 10 or more years old. Additional retrofits from 2005 are assumed to be negligible as the age of the population increases. Adjustment of the HFC-134a population is required to account for the retrofitted vehicles being scrapped. The populations are shown in Figure 4.

All CFC vintages are estimated to be scrapped in 2009 (it is likely that this will occur earlier due to shortages of CFC-12). The sharp growth in the HFC population shown in Figure 4 is due to retrofitting of CFC vintages up to 2004 and growth in the proportion of the vehicle population with airconditioning. Growth in the number of HFC vehicles will level out beyond 2020. Retrofitted CFC-12 vehicles are estimated to be retired from the population by 2018.



6.3 ESTIMATING EMISSIONS FROM MOTOR VEHICLES

6.3.1 Passenger motor vehicles

The variables that have been discussed are combined with estimates of several other key variables to derive emissions from passenger motor vehicles. Values assigned to the additional variables are shown in Table 24.

An important issue to be considered is the status of airconditioning systems when vehicles are retired, whether prematurely as a result of an accident, or at the end of the vehicle's useful life. It is conjectured that most vehicles when they are scrapped do not have functioning airconditioning systems. Servicing of airconditioners is a cost that owners are likely to avoid as the vehicle becomes older. The issue is the age at which airconditioner servicing becomes a foregone optional extra and the vehicle is used without a working airconditioner.

The phase-out of CFC-12 has made it more likely that as these vintages age many vehicles will have airconditioners that do not work because of the scarcity of CFC-12 and the reluctance of owners to spend money on a retrofit. This means that the majority of the charge leaks from the system over the following years and a negligible residual charge only remains when the vehicle is scrapped. Disposal emissions are reduced to zero by this assumption, and emissions later in the life of vehicles also decline in that all refrigerant charge is spent by the time the vehicle is more than 15 years old. Despite these attributes of the market, the average emission factors discussed below are applied to the total population of airconditioned vehicles irrespective of age.

The analysis can be simplified if the total emissions from a representative vehicle are averaged over the assumed life of the vehicle. Estimating emissions relies on factors derived from Baker (1999), which assumes that the average lifetime is 12 years, and for current practices:

• without recycling and recovery at scrap, average emissions per year based on an initial charge of 0.91 kilograms are 0.266 kilograms or 29.2% of the system charge

with recycling and recovery at scrap, average emissions per year are 0.115 kilograms or 12.6% of the original charge.

Future emission parameters estimated by Baker (1999) to apply from approximately 2005 are:

- without recycling and recovery at scrap, average emissions per year based on an initial charge of 0.80 kilograms are 0.15 kilograms or 18.8% of the system charge
- with recycling and recovery at scrap, average emissions per year are 0.071 kilograms or 8.9% of the original charge.

The assumptions are shown in Table 24.

	0
Item	Value and source
Charge per unit	1000 grams for CFC-12; 850 grams for HFC-134a (± 50 grams)
	(advice)
Charging (assembly) losses	5% (assumption)
Average emissions per year	30, 35 and 40% CFC-12
	12.6% to 29.2% of HFC-134a charge depending on whether there is
	recycling and recovery. Assumed 40% recovery and 60% no
	recovery from 1995 to 2000. Also assumed that recovery increases
	by 1% per year from 2000
Disposal emissions	Nil-encompassed by assumptions on average emissions per year
Airconditioner operational	12 years (assumption)
life	
Vehicle operational life	Up to 30 years with residual of much older vehicles (assumption)

Table 24. Motor vehicle airconditioning assumptions

The assumed rates of recovery for HFC-134a take into account that despite Codes of Practice that were effective in minimising emissions of CFCs, it is understood that many of these sound management practices are not necessarily being adhered to when HFC-134a systems are serviced. Emissions estimates for CFC-12 are shown Table 25 and baseline estimates for HFC-134a are shown in Table 26.

The data in Table 25 show that estimated emissions of CFC-12 peaked in 1995 in the range 1329 tonnes to 2126 tonnes, depending on whether emissions are subject to conservation practices or whether they are taken to be at the maximum.

It is much more likely that the emissions tend towards the conservation estimate as increasing scarcity along with management practices when systems are serviced promote careful handling of CFC-12. It is estimated that over the period from 2001 to 2009, the year when it is projected that CFC-12 systems will all be scrapped, aggregate emissions of CFC-12 will be 2058 tonnes.

Emissions of HFC-134a from motor vehicle airconditioning are estimated to increase from 43 gigagrams of CO₂-e in 1995, to 1194 gigagrams in 2000, and to 2931 gigagrams in 2010. That is emissions from this source are projected to grow by a factor of 66.6 from 1995 to 2010. In the context of industrial process emissions, the contribution of motor airconditioning emissions increases these emissions in 1999 by around 10% (9.8 megatonnes of CO₂-e compared with 10.8 megatonnes including motor vehicle airconditioning). This is a significant additional source of emissions that has so far not been accounted for in Australia's National Greenhouse Gas Inventory.

Year	Population of vehicles	Annual emissions (tonnes) based on		Emissions (tonnes)	
	using CFC-12	average emi	ssion factors (A	AEFs) shown:	(AEF falls from 30% to 15%)
		30%	35%	40 %	Conservation
1990	3594959	1078	1258	1438	1078
1991	3993641	1198	1398	1597	1158
1992	4344842	1303	1521	1738	1217
1993	4719854	1416	1652	1888	1274
1994	5104705	1531	1787	2042	1327
1995	5315841	1595	1861	2126	1329
1996	5161701	1549	1807	2065	1239
1997	4718314	1415	1651	1887	1085
1998	4036700	1211	1413	1615	888
1999	3411457	1023	1194	1365	716
2000	2977640	893	1042	1191	596
2001	2610331	783	914	1044	496
2002	2271352	681	795	909	409
2003	1971192	591	690	788	335
2004	1498805	450	525	600	240
2005	1223507	367	428	489	184
2006	1003340	301	351	401	151
2007	843877	253	295	338	127
2008	606862	182	212	243	91
2009	175287	53	61	70	26

Table 25. Estimated emissions of CFC-12 from passenger motor vehicle airconditioning

Source: Estimated

Table 26. Estimated emissions of HFC-134a from motor vehicle airconditioning

Year	Population of	Recycling/recovery	No recycling/recovery	Total	Total
	vehicles using	(% pop.)	(% pop.)	(tonnes)	(Gg CO ₂ -e)
	HFC-134a	AEF = 12.6 %	AEF = 29.2%		
1995	173582	40	60	33	43
1996	825904	40	60	158	206
1997	1669853	40	60	320	416
1998	2844624	40	60	545	709
1999	3845023	40	60	737	959
2000	4790924	40	60	919	1194
2005	9017085	45	55	1666	2165
2010	12690505	50	50	2254	2931
2015	15193202	55	45	2592	3369
2020	17909746	60	40	2929	3808

Notes: AEF = Average emission factors, derived from Baker (1999). Other data are estimated.

Some of the options for limiting emissions from motor vehicle airconditioning are relatively simple and do not require new technology. Emissions were estimated based on relatively conservative assumptions about the impact of two measures. These assumptions were:

- average charge per unit falls from 0.85 kilograms to 0.75 kilograms from 2005
- recycling and recovery for new vehicles is assumed to be 90% from 2005, and older vehicles recycling and recovery increases from 40% in 1990 to 76% in 2020
- average emission factors for recycling and recovery fall from 12.6% to 8.9%, and from 29.2% to 18.8% without recovery and recycling for new vehicles entering the population from 2005.

The estimates are shown in Table 27.

_			
Year	Total (tonnes)	Total (Gg CO ₂ -e)	Reduction from basecase
1995	33	43	0%
1996	158	206	0%
1997	320	416	0%
1998	545	709	0%
1999	737	959	0%
2000	919	1194	0%
2005	1581	2056	5%
2010	1750	2275	22%
2015	1694	2202	35%
2020	1668	2168	43%

Table 27. Estimated emissions of HFC-134a from reduced average system charges in 2004 and increased recycling and recovery

Source: Estimated

Compared with the basecase, these relatively simple measures lead to a reduction in emissions in 2005 of 5% and a reduction in emissions in 2010 of 22%.

Note that these are reductions against the basecase and not reduction from the 1995 base year. Reducing emissions to the level of 1995 from this source would effectively require the use of HFC-134a to be eliminated. Recycling when the vehicle is serviced and recovery when vehicles are scrapped would in many cases restore the management practices that were adopted during the main period of the phase-out of CFCs. The impact of the measures is illustrated in Figure 5.

Figure 5. HFC-134a emissions from passenger motor vehicles with and without measures (Gg CO₂-e)





Rigid trucks

Rigid trucks are assumed to use CFC-12 up to 1994 and HFC-134a from 1995 onwards. The population of rigid trucks in each age class is estimated using the same profile of age classes derived from the total

vehicle population shown in Table 22. This profile is also used for articulated trucks, buses and light commercial vehicles. Although this method is not precise, it is adequate and the resulting uncertainty is no greater than the uncertainty in the other parameters used in the model.

Age class disaggregation is used to construct airconditioned populations for each year and enables the fact that the proportion of vehicles with airconditioning manufactured in different years differ across the estimation period. Rigid trucks have the highest numbers of old vehicles of all of the vehicle types. It is recognised that the age class profile is dominated by passenger motor vehicles, and application to rigid trucks will overestimate the numbers with HFC-134a systems (new vehicles and retrofitted vehicles). Estimates are derived from 1990 onwards with an initial assumption about the proportion of the total population in 1990 (vehicles manufactured in 1990 or earlier) with airconditioning. The proportions used are shown in Table 28.

The following assumptions are made:

- from 2009 all CFC-12 systems are spent (either empty or vehicles have been retired)
- the average charge for CFC-12 systems is 1.5 kilograms and for HFC-134a systems it is 1.2 kilograms
- average lifecycle emissions expressed as an average per year range from 30% to 40% for CFC-12 systems
- average lifecycle emissions expressed as an average per year range from 15% to 25% for HFC-134a systems.

Year	Proportion	Year	Proportion
of trucks			of trucks
2020	0.85	2005	0.4
2019	0.8	2004	0.4
2018	0.75	2003	0.4
2017	0.7	2002	0.4
2016	0.65	2001	0.35
2015	0.6	2000	0.35
2014	0.6	1999	0.35
2013	0.55	1998	0.3
2012	0.55	1997	0.3
2011	0.5	1996	0.3
2010	0.5	1995	0.3
2009	0.45	1994	0.25
2008	0.45	1993	0.25
2007	0.45	1992	0.25
2006	0.45	1991	0.25
		1990	0.1

Table 28. Assumed proportion of new rigid trucksmanufactured with airconditioning

Source: Assumptions and advice

The assumptions in respect of average emission factors for HFC-134a emissions from rigid trucks differ from those made for passenger motor vehicles in that the range is not as wide and the lower and upper limits are higher and lower respectively. The limits for passenger motor vehicles were derived from information in Baker (1999).

In this case assumptions have been made that are considered reasonable given that many rigid and articulated trucks (and buses) are part of fleets that are serviced and maintained within company workshops. It is conjectured that this results in better servicing practices for a proportion of the fleet and this gives a lower average factor at the upper limit. The emissions are shown in Table 29.

Year		CFC-12			HFC-134a	
	(average emission factors as shown)			(average emission factors as sho		
	30%	35%	40%	15%	20%	25%
1990	15	17	20			
1991	16	18	21			
1992	17	20	23			
1993	18	21	24			
1994	20	23	26			
1995	20	23	27	0	1	1
1996	19	22	25	2	2	3
1997	17	20	22	3	4	6
1998	15	17	20	5	7	8
1999	13	15	17	6	9	11
2000	12	13	15	8	11	13
2005	4	5	6	15	21	26
2010				22	30	37
2015				28	38	47
2020				36	48	61

Table 29. Estimated emissions per year from rigid trucks (tonnes) – basecase

The higher lower limit attempts to reflect the fact that there would be significant variability across the fleet in terms of recycling and recovery practices. Even where vehicles are maintained in company workshops, it is possible that recycling and recovery of HFC-134a would not be standard practice. The same assumptions on factors and rationale is applicable to articulated trucks, and buses.

Note that it is not plausible for any estimate of emissions to significantly exceed the estimated bank in the initial year because the only sources are residual stocks and recycled and recovered substances. Assuming that there are no supplementary supplies available from other sources, the estimates indicate that a total of 38 to 51 tonnes of CFC-12 will be emitted from 2000 to 2009. This is the bank of gas contained in vehicles in 2000.

After 2009 it is expected that there will be no further emissions of CFC-12 and it is highly probable that emissions will be exhausted earlier than this time due to CFC-12 becoming more and more scarce. A consequence of this is that recycling and recovery practices will need to be meticulously pursued to ensure future availability of CFC-12. This will effectively further reduce emissions at each time period and that average emission factors are likely to decline as the CFC-12 systems approach the end of the assumed life.

Another consideration is that higher leakage rates will result in a more rapid exhaustion of the supplies of CFC-12. Nonetheless, CFC-12 does not 'wear out' and it will either be emitted or recovered for destruction. Recycled and recovered gas that is used in airconditioning systems eventually will be emitted.

Rigid trucks are a relatively minor source of HFC-134a emissions, increasing from 11 tonnes (14.3 gigagrams CO_2 -e) in 2000 (average emission factor = 20%), to 30 tonnes in 2010 (39 gigagrams CO_2 -e).

Articulated trucks

Emissions estimates for articulated trucks are the same as used for rigid trucks (see page 42), with ageclasses as shown in Table 30.

	5	0	
Year	Proportion of trucks	Year	Proportion of trucks
2020	1	2005	0.85
2019	1	2004	0.8
2018	1	2003	0.8
2017	1	2002	0.8
2016	1	2001	0.75
2015	1	2000	0.75
2014	1	1999	0.7
2013	1	1998	0.65
2012	1	1997	0.65
2011	0.95	1996	0.65
2010	0.95	1995	0.65
2009	0.9	1994	0.6
2008	0.9	1993	0.6
2007	0.85	1992	0.6
2006	0.85	1991	0.6
		1990 and earlier	0.6

Table 30. Assumed proportion of articulated trucksmanufactured with airconditioning

Source: Assumptions and advice

The estimates suggest that the entire bank in 2000, some 29 to 38 tonnes of CFC-12, will be emitted from 2000 to 2009. In 2000, five tonnes of HFC-134a (6.5 gigagrams CO_2 -e at an average emission factor of 20%) are estimated to be emitted from articulated trucks increasing to 14 tonnes (18.2 gigagrams CO_2 -e) in 2010.

Year		CFC-12			HFC-134a	
	(average emission factors as shown)			(average en	rs as shown)	
	30%	35%	40%	15%	20%	25%
1990	14	16	18			
1991	14	16	19			
1992	14	16	19			
1993	14	17	19			
1994	15	17	20			
1995	15	18	21	0	0	0
1996	14	17	19	1	1	1
1997	13	15	17	1	2	2
1998	12	14	15	2	3	4
1999	10	12	14	3	4	5
2000	9	10	12	4	5	6
2005	3	3	4	7	10	12
2010				10	14	17
2015				12	16	20
2020				14	19	23

Table 31. Estimated emissions per year from articulated trucks (tonnes)

Buses

The assumed age distribution of the population is shown in Table 32.

Year	Proportion of buses	Year	Proportion of buses
2020	1	2005	0.6
2019	1	2004	0.6
2018	1	2003	0.6
2017	1	2002	0.6
2016	1	2001	0.55
2015	0.95	2000	0.55
2014	0.9	1999	0.55
2013	0.85	1998	0.55
2012	0.8	1997	0.55
2011	0.75	1996	0.5
2010	0.7	1995	0.5
2009	0.7	1994	0.5
2008	0.65	1993	0.45
2007	0.65	1992	0.6
2006	0.65	1991	0.6
		1990 and earlier	0.6

Table 32. Assumed proportion of new buses manufactured with airconditioning

Source: Assumptions and advice

Emissions estimates for buses are based on the following assumptions:

- from 2009 all CFC-12 systems are spent (either empty or vehicles have been retired)
- the average charge for CFC-12 systems is 12 kilograms and for HFC-134a systems it is 7.5 kilograms
- average lifecycle emissions expressed as an average per year range from 30% to 40% for CFC-12 systems
- average lifecycle emissions expressed as an average per year range from 15% to 25% for HFC-134a systems.

It is estimated that 179 to 224 tonnes of CFC-12 (the bank in 2000) will be emitted from buses from 2000 to 2009. As with rigid trucks and articulated trucks, more stringent recycling and recovery practices will need to be adopted to prolong the life of CFC-12 systems. It is highly probable that all systems will be retired earlier than 2009.

The estimates show that buses are a rapidly growing source of HFC-134a emissions. Emissions in 2000 are estimated to be 27 tonnes (35.1 gigagrams CO₂-e) and 102 tonnes (132.6 gigagrams CO₂-e) in 2010. This growth results from a projected large increase in the population of buses, with a growth rate of around 6% per year derived from the trend in the bus population during the 1990s. An initial impression of this growth rate is that it is very high and unlikely to be achieved. Pressures to encourage greater use of public transport and ease pollution and congestion problems in the large metropolitan areas suggest that the growth rate is at least plausible.

Year		CFC-12			HFC-134a	
	(average emission factors as shown)			(average emission factors as shown)		
	30%	35%	40%	15%	20%	25%
1990	64	75	86			
1991	68	80	91			
1992	72	84	96			
1993	76	88	101			
1994	80	93	107			
1995	83	97	110	1	1	1
1996	86	100	114	3	4	5
1997	79	92	105	7	9	12
1998	72	83	95	11	15	18
1999	61	71	81	16	21	26
2000	54	63	72	21	27	34
2005	27	32	36	45	60	75
2010				76	102	127
2015				119	159	198
2020				189	252	315

Table 33. Estimated emissions per year from buses (tonnes)

Light commercial vehicles

Emissions estimates for light commercial vehicles are based on the following assumptions:

- from 2009 all CFC-12 systems are spent (either empty or vehicles have been retired)
- the average charge for CFC-12 systems is 1kg and for HFC-134a systems it is 0.85 kilograms
- average lifecycle emissions expressed as an average per year range from 30% to 40% for CFC-12 systems
- average annual lifecycle emissions range from 15% to 25% for HFC-134a systems.

Light commercial vehicles are assumed to have the same age profile as passenger motor vehicles and the same proportion of vehicles in each class with airconditioning (Table 34).

It is estimated that 424 to 509 tonnes of CFC-12 (the bank in 2000) will be emitted from light commercial vehicles from 2000 to 2009 (Table 35). Strict recycling and recovery practices will need to be implemented to ensure availability up to 2009 when all systems are assumed to be retired.

Emissions of HFC-134a are projected to increase from 134 tonnes (174.2 gigagrams CO₂-e) in 2000 to 338 tonnes (439.4 gigagrams CO₂-e) in 2010.

Year	Proportion of	Year	Proportion
	LCVs		of LCVs
2020	1	2005	1
2019	1	2004	1
2018	1	2003	1
2017	1	2002	1
2016	1	2001	1
2015	1	2000	1
2014	1	1999	1
2013	1	1998	1
2012	1	1997	0.95
2011	1	1996	0.95
2010	1	1995	0.95
2009	1	1994	0.95
2008	1	1993	0.95
2007	1	1992	0.92
2006	1	1991	0.9
		1990 and earlier	0.4

Table 34. Assumed proportion of new light commercial vehicles(LCV) manufactured with airconditioning

Source: Assumptions and advice

Table 35. Estimated emissions per year from light commercial vehicles (tonnes)

Year		CFC-12			HFC-134a	
	(average emission factors as shown)			(average emission factors as shown)		
	30%	35%	40 %	15%	20%	25 %
1990	174	203	231			
1991	185	215	246			
1992	195	228	260			
1993	204	238	272			
1994	225	262	299			
1995	234	273	312	4	5	7
1996	228	265	303	19	25	31
1997	206	240	275	36	48	61
1998	177	206	235	60	81	101
1999	149	173	198	81	108	135
2000	127	148	170	100	134	167
2005	51	60	68	182	243	304
2010				254	338	423
2015				291	387	484
2020				331	441	551

6.3.3 Total HFC-134a emissions from passenger motor vehicles, trucks, buses and light commercial vehicles

Total HFC-134a emissions from trucks, buses and light commercial vehicles are shown in Table 36. Based on an average emission factor of 20%, these vehicles are projected to produce 228 gigagrams of CO_2 -e emissions in 2000, which will increase to 623 gigagrams of CO_2 -e emissions in 2010.

Measures that reduce the average emission factors are likely to be better accepted if they target good management practices related to recycling and recovery, rather than targeting price or availability. It is assumed that better practices and improved sealing of systems results in the average emission factor

declining from 20% in 2001 to 9% in 2007, and remaining at this level to 2020. The values of 20% to 9% were chosen based on the average values for passenger vehicles derived from Baker (1999). The results in Table 36 show that this would result in emissions in 2010 of 280 gigagrams of CO_2 -e compared with 623 gigagrams of CO_2 -e, a reduction of 55%.

Year	Basecas	e emissions (C	Gg CO ₂ -e)	Emissions with	% reduction on
	Average	emission fact	ors (AEFs)	measures (Gg CO ₂ -e)	20% basecase
1005	1370	2070	2370	2070 Dasecase ALL	(0g CO2-e)
1995	7	9	11	9	0
1996	31	42	52	42	0
1997	62	82	103	82	0
1998	101	135	169	135	0
1999	137	183	229	183	0
2000	171	228	285	228	0
2001	202	269	337	269	0
2002	233	310	388	279	10
2003	262	349	437	280	20
2004	294	392	491	275	30
2005	322	430	537	258	40
2010	467	623	779	280	55
2015	580	773	967	348	55
2020	735	980	1226	441	55

Table 36. Total HFC-134a emissions from trucks, buses and LCVs - with and without measures

Estimates for all motor vehicle emissions are shown in Table 37 and Figure 6, both without and with measures. It is clear that the relatively simple measures assumed in the earlier discussion leads to a significant decline in aggregate emissions over the basecase. For example, by 2005 emissions are 12% less than they would otherwise have been and by 2010 they are 39% less.

Year	Basecase (without measures) (Gg CO2-e emissions)	With measures (Gg CO ₂ -e emissions)
1995	52	52
1996	248	248
1997	499	499
1998	846	846
1999	1143	1143
2000	1424	1424
2005	2598	2316
2010	3559	2558
2015	4149	2552
2020	4795	2613

Table 37. Total emissions from all motor vehicles – without and with measures



Figure 6. Total HFC-134a emissions from all motor vehicles, with and without measures (Gg CO₂-e)

6.4 CONCLUSION

Motor vehicle airconditioning is the most significant actual and potential source of emissions of synthetic greenhouse gases. This compares with estimates for countries and regions, such as the United Kingdom and Europe (DETR 1999; March Consulting Group 1998) where commercial refrigeration is the largest potential source of emissions, and emissions from motor vehicle airconditioning are second largest. Differences in climate mean that a much larger proportion of the motor vehicle population in Australia is airconditioned compared with Europe.

The estimates indicate that in 1999, motor vehicles contributed approximately 1.1 megatonnes of CO₂-e emissions. This is projected to increase to 2.6 megatonnes in 2005 and 3.6 megatonnes in 2010. Motor vehicle airconditioning is the fourth largest source of greenhouse gas emissions in the Australian industrial processes sector. Measures to control or limit emissions are essential to ensure that growth in Australia's greenhouse gas emissions remain within a reasonable targeted range, whether that is the current Kyoto target or a revised target that is agreed to in any future negotiations. Problems that might exist with ratification of the Kyoto Protocol should not be seen as a signal to increase emissions where sensible environmental management policies that will restrain emissions growth can be implemented.

The emission estimates are based on assumptions about average emission factors. These were supplemented by information from individuals that recovery and recycling practices implemented during the phase-out of ozone depleting substances are no longer strictly observed when HFC-134a systems are serviced.

It is recommended that Standards and Codes of Practice that applied during the phase-out of ozone depleting substances be reinforced, with the possibility of legislative backing. Motor vehicle manufacturers should be encouraged to continually improve fittings that minimise leakage from systems. A requirement to report annual use along with the quantity contained in charged imported equipment and system characteristics (losses on charging and leakage rates) is an essential component of any program to monitor, estimate, and limit emissions. The marginal cost of reporting would be trivial given that the information sought should be readily available to manufacturers. Reporting by major vehicle importers should also be required.

7 DOMESTIC AND COMMERCIAL AIRCONDITIONING

Domestic and commercial airconditioning is a significant area of use of ozone depleting substances with the potential to become a substantial user of synthetic greenhouse gases. Prior to the phase-out of ozone depleting substances, CFC-11 and CFC-12 were commonly used in large commercial airconditioning installations. Domestic airconditioning uses HCFC-22 and it was the development of this substance that facilitated the development of small scale efficient airconditioning units suitable for residential applications. Australia due to its relative affluence is a substantial market for airconditioning in the Asia-Pacific.

There are several large residential airconditioning suppliers in Australia such as Emailair, National Panasonic, Daikin, Trane, Carrier, York International, Fujitsu, and Mitsubishi. Several of these companies had manufacturing operations in Australia but these have now closed. Email was the last manufacturer of domestic equipment to cease operation, closing in 1999. Other manufacturers produced packaged commercial equipment. York International was the last of the large producers to cease manufacture closing its operation in late 2000. A subsidiary of Carrier, APAC, manufactures commercial units in Western Australia estimated to be around 35000 units per year.

Information on airconditioning was sought from industry. A selection of companies were contacted by telephone and an explanation of the project was provided. Further explanatory material was forwarded by e-mail to each company. The following information was requested:

- the charge size of units and any changes in charge sizes over time from 1990 to the present
- the timing of any changes in gases used; for example, when use of HCFC 22 commenced and the proportion of units that were affected by the change
- an indication of the average charge per unit from 1976
- whether units are charged in Australia and estimated losses on charging (%)
- leakage rates of units in-service (%)
- recovery practices when units reach the end of their useful life
- the quantity of gases held in stock for servicing equipment
- the estimated size of the market for various systems
- any time series data on the number of units that are imported fully charged. There are import data on compressor imports and an appropriate classification for average charge sizes could be based on compressor size (kilowatts or Btu). Any comments would be appreciated.

In addition the industry's views on future developments in compressors, charge sizes and the use of HFCs and substances other than HFCs were sought. The importance of understanding the impact of changes on the economics of the domestic industry was emphasised.

No response to the request for information was received. Advice was provided that data on the number of units sold each year were collected on behalf of the industry by a private company and that these data had been provided for the compilation of a regulatory impact statement for the Australian Greenhouse Office. These data were requested but difficulties were encountered by the industry as a group in obtaining agreement to its provision.

7.1 TYPES OF AIRCONDITIONER

Airconditioners fall into four broad categories:

- room airconditioners
- duct-free packaged and split systems
- ducted systems
- single packaged units or large capacity split systems intended primarily for commercial use (UNEPc 1998; p. 136).

Room airconditioners are small airconditioning units suitable for comfort cooling of a single room or enclosed small commercial space. They comprise portable units that can be moved from room to room or fixed units that can be mounted in a wall or window. Units are fully self-contained with the fan coil, compressor, and condenser integrated into a single unit of equipment. These units are commonly referred to as window/wall units, a classification adopted by the Australian Customs Service and Australian Bureau of Statistics when reporting data on imports of airconditioners. Room airconditioners are the most common residential comfort cooling units and units for small commercial spaces, although in recent years changes have been taking place with duct-free systems becoming more popular in the residential market.

7.2 DATA ON AIRCONDITIONERS

A deficiency of data on airconditioners, including their characteristics (average charges, leakage rates, disposal losses, etc.), is a substantial impediment to a detailed analysis of airconditioners. Import data were purchased from the Australian Bureau of Statistics but these are problematic because of a substantial volatility in imports. This is not unexpected because airconditioner demand is closely linked to variations in climatic conditions. An unusually hot summer will result in a surge in demand for airconditioners, whereas more mild conditions will lead to sales remaining relatively flat. In the absence of climate-induced surges in demand, domestic airconditioners have been seen as a luxury rather than as a necessity (for example, compared with domestic refrigeration). This market characteristic appears to be changing if the import data are accepted as a reliable indicator.

From 1989 to 1999, the Australian Bureau of Statistics data show that imports have more than trebled (Figure 7). Imports exhibited strong growth until 1997, and surged in 1998 and 1999. The highest volume import categories from the Australian Bureau of Statistics data are self-contained window/wall units and reverse cycle units excluding window/wall units (Figure 8). Different views were expressed as to whether the import data were reliable. There was some suggestion that recording of data failed to distinguish between complete airconditioning units and parts, thereby inflating the import data. In an informal discussion with an industry participant the view was expressed that the spectacular growth was consistent with the experience in the market in which the company operates.

The Australian Bureau of Statistics categories in summary form are:

- window/wall not exceeding 3.0 kilowatts
- window/wall exceeding 3.0kilowatts but not exceeding 4.0 kilowatts
- window/wall exceeding 4.0 kilowatts but not exceeding 5.0 kilowatts
- window/wall exceeding 5.0 kilowatts
- reverse cycle machine with refrigerating unit



Figure 7. Total imports of airconditioners from 1989 to 1999 (calendar years)

Source: Australian Bureau of Statistics Import Data



Figure 8. Total imports of each type of airconditioner from 1989 to 1999 (calendar years)

Source: Australian Bureau of Statistics Import Data

The 'Other' category shown in Figure 8 comprises airconditioners incorporating a refrigerating unit that are not included in the window/wall and reverse cycle categories. It is conjectured that these units are the larger machines and include chillers and rooftop units used in commercial buildings. These units were imported with a holding charge with the charging of the system undertaken in Australia either prior to installation (for larger commercial packaged systems) or at the time of installation (for chillers).

Examination of Figure 8 shows that although there has been growth in window/wall units, the spectacular growth has taken place in reverse cycle machines. In recent years there has been increased market penetration of small split systems at the expense of growth in the market for window/wall units. These split systems have separate indoor and outdoor components with the compressor located outdoors and a fan located indoors. Not all of these units are reverse cycle, and it is likely that the import data on reverse cycle machines includes all split systems (reverse cycle and cooling only). The number of imports of these machines has grown by a factor of ten since 1989. Although this is substantial, the developments in split systems leading to more compact units suitable for a single room and lower prices have combined to change market attitudes. Promotional literature from major airconditioning manufacturers now emphasise split systems for single rooms far more than window/wall units.

Import data are a small part only of the information required to analyse airconditioners. Production data were published by the Australian Bureau of Statistics until 1980–81. Data fragments were published in 1982–83 and no further production data have been published since that time. Sales data are not available either from the industry or Australian Bureau of Statistics publications. In 1999, the Australian Greenhouse Office published a report entitled Australian Residential Building Sector Greenhouse Gas Emissions 1999–2010 (AGO 1999). This report included data appendices that, amongst other things, can be used to derive the total domestic stocks of airconditioners. Energy Efficient Strategies provided updated data on these stocks. The classification of airconditioners in the report is:

- evaporative
- central—reverse cycle
- central cooling only
- non-ducted reverse cycle
- non-ducted cooling only.

Evaporative units do not contain or use refrigerant and are not relevant to this study. The remaining categories of systems that do use refrigerant are very broad, which makes it difficult to determine appropriate average charges and leakage rates.

Window/wall systems are a single box type unit without any piping and are effectively sealed systems. Leakage rates are low with the majority of emissions arising on disposal.

Split systems, whether single room or ducted, have piping that connects the inside unit to the outside unit. Until recently, most of these units used flared joints that have higher leakage rates than completely sealed systems — leakages rates have been estimated to be 10 to 15% per year irrespective of the quality of the installation. Brazed or soldered joints are becoming more generally accepted and reduce leakage rates, but these are still higher than leakage rates from sealed systems. Some joint failures are inevitable and average leakage rates need to reflect this fact.

To make use of the only comprehensive data available, various assumptions need to be made about the composition of stocks and the impact of changes in market preferences of the residential sector from window/wall systems to split systems.

Assumptions made are as follows:

• Local production of window/wall units from 1989 to 1992 is as stated in GWA (1993 p.200); from 1993 to 1998 production is constant at 30000 units, and in 1999 production falls to zero when Emailair closed their production plant.
- Domestic sales are equal to imports plus local production with exports assumed to be zero.
- From 2000 to 2020, the window/wall market is held constant at the 1999 level of 232059 units.
- All market growth in the residential sector is met by split systems (non-ducted and ducted).
- Australian Bureau of Statistics data on reverse cycle imports are assumed to include all split systems (both reverse cycle cooling only and split ducted and non-ducted systems).
- The import data for 1998 and 1999 are not considered representative of long-term growth in the market. A growth rate for total demand was estimated omitting the values for 1998 and 1999. Volatility in demand even with 1998 and 1999 omitted yielded a growth rate of 6.49% with a standard error of 3.64%. A compound growth rate of 6.49% was applied to a three-year moving average of demand (equal to imports) for reverse cycle units. The three-year moving average was chosen to smooth the impact of climate-induced volatility in demand. These assumptions result in total demand in 1999 not being achieved again until 2007.
- Refrigerant per kilowatt of cooling capacity is 0.32 to 0.34 kilograms for split systems and 0.24 to 0.26 kilograms for window/wall units. The sales weighted capacity of systems from GWA (1993 p. 201) is 4.2 kilowatts for split systems and 3.5 kilowatts for window/wall units. This implies averages of 1.34 to 1.43 kilograms for split systems, and 0.84 to 0.91 kilograms for window/wall units. Window/wall units do not require the same quantity of refrigerant because they are self-contained sealed units without piping.
- The stock for 1990 is assumed to comprise 10% split systems and 90% window/wall units. This composition changes as sales of split systems increase and most retirements are assumed to be window/wall units.
- Average leakage rates for split systems take into account system failures where a unit loses all of its charge and venting of gas when units are serviced. That is, although the majority of units have low leakage rates, when a unit fails and loses all of the charge the average across all units is increased. The average leakage rate assumed is 20%. This implies that the each unit loses the equivalent of two complete charges over the average life.
- Average leakage rates for window/wall units are assumed to be 2% per year. Average loss on disposal is assumed to be around 80% taking into account the age profile of the units scrapped.
- Average system life is assumed to be 10 years; all units survive for one third of the average life and units are scrapped according to a linear retirement schedule each year after one third of the average life. The last units are scrapped after five thirds of the average life.
- The simplifying assumption is that the retirements each year are equal to 9.1% of the stock for that year. This is derived from an initial assumption that sales increase at 3% each year and retirements are according to the schedule described above; the result is that the ratio of retirements to stocks converges to 9.1% once all vintages are represented in the retirements.

The classifications adopted are gross and relatively crude. GWA (1993 p. 201) estimated that there were 283 different models of window/wall and split systems. Disaggregation to the level of models would be absurd and would further complicate the analysis without providing substantial additional information. There is a relationship between the power of units and the quantity of refrigerant contained in the units. This appears to be the most sensible method of classifying units but would require industry cooperation.

7.3 EMISSIONS FROM DOMESTIC AIRCONDITIONING

7.3.1 Substance bank and imports of HCFCs contained in equipment

Estimated stocks, sales and retirements are shown in Table 38. Stocks of domestic airconditioners are estimated to increase from 1 664 082 in 1990 to 6 571 637 in 2020.

Year		Stocks		Sales		Retireme	nts
	Total	Window/wall	Split	Window/wall	Split	Window/wall	Split
1990	1664082	1478556	185526	92800	31553	138728	15414
1991	1736334	1512232	224102	168224	55459	134549	16883
1992	1754374	1513365	241010	138746	37301	137613	20393
1993	1733475	1478437	255038	102789	35960	137716	21932
1994	1793165	1494005	299160	150105	67331	134538	23208
1995	1907666	1546321	361345	188271	89408	135954	27224
1996	1973543	1578562	394981	172956	66519	140715	32882
1997	2126500	1649812	476688	214899	117650	143649	35943
1998	2440970	1787065	653906	287386	220596	150133	43379
1999	2782780	1856501	926279	232059	331879	162623	59505
2000	2999478	1919618	1079860	232059	237872	168942	84291
2005	4090225	2158816	1931409	232059	320557	192888	161262
2010	4976213	2307264	2668948	232059	373396	207749	229808
2015	5778646	2399393	3379253	232059	437141	216972	294535
2020	6571637	2456569	4115068	232059	511994	222696	360704

Table 38. Estimated stocks, sales and retirements of domestic airconditioners from 1990–2020

The number of households in 2020 is estimated to be around 8.9 million. The associated growth in stocks would be achieved only if the market perception of airconditioners as a luxury good has changed or does change. As commented earlier, the evidence in recent years suggests that there has been a change in market perceptions. The estimate of stocks is substantially higher than in AGO (1999) because the sales during the late 1990s and estimated sales up to 2020 are larger than those that could be implied from the data in AGO (1999).

Bank and emission estimates were derived using the data in Table 38. The basecase is derived assuming:

- average system charge for window/wall units of 0.91 kilograms
- average system charge for split systems of 1.43 kilograms
- average leakage rate for window/wall units of 2% per annum
- average proportion of charge vented on retirement of window/wall units of 81%
- average leakage rate for split systems of 20% per year (encompasses any residual charge vented on servicing and retirement)
- all new units from 2004 use R-410A in place of HCFC-22. It is possible that some residential systems will use R-407C. This has a GWP of 1526 compared with 1725 for R-410A. There is a possibility that systems with secondary loops could be developed that use propane (HC-290). However, use of R-410A is considered the most likely prospect as noted by UNEP (1998c) and some units are already commercially available. If R-407C were to be adopted the projected CO₂-e emissions would be lower given the lower GWP of this substance.

An important caveat on the assumptions is that the leakage rate for split systems could be too high. As stated, the leakage rate encompasses substance that is vented when equipment is serviced or retired. If equipment has a 10-year life and is serviced once during that period and substance is vented both when the equipment is serviced and when it is retired, this implies an average annual lifetime emission factor (leakage) of 20%. The assumption means that the estimates do not reflect the time profile of emissions accurately. Comment and data from industry are required to decide whether and in what way this assumption should be modified.

Table 39 shows the estimated bank of substances contained in equipment. The bank of HCFC-22 is 3291 tonnes in 2000, 3402 tonnes in 2005, and 1030 tonnes in 2010. The bank peaks in 2004 at 4190 tonnes, and all HCFC-22 units are eliminated from 2014 with the last units retired in 2013. The bank of R-410A increases from 1324 tonnes in 2005 to 4886 tonnes in 2010 and 8120 tonnes in 2020.

Year		Stocks			Sales	
	Total	Window/wall	Split	Total	Window/wall	Split
1990	1611	1345	265			
1991	1697	1376	320			
1992	1722	1377	345			
1993	1710	1345	365			
1994	1787	1360	428			
1995	1924	1407	517			
1996	2001	1436	565			
1997	2183	1501	682			
1998	2561	1626	935			
1999	3014	1689	1325			
2000	3291	1747	1544			
2005	3402	1542	1860	1324	422	902
2010	1030	621	409	4886	1478	3408
2015				7016	2183	4832
2020				8120	2235	5885

Table 39. Estimated bank of substance contained in equipment

There is a substantial quantity of HCFC-22 imported contained in equipment. In 1990, around 104 tonnes of HCFC-22 were imported contained in equipment and this increased to 551 tonnes in 2000. Peak imports of HCFC-22 contained in equipment are estimated to have occurred in 1999 with the next highest volume of imports projected to occur in 2002 (Table 40). Expressed in terms of tonnes of ozone depleting potential (ODP tonnes), the quantity in imported equipment in 2002 is equivalent to 35.4 ODP tonnes which represents 18.6% of the HCFC industry limit specified in Column 3 of section 24 of the *Ozone Protection Act 1989*.

Table 40. Estimated quantity of substances contained in imported equipment

			•														
Year				1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
HCFC-22 (t	onnes)			104	184	139	118	206	272	225	336	550	686	551	612	643	628
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
R-410A	655	670	679	697	713	728	745	762	780	798	817	836	856	877	898	921	943
(tonnes)																	

From 2004 onwards all imported equipment is assumed to contain R-410A. This results in imports contained in equipment of 655 tonnes in 2004, which increases to 745 tonnes in 2010 and 943 tonnes in 2020 (Table 40). If the timing of R-410A displacing HCFC-22 is as assumed, the high level of imports contained in equipment will not pose a problem in the phase-out of HCFCs. At present, Australia does not control imports of equipment containing HCFCs nor is adequate data collected and reported that would give any indication of the extent of these imports.

7.3.2 Emissions

Table 41 shows estimated emissions of HCFC-22 and R-410A from 1990 to 2020, and the profile of emissions is illustrated in Figure 9.

Year	Emissions	(tonnes)	Year	Emissions (tonnes)			
	HCFC-22	R-410A		HCFC-22	R-410A		
1990	182		2005	545	189		
1991	191		2006	494	287		
1992	198		2007	438	388		
1993	201		2008	379	493		
1994	212		2009	315	600		
1995	232		2010	247	711		
1996	245		2011	176	826		
1997	272		2012	161	883		
1998	330		2013	36	1050		
1999	419		2014		1128		
2000	468		2015		1170		
2001	526		2016		1212		
2002	584		2017		1255		
2003	634		2018		1298		
2004	592	93	2019		1342		
			2020		1386		

Table 41. Estimated emissions of HCFC-22 and R-410A from 1990–2020

Figure 9. Time profile of emissions of HCFC-22 and R-410A



Emissions of HCFC-22 peak in 2003 at 634 tonnes (based on the assumption that all systems from 2004 onwards contain R-410A). Emissions of R-410A increase from 189 tonnes in 2005, to 711 tonnes in 2010, and to 1386 tonnes in 2020. From 2014 there are no further emissions of HCFC-22.

The profile of use of HCFC-22 and emissions is consistent with the phase-out schedule of HCFCs that Australia has adopted. This is an accidental but convenient outcome rather than a contrived result.

Table 42 shows the impact of assuming that the average annual emission factor for split systems falls with the introduction of R-410A from 20% to 15%.

Basecase emissions fall from 326 gigagrams CO_2 -e in 2005 to 248 gigagrams CO_2 -e. In 2010, basecase emissions are 1227 gigagrams CO_2 -e compared with 933 gigagrams CO_2 -e with an average emission factor of 15%.

Note that the average emission factor includes not only leakage but also emissions from servicing and disposal. Over a 10-year average life, a factor of 15% implies that approximately 1.5 full system charges will be lost to the atmosphere. Substantial reductions in emissions can be achieved through improved pipe fittings combined with the implementation of recovery and recycling practices. Only direct emissive applications, such as aerosols, are not amenable to better management practices.

Year	Year Emissions Gg CO ₂ -e		
	Basecase	Measure (split average leakage	(%)
		falls from 20% to 15%)	
2004	160	122	24
2005	326	248	24
2006	494	376	24
2007	669	509	24
2008	850	646	24
2009	1035	787	24
2010	1227	933	24
2011	1424	1083	24
2012	1522	1158	24
2013	1812	1430	21
2014	1946	1546	21
2015	2018	1602	21
2016	2091	1657	21
2017	2165	1713	21
2018	2239	1769	21
2019	2314	1825	21
2020	2390	1883	21

Table 42. Estimated impact of reduced average annual emission factor for split systems

7.4 COMMERCIAL AIRCONDITIONING

Commercial airconditioning comprises single packaged airconditioners and chillers. Packaged systems are mounted on the roof of individual offices, shops or restaurants or outside the structure on the ground. Multiple units containing one or more compressors are often used to cool entire low-rise shopping centres, schools, hospitals, exhibition halls or other large commercial structures. Other commercial unitary products include indoor packaged units as well as split systems with an outdoor compressor and heat exchanger unit connected by refrigerant piping to one or more indoor fan coils over which air passes to be cooled or heated (UNEP 1998c; p.137-138)

Chillers are large systems where the refrigerant is used to cool water that circulates through the area to be cooled. Air passes over the secondary loop system that conveys the chilled water and cools the space. They are used in large buildings and are housed in a plant room that takes up a substantial amount of space within a building.

Water chillers using the vapour-compression cycle are manufactured in capacities from about seven kilowatts to over 35000 kilowatts. Two types of compressors are used – positive displacement and centrifugal. Positive displacement scroll and reciprocating compressors are typically used from seven kilowatts up to 1600 kilowatts. Positive displacement screw compressors are used from 140 kilowatts to 6000 kilowatts. Centrifugal compressors are used from 350 kilowatts to over 35000 kilowatts (UNEP 1998c; p. 161). Average capacities of chillers produced in 1997 are shown in Table 43. Table 44 shows the average refrigerant charge as a function of capacity in 1997.

Refrigerant	Average capacity in kilowatts
HCFC-22 reciprocating	15
HCFC-22 screw	1000
HCFC-123	1500
HFC-134a	1300
R-500 (CFC-12/HFC-152a)	Not applicable
R-717 (Ammonia)	770

Table 43. Average capacity of airconditioning chillers produced in 1997

Source: UNEP (1998c; p. 163)

Refrigerant	Kilograms per kilowat		
	(kg/kW)		
CFC-11	0.25		
CFC-12	0.35		
HCFC-22 reciprocating	0.34		
HCFC-22 screw	0.35		
HCFC-123	0.22		
HFC-134a	0.35		
R-500 (CFC-12/HFC-152a)	0.33		
R-717 (Ammonia)	0.15 (0.04 to 0.25)		

Table 44. Average refrigerant charge in airconditioning chillers in service as a function of capacity in 1997

Because of the lack of Australian data, the extent to which the data shown in Table 43 and Table 44 are relevant to the characteristics of systems in place in Australia is unknown. For large chillers an alternative approach that was explored was to obtain data on commercial buildings and management of airconditioning in these buildings. The successor organisation to the Building Owners and Managers Association, the Property Council of Australia, was contacted for data and information. No response was received.

The only data that are available are those presented in work undertaken by Price Waterhouse in 1997. Price Waterhouse disaggregated commercial airconditioning into non-chillers over 18 kilowatts and chillers over 18 kilowatts. These data are not adequate to enable a detailed analysis that would result in a high level of confidence in the results. The range of system sizes that are used in commercial airconditioning suggests that more extensive disaggregation is required to properly identify the market structure and the quantity of substances used. Although the industry did not cooperate, some information was provided by individuals familiar with the industry. This information has been used to develop a limited understanding of the industry.

Before the phase-out of ozone depleting substances, packaged commercial airconditioning systems used CFC-12 and HCFC-22. Most equipment in this category used HCFC-22, and it remains the most common substance for this type of equipment. Chillers used CFC-11, CFC-12, and HCFC-22. In large chillers, the most common substance was CFC-11. Following the phase-out of CFCs, chillers based on CFC-11 were in some cases retrofitted to HCFC-123 or replaced by HCFC-123 equipment. It is estimated that 30% to 50% of chillers switched to HCFC-123 systems which have a similar charge and capacity to CFC-11 equipment. In 2000, around 20% of older chillers continued to operate using CFC-11. This will change in the near future as CFC-11 becomes increasingly scarce. Equipment will either be retrofitted to HCFC-123 (not a long-term solution) or replaced with new systems based on HFCs.

Many new large systems use HFC-134a and intermediate systems are based on R-407C (HFC-32/ HFC-125/HFC-134a). Some new packaged systems now use R-410A. Whereas some packaged systems can be retrofitted for R-407C, R-410A operates at a very high pressure and equipment must be designed for use with this substance.

Chillers contain substance charges ranging from tens of kilograms to hundreds of kilograms. Leakage rates of CFC chillers are stated to range from 12% to 15% of the charge per year, and leakage from new equipment is 5% to 6% of the charge each year. These rates do not take into account the fate of residual substance when equipment is serviced or substance disposal when equipment is retired or scrapped. These are not annual average lifetime emission factors, unlike the rates applied to the analysis of domestic airconditioning. Packaged commercial equipment has lower leakage rates that are said to be comparable with domestic systems.

Average annual lifetime emission factors for chillers are conjectured to be 15% to 25% of system charge for older chillers, and 10% to 15% for new equipment.

7.5 EMISSIONS FROM COMMERCIAL AIRCONDITIONING

Estimation of emissions relies upon a very sparse set of data on equipment and characteristics. The base data used is that in the Price Waterhouse study. This has been supplemented by information provided by individuals. The assumptions are shown in .

Data item	Data source
Number of non-chillers over 18kW	Price Waterhouse (1997)
Number of chillers over 18kW	Price Waterhouse (1997)
Growth rate of non-chillers over 18kW	Assumed to increase at the same rate as real gross domestic
	product
Growth rate of chillers over 18kW	Advice
Equipment charges (average)	Price Waterhouse (1997)
Substances used	Assumption and advice
Leakage rates (average annual lifetime	Assumption and advice-15% for chillers except HCFC-123
emission factors)	chillers (10%); 15% for non-chillers
Substances used:	
Non-chillers	HCFC-22 switching to HFC-134a, R-407C and R-410A
Chillers	CFC-11 and CFC-12 switching to HCFC-123, HCFC-22 then
	HFC-134a and R-407C and R-410A

Table 45. Data sources and assumptions

The lower emission factor for chillers using HCFC-123 reflects the fact that HCFC-123 chillers operate at sub-ambient pressures. When a leak develops, air leaks in until the internal pressure equals atmospheric pressure when refrigerant will be emitted by diffusive processes. This is very slow and the main source of emissions is assumed to be when equipment is serviced.

Further assumptions for chillers are:

- in 2000, 40% of chillers use CFC-11, 25% use HCFC-22, 30% use HCFC-123 and 5% use HFC-134a; all CFC-12 equipment has been replaced
- all CFC-11 equipment is scrapped by the end of 2005, HCFC-22 and HCFC-123 equipment is displaced from 2010
- from 2010, 70% of chillers use HFC-134a and 30% use HFC blends: either R-407C and R-410A. The lower penetration of the blends recognises that product redesign and retooling would be required.

Additional assumptions with regard to non-chillers are:

- in 2000, all non-chillers use HCFC-22
- HFC-134a, R-407C and R-410A penetrate the market from 2002
- HCFC-22 is displaced from 2009, when 30% of systems are HCFC-134a and 70% are HFC blends: R-407C and R-410A.

Estimated emissions of the various substances are shown in Table 46 and illustrated in Figure 10.

Year	CFC-11	CFC-12	HCFC-22	HCFC-123	HFC-134a	R-407C/R-410A
1990	152	19	96			
1991	159	20	100			
1992	166	21	104			
1993	173	22	108			
1994	181	23	113			
1995	165	24	129	8		
1996	166	25	135	12		
1997	166	26	140	17		
1998	147	13	160	36		
1999	126	14	181	47		
2000	117		189	58	15	
2005	17		176	104	83	51
2010					333	235
2015					390	275
2020					452	319

Table 46. Estimated emissions from commercial airconditioning (tonnes)

Table 47 shows estimated CO_2 -e emissions from commercial airconditioning (non-chillers and chillers). In 2000, HFC emissions are small because it is assumed that the predominance of equipment operates using CFC-11, HCFC-22 and HCFC-123. By 2005, as equipment switches to greater use of HFC-134a, R-407C and R-410A, emissions are projected to increase to 192 gigagrams CO_2 -e, and 814 gigagrams CO_2 -e by 2010.

Figure 10. Time profile of emissions from commercial airconditioning



Table 47. Estimated emissions from commercial airconditioning

Year	Emissions (Gg CO ₂ -e)
2000	19
2005	192
2010	814
2015	954
2020	1105

As with all equipment, a key factor driving emissions is recovery and recycling when equipment is serviced. Implicit in the average annual emission factors is that a substantial quantity of substance is vented when equipment is serviced or scrapped. Assuming an average annual emission factor of 10% for non-chillers and chillers, emissions in 2005 and 2010 would be 50% lower than the basecase (Table 48).

Table 48. Projected emission reductions with lower average emission fac	ctors
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Year	Baseline	Measures	Reduction from
	(Gg CO ₂ -e)	(Gg CO ₂ -e)	baseline (%)
2000	19	13	50
2005	192	128	50
2010	814	543	50
2015	954	636	50
2020	1105	737	50

Environment Canada (1999b) compared the performance of commercial systems, both non-chillers and chillers, using different substances. The coefficient of performance of systems (a measure of the efficiency of heat exchange equipment) showed small differences only as between different substances. For small commercial systems the coefficient of performance for HFC-407C was slightly lower than HCFC-22, whereas the coefficient of performance for HFC-410A was slightly higher. Energy efficiency ratings were similar (Environment Canada 1999b; p. 11). A large chiller based on CFC-12 was compared with chillers based on HCFC-123, HFC-245ca, HFC-134a, HFC-407C, HFC-410A, and R-717

(ammonia). Coefficient of performance values for HCFC-123 and R-717 were similar to the CFC-12 unit. HFC-245ca was slightly worse followed by HFC-134a and HFC-407C and HFC-410A. The difference between the CFC-12 system and least efficient alternatives (HFC-407C and HFC-410A) was around 9%. Ammonia has a comparable coefficient of performance and is commonly used in large industrial systems. Commercial system usage would require careful design and monitoring to manage the flammability and toxicity of ammonia.

7.6 CONCLUSION

Domestic and commercial airconditioning have the potential to become an important source of greenhouse gas emissions as HFCs penetrate the market.

At present most domestic systems use HCFC-22, and commercial systems operate on CFC-11, CFC-12, HCFC-22, HCFC-123, and HFC-134a. It is expected that in the future HFC-134a and HFC blends, R-407C and R-410A, will become the dominant substances in commercial airconditioning. The HFC blends, R-407C and R-410A, are also expected to displace HCFC-22 in domestic airconditioning equipment, with R-410A being the main substance.

In 2005, domestic airconditioning could contribute 326 gigagrams of CO_2 -e emissions, which could increase to 1227 gigagrams in 2010. Commercial airconditioning has the potential to contribute 192 gigagrams of CO_2 -e emissions in 2005, and 814 gigagrams in 2010. This gives a total of 518 gigagrams in 2005 and 2041 gigagrams in 2010.

Recovery and recycling practices combined with installations that are designed to minimise leakage such as brazed rather than flared joints in pipework, would reduce emissions significantly. Ammonia (R-717) is an alternative that could be used if appropriate means of managing its toxicity and flammability can be developed.

8.1 COMMERCIAL REFRIGERATION—RETAIL FOOD

Commercial refrigeration is classified as equipment used in the retail food sector. The sector comprises supermarkets (small, medium and large), convenience stores, and a multitude of small retail outlets such as milk bars, small take-away outlets, etc. Commercial refrigeration encompasses three different categories of equipment:

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

Indirect systems are composed of primary heat exchangers where a heat transfer fluid is cooled down, pumped towards display cases where it recovers heat and then comes back in the primary heat exchanger (UNEP 1998c; p. 94).

All areas of use of ozone depleting substances and synthetic greenhouse substances are difficult to analyse due to data problems. Commercial and industrial refrigeration and airconditioning are probably the most difficult uses because of the proliferation of these substances, including transitional HCFC blends that contain some HFCs. In the automotive sector, gas speciation is relatively straightforward in that the majority of the market moved from a pure CFC (CFC-12) to a pure HFC (HFC-134a). Some blends, namely, R-401C (MP-52) and R-416A (FR-12), were introduced in the early stages of the phase-out for automotive uses but the industry preference for single component fluids limited market acceptance and adoption. Domestic refrigeration moved from CFC-12 to HFC-134a.

Direct substitution to a single easily identified substance has not occurred in commercial refrigeration. There has been increased product differentiation amongst manufacturers in developing transitional substances and HFC substitutes for ozone depleting substances. Differentiation has probably been encouraged by the need for retrofits of large installations that are costly to replace and require a low risk of failure to avoid expensive spoilage of perishable products. The scope to introduce patented proprietary products has also increased the difficulty of differentiation.

Low temperature applications used R-502. Medium temperature applications relied on CFC-12, and to a lesser extent, R-500 (CFC-12/HFC-152A), R-502 (HCFC-22/CFC-115) and HCFC-22. High temperature applications used CFC-12 and HCFC-22. Until the phase-out of CFCs commenced, HCFC-22 was used primarily in airconditioning. During the phase-out it became more common in refrigeration, a trend that is now being reversed. R-500 was not commonly in use.

As can be seen from Table 49, there are 10 replacement gases for R-502 and at least nine replacement gases for CFC-12, all of which are available for retrofits and new equipment. Not all of these gases are transitional substances (HCFC blends). Some are HFC blends and will be long term replacements for HCFCs and HCFC blends. Many of the HCFC blends include a HFC, PFC or hydrocarbon component. These components need to be accounted for in deriving the inventory whereas the HCFC components are omitted. The relevant GWP, namely that attributable to other than HCFC constituents, is shown for the most important of the substances in Table 1.

Substitute	Replaces	Application
R-401A (HCFC/HFC)	CFC-12	Medium and high temperature
R-401B (HCFC/HFC)	CFC-12; R-500	Low temperature
R-401C (HCFC/HFC)	CFC-12	Automotive airconditioning - little used
R-402A (HCFC/HFC/HC)	CFC-502	Low temperature
R-402B (HCFC/HFC/HC)	CFC-502	Small hermetic systems such as icemaking
		machines
R-403A (HCFC/PFC/HC)	CFC-502	Low temperature
R-403B (HCFC/PFC/HC)	CFC-502	Low temperature
R-404A (HFC)	CFC-502	Low temperature
R-405A (HCFC/HFC/PFC)	CFC-12	Medium and high temperature
R-406A (HCFC/HC)	CFC-12	Medium and high temperature
R-407A (HFC)	CFC-502	Low temperature
R-407B (HFC)	CFC-12	Medium and high temperature
R-407C (HFC)	HCFC-22	Airconditioning
R-408A (HCFC/HFC)	CFC-502	Low temperature
R-409A (HCFC)	CFC-12	Medium and high temperature
R-409B (HCFC)	CFC-12; R-500	Medium and high temperature; transport
		refrigeration
R-410A (HFC)	HCFC-22	Airconditioning but only for equipment designed for R-410A
R-411A (HCFC)	HCFC-22	Airconditioning
R-411B (HCFC)	CFC-502	Low temperature
R-412A (HCFC/PFC)	R-500	Transport refrigeration
R-413A (HFC/HC)	CFC-12	Low and medium temperature refrigeration
R-417A (125/134a/600) (HFC/HC)	HCFC-22	Low and medium temperature refrigeration
R-507A (HFC)	CFC-502	Low and medium temperature
R-509A (HCFC/PFC)	CFC-502	Low temperature

Table 49. HCFC and HFC blends that are substitutes for CFC and long-term replacement substances

HC hydrocarbon; Source: Adapted from AIRAH (1998; p. 20-22); A-Gas (2000); DuPont (1998)

8.1.1 Modelling emissions from commercial refrigeration—retail food

There are significant difficulties with modelling emissions from commercial refrigeration. Three different approaches are possible:

- Gas sales-based estimation data on gas sales to the commercial refrigeration sector and the amount used for installation, retrofit and servicing could be obtained from the main manufacturers and contractors. This would need to be supplemented by data on the charge of substance and its fate when equipment is decommissioned. Disposal emissions due to decommissioning would not be reflected in the amount of gas used for servicing equipment. Average installation and retrofit losses would also be required.
- Equipment-based estimation data on equipment and the characteristics of the equipment (average charge, average annual leakage, average loss on servicing, average charge on disposal) could be obtained from equipment suppliers and manufacturers.
- 3. Establishments-based estimation Gas use could be classified by establishments based on the types of equipment of representative establishments. This approach appears to be favoured in that it has been used previously and is the approach adopted in UNEP (1998c). Specifically, UNEP focus on the establishment surface area (the area of retail space) and number of establishments from which they compile an estimate of the number of units of different types of equipment (p. 95–96). They recognise the difficulties with this approach but note that 'the number of standalone equipment is difficult to evaluate' UNEP (1998c; p 96).

The data are not available to enable use of the gas-sales based and equipment-based approaches in Australia. The only data that are available, albeit limited and fragmented, are on the number of establishments. These have been used to compile estimates on substance use and emissions. The uncertainty inherent in this approach can be reduced through atmospheric measurements of emissions that are then compared with estimates obtained from establishments. This provides a method to validate estimates and has been used in this research (Chapter 10).

The establishments have been classified as follows:

- Supermarkets large
- Supermarkets medium
- Supermarkets small
- convenience stores
- other remaining retail food.

This is the same classification as that adopted by Price Waterhouse (1997). Price Waterhouse's data have been supplemented by data from the annual reports of Coles and Woolworths, and information provided by the Commercial Refrigeration Manufacturers' Association.

Australia's supermarket sector is dominated by three large companies. Coles and Woolworths jointly comprise in excess of 60% of the Australian market. Along with Franklins, it is likely that 70% to 80% of the supermarket sector is controlled by these three companies. Estimates derived from information on these companies captures the majority of the commercial refrigeration sector in Australia.

Figure 11 shows the estimated number of establishments from 1990 to 2020. Large supermarket numbers have grown over the 1990s at the expense of medium and smaller independent supermarkets. It is estimated that this trend will continue over the next 20 years with medium and smaller independent supermarkets continuing to decline, although at a slower rate than has occurred during the 1990s. Applying the rates of decline observed in the 1990 to 1996 would virtually eliminate all medium and small independent supermarkets. This outcome is considered unlikely and the rate of decline from 1997 to 2020 is assumed to be half that from 1990 to 1996. The recent entry of German

supermarket company, Aldi, into the Australian market reinforces the likelihood of continuing decline in the number of small and medium supermarkets. Convenience store numbers increased over the 1990s and it is estimated that there will be continued slow growth over the next twenty years. These outcomes are considered reasonable in that with fewer operators in the market there is a common interest in consolidating stores into larger operations to reduce overheads such as the costs of maintaining a larger number of smaller stores.



Figure 11. Estimated number of supermarkets and convenience stores from 1990 to 2020

Source: Price Waterhouse (1997); Coles Annual Report; Woolworths Annual Report; Supplementary information from the Commercial Refrigeration Manufacturers' Association

Not shown in Figure 11 is 'Other remaining retail food' (milkbars, takeaways, etc.). Based on Price Waterhouse (1997) data for 1990 and 1996 these establishments would decline from 40500 establishments in 1990 to 25879 in 2020. This method gives an estimate that is considered to be implausible. However, there are so many of these establishments that this category is significant in terms of the gas bank and emissions, and so implausible estimates cannot be ignored. These establishments are more likely to increase in number rather than decline. It is assumed, arbitrarily, that from 1996 the number of these establishments increase by 1% each year so that in 2020 there are around 47000 establishments. Given increases in population and the workforce, some growth in demand for takeaway food and the services of small cafes is considered reasonable.

Modelling of emissions uses the data on establishments along with the following:

- average quantity of refrigerant per establishment
- average annual leakage per establishment adjusted to reflect the charge emitted on disposal.

8.1.2 Substances and emissions

It is assumed that the main gases used prior to the phase-out of CFCs were CFC-12 and R-502 (CFC-115/HCFC-22). Small quantities of R-500 (CFC-12/HFC-152a) were used but these are ignored. No attempt is made to disaggregate the use of CFC-12 and R-502. For retrofit applications as part of the phase-out of CFCs, initially R-401A and R-402A were the primary substances. These were later displaced by R-408A and R-409A. R-401A, R-402A and R-408A are blends each of which include at

least one HFC, and in the case of R-402A includes a hydrocarbon (propane), with relevant GWPs of 18, 1680 and 1944 respectively. R-409A is a HCFC blend and its contribution to global warming does not need to be included in the estimates. The starting point for speciation of gases is the data in Price Waterhouse (1997). This provides a disaggregation for 1990 and 1996 in terms of CFCs, HCFCs and HFCs. Further disaggregation is based on assumptions supplemented by broad data provided by the Commercial Refrigeration Manufacturers' Association. Without further information it is impossible to disaggregate the HCFC/HFC blends.

The HFC substitute gases are assumed to be R-404A and R-507. No attempt has been made to disaggregate these gases, R-404A has a GWP of 3260 and R-507 has a GWP of 3300. CO₂-e emissions are derived by taking the average of these two GWPs which implies a 50:50 ratio of R-404A to R-507. The closeness of the GWPs means that the error introduced is not excessive compared with uncertainties elsewhere. Another HFC, R-417A (Isceon 59) is used in small quantities at present but is seen as a long-term replacement in low and medium temperature refrigeration. It has a GWP of 1955, substantially lower than R-404A and R-507. Displacement of R-404A or R-507 by R-417A would reduce the contribution of commercial refrigeration to greenhouse emissions. No information is available to enable analysis of the extent to which displacement might occur.

The assumptions used to estimate the bank of gas and emissions are shown in Table 50. In Table 51 the assumptions on the percentage of the bank that is CFCs, HCFCs (including blends) and HFCs are shown. The percentages for 1990 and 1996 are derived from Price Waterhouse (1997) and assumptions for later years are based, in part, on some industry advice. The assumptions for all other establishments are shown in Table 52.

Type of establishment	Average charge per		
	establish	ment (kg)	
	1990	1996	
Supermarkets – Large	713	950	
Supermarkets – Medium	192	450	
Supermarkets – Smaller Independents	95	100	
Convenience Stores	30	23	
Other Remaining, Retail Food (Corner Stores, etc.)	15	14	

Table 50. Assumed average quantity of gas used per establishment

Source: Price Waterhouse (1997)

The assumptions in Table 51 and Table 52 are based on the view that large supermarkets moved more rapidly out of CFCs to HCFCs and then to HFCs. The HCFC bank in large supermarkets is taken to have peaked in 1997 as a proportion of the total bank. By comparison, the HCFC bank for all other establishments peaks in 2000.

This assumption is based on the further assumption that large supermarkets are more likely to replace equipment whereas smaller establishments are more likely to retrofit equipment or replace CFCs with HCFC service blends such as happened with the use of R-401A and R-402A.

All CFCs are taken to have been eliminated from the market by 2004 for large supermarkets and 2007 for all other establishments.

Year	CFC-12 and CFC-502	HCFCs (including blends)	HFCs
	(% of total bank)	(% of total bank)	(% of total bank)
1990 to 1993	92	8	0
1994	60	20	20
1995	30	40	30
1996	15	45	40
1997	10	45	45
1998	5	40	55
1999	3	36	61
2000	3	27	70
2001	3	22	75
2002	3	17	80
2003	3	12	85
2004	0	10	90
2005	0	5	95
2006	0	5	95
2007	0	0	100
2008	0	0	100

Table 51. Estimated percentage of substances comprising the bank in large supermarkets

Table 52. Estimated percentage of substances comprising the bank in all other establishments

Year	CFC-12 and CFC-502	HCFCs (including blends)	HFCs	
	(% of total bank)	(% of total bank)	(% of total bank)	
1990 to 1993	94	6	0	
1994	70	20	10	
1995	50	35	15	
1996	30	50	20	
1997	30	50	20	
1998	28	52	20	
1999	25	54	21	
2000	16	54	30	
2001	10	50	40	
2002	5	45	50	
2003	5	40	55	
2004	5	30	65	
2005	5	25	70	
2006	5	15	80	
2007	0	10	90	
2008	0	0	100	

The estimated bank of gases is shown in Figure 12. The bank of R-404A and R-507 is projected to grow from 1995 to 2020 as all CFCs and HCFCs are displaced in all establishments.



Figure 12. Estimated bank of refrigerant gases used in commercial refrigeration from 1990 to 2020

The bank of CFCs is assumed to have peaked in 1990, and HCFCs peak in 1998. Once all CFCs and HCFCs are eliminated the trend growth in HFCs slows ranging from 2.3% per year to 2.9% per year. This is driven by the assumed growth in the number of large supermarkets relative to other establishments. The bank per establishment for large supermarkets is bigger than for other establishments.

The final step in estimating emissions is to determine average annual losses per establishment. It is reasonable to assume that equipment in large supermarkets is well-maintained with system charges maintained at optimum levels and leakage from systems minimised. Refrigeration equipment that is not serviced regularly would increase the risk of goods spoiling due to system failure, and increases in refrigerant cycling due to gas loss would increase energy costs. Establishments that have smaller systems have similar incentives to ensure proper maintenance of equipment, although the costs of system failure and frequent cycling of refrigerant are not expected to be as high. Some variability in the quality of maintenance across the range of smaller establishments would be expected. Incorporating adjustments in the model without quantitative information on the level of variability in average emissions cannot be justified. Average annual emission factors are applied to all establishments.

The average annual emission factor encompasses system leakage, losses on charging and servicing, and emissions on disposal. Average equipment lifetimes are assumed to be 10 years. In some cases this is an overestimate because store refurbishment can lead to equipment being retired earlier, and in some cases it is an underestimate because the operating life of well-maintained equipment is longer than 10 years. The average annual leakage rate is assumed to be 25% of the charge per year in 1990 declining to 10% in 2001 where it is held constant until 2020.

The assumption of 25% means that if the equipment has a 10-year life, it will emit the equivalent of 2.5 full charges in the lifetime of equipment. An average annual emission factor of 10% implies emission of one complete charge during the lifetime of the equipment. There are several assumptions that underlie the average emission factors. In particular, it is implicit that when equipment is serviced, there is no venting of gas to the atmosphere—it is recovered and recycled. Large equipment is likely to

be serviced on average every two years. If gas was vented on servicing the average emission factor would be much larger. Estimated emissions of substances are shown in Figure 13 and CO₂-e emissions of R-404A and R-507 combined are shown in Figure 14.



Figure 13. Estimated emissions of substances used in commercial refrigeration from 1990 to 2020

Figure 14. Emissions of R-404A and R-507A (Gg CO₂-e)



Emissions of the HFCs – R-404A and R-507 – are estimated to increase from 124 gigagrams CO_2	-e in
1994 to 498 gigagrams in 2000, 728 gigagrams in 2005, and 942 gigagrams in 2010 (Table 53).	

Year	Emissions of R404A/R507
1994	124 Gg CO ₂ -е
1995	192 Gg CO ₂ -е
1996	316 Gg CO ₂ -е
1997	351 Gg CO ₂ -е
1998	389 Gg CO ₂ -е
1999	437 Gg CO ₂ -е
2000	498 Gg CO ₂ -е
2005	728 Gg CO ₂ -e
2010	942 Gg CO ₂ -е
2015	1068 Gg CO ₂ -е
2020	1226 Gg CO ₂ -е

Table 53. Combined emissions of R-404A and R-507

The impact on emissions of changing several assumptions was evaluated. Hydrocarbons are assumed to be used in large supermarkets in 2003, which displaces some HFCs. Initially, 5% of the bank is hydrocarbons, and this increases to 10% by 2010 and 15% by 2020. Average emission factors are assumed to fall from 10% in 2002 to 7% by 2010. The results are shown in Table 54 and illustrated in Figure 15.

Year	Emiss	Emissions				
	Business-as-usual	With measures	emissions over			
	(Gg CO ₂ -e)	(Gg CO ₂ -e)	Business-as-usual			
1994	124	124	0			
1995	192	192	0			
1996	316	316	0			
1997	351	351	0			
1998	389	389	0			
1999	437	437	0			
2000	498	498	0			
2005	728	572	21			
2010	942	613	35			
2015	1068	665	38			
2020	1226	759	38			

Table 54. Emissions under business-as-usual and with measures

As shown in Table 54, the changes lead to a reduction in emissions over business-as-usual in 2005 of 21% and a reduction in 2010 of 35%. The assumption of an average emission factor of 7% implies that over 10 years only 70% of a complete system charge would be lost. This would require an emphasis on recycling and recovery when equipment is serviced or decommissioned, and additional care in the installation of equipment to ensure that leakage from pipe fittings is minimised. The use of hydrocarbons in other than large supermarkets is not included in the analysis because the flammability of hydrocarbons restricts use to other than public areas and requires high standards of equipment maintenance. Large supermarkets are considered more likely to adhere to the required standards.



Figure 15. CO₂-e (Gg) emissions from commercial refrigeration without and with measures

8.1.3 Insulation of commercial refrigeration

Supermarket refrigeration equipment is insulated with foam that, in Australia, is understood to be blown with HCFC-141b. Analysis by Environment Canada (1999b) for Canadian supermarkets indicated that foam was blown with HCFC-22 or HFC-134a. Data for Australia have not been provided for this study. Emissions estimates are based on the several assumptions adapted from Environment Canada's analysis.

A typical large supermarket is assumed to have 38.7 cubic metres of insulation foam with a density of 36 kilograms per cubic metre. This gives an overall mass of foam of 1393 kilograms. Blowing agent comprises approximately 7% by weight of the foam – 97.5 kilograms. Foam blowing losses are estimated to be 3% (Environment Canada 1999; p. 54).

These assumptions have been modified as follows:

- large supermarkets use on average 100 kilograms of insulation
- medium supermarkets include 60 kilograms of insulation
- small supermarkets include 30 kilograms of insulation
- convenience stores use 15 kilograms of insulation
- other stores use 10 kilograms of insulation.

These assumptions allow an estimate of the bank of substance to be obtained, albeit a rough estimate with a high level of uncertainty. Trade in used equipment means that some establishments obtain equipment that already contains foam insulation. This is likely to be the case for smaller establishments. Additional information is required to enable estimation of emissions. Industry has not made available information that indicates the rate at which equipment is scrapped and the quantity of foam blown each year. This means that there is no sensible starting point on which to base further assumptions.

Estimates of the bank of substance are shown in Table 55.

Year	Bank of substance (tonnes)
1990	668
1991	652
1992	637
1993	625
1994	615
1995	607
1996	600
1997	605
1998	610
1999	615
2000	621
2005	657
2010	703
2015	761
2020	831

Table 55. Bank of substances contained in commercial refrigeration foam

Table 55 shows that the estimated bank of substance contained in foam is 615 tonnes in 1994, 621 tonnes in 2000, 657 tonnes in 2005, and 703 tonnes in 2010. If it assumed that the total bank in 1994 is CFC-11, all new equipment switches to HCFC-141b in 1995, and equipment is scrapped at the rate of 5% per year then:

- all CFC-11 foam would be discarded by 2015
- emissions of CFC-11 would be around 31 tonnes per year from foam disposal, treating all emissions as arising on disposal
- HCFC-141b use would increase from 23 tonnes in 1995 to 43 tonnes in 2014.

Some of the HCFC-141b equipment would be disposed of after a relatively short period. Assuming that after five years, on average 5% of the HCFC-141b equipment is scrapped, reconciling the bank with disposals implies that:

- in 2000, 46 tonnes of HCFC-141b is used for foam blowing, and this increases to 58 tonnes in 2005, and to 70 tonnes in 2010
- emissions of HCFC-141b increase from about 10 tonnes in 2000, to 19 tonnes in 2005, and to 29 tonnes in 2010.

These estimates should be treated with caution.

8.2 TRANSPORT REFRIGERATION

There are two large companies, Carrier and Thermo-King, and a smaller company, Heuch, which manufacture transport refrigeration. Carrier and Thermo-King were approached for data and information on the characteristics of transport refrigeration equipment.

Data on the population of refrigerated vehicles are scarce and this lack of information is not merely a problem for research of this type, but it is also a problem for industry participants. Registration authorities do not require vehicles to indicate whether they are refrigerated or not, and no data are collated on the population of refrigerated vehicles. The lack of accurate records is a source of frustration for the industry and could be addressed simply through a check-box on registration forms.

From a policy perspective, and particularly in relation to food safety, it would be of value for governments to be informed of the numbers of refrigerated vehicles that are suitable for the safe carriage of perishable goods.

8.2.1 Emissions from transport refrigeration

Emissions from transport refrigeration were derived using data from Price Waterhouse (1997) that were modified and supplemented by additional data obtained through consultation with individuals in industry.

Construction of the data on the population of refrigerated vehicles is based on the following assumptions:

- The proportion of vehicles in each of three categories (semi-trailers, rigid trucks, and short haul/food service transport) for 1990 specified by Price Waterhouse is taken as correct, but the total population of refrigerated vehicles was adjusted. The proportions were applied to the revised population, to derive the numbers in each category for 1990.
- Vehicles in each category were expressed as a proportion of the total vehicle population in 1990 and this proportion is assumed to remain constant to 2020. Populations in each category for each year were derived. Refrigerated containers were expressed as a proportion of the semi-trailer population and the same method as for other refrigerated vehicles was applied to determine numbers for each year to 2020.

Estimates are shown Table 56.

Year	Road Transport	Road Transport	Road Transport	Refrigerated
	Trailers	Trucks	Off Engine	Containers
	(Semi-Trailers)	(Rigid)	(Short Haul/Food Service)	
1990	11660	6570	6770	5000
1991	11994	6602	6803	5143
1992	12087	6634	6836	5183
1993	12180	6666	6869	5223
1994	12838	6676	6879	5505
1995	13531	6685	6888	5802
1996	13538	6756	6962	5805
1997	13756	6784	6990	5899
1998	14448	6879	7088	6196
1999	14685	6871	7080	6297
2000	14921	6906	7116	6398
2005	16158	7085	7300	6929
2010	17497	7268	7489	7503
2015	18948	7455	7682	8125
2020	20519	7648	7881	8799

Tahle 56	Bank of	substances	contained	in	commercial	refrice	ration	foam
14010 50.	Dunk Of	Substances	comunica	ιn	commerciai	refrige	iunon	joum

Source: Estimated

The assumptions made to estimate emissions are:

- CFC-12 and R-502 (CFC-115/HCFC-22) are used up until 1995. Equipment is 80% CFC-12 and 20% R-502
- HFCs are used from 1996. Semi-trailers and rigid trucks switch to R-404A (HFC-143a/HFC-125/HFC-134a), and small off-engine systems switch to HFC-134a. Refrigerated containers are assumed to use R-404A
- average annual emission factors are 20% for CFCs, and 15% for HFCs. These factors include leakage, losses on servicing and losses on disposal.

Estimated emissions are presented in Table 57. Transport refrigeration is a relatively small source of emissions despite the high GWP of R-404A of 3260. Emissions increase from 51 gigagrams CO₂-e in 2000 to 83 gigagrams in 2005, and to 89 gigagrams in 2010. Further, it is possible that these estimates overstate emissions because conservation practices that were adopted during the phase-out of ozone depleting substances are understood to have been maintained with the introduction of substitutes.

Year	CFC-12	R-502	HFC-134a	R-404A	HFC CO ₂ -e emissions
	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(Gg)
1990	30	7			
1991	30	8			
1992	31	8			
1993	31	8			
1994	32	8			
1995	33	8			
1996	30	8	0	3	9
1997	27	7	1	6	19
1998	24	6	1	9	31
1999	21	5	1	12	41
2000	18	5	1	15	51
2005			2	24	83
2010			2	26	89
2015			2	28	95
2020			2	30	102

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				2 0	

Source: Estimated

8.3 DAIRIES

Dairies use refrigeration equipment to cool and hold milk at a low temperature (around 4°C) prior to collection for delivery to milk processors. Recently the Australian dairy industry has undergone major changes as a result of the removal of regulations that constrained trade in fresh milk between the States and Territories. From 1990 to 2000, the number of dairies has fallen by around 16% and the numbers are expected to fall further as the full impact of deregulation of the industry flows through to all areas. The number of dairies is estimated to be slightly less than 11000 by 2010 (Table 58).

It is assumed that in 2000, 40% of dairy refrigeration uses CFC-12, 40% uses HCFC-22, and 20% uses HFC-134a. All CFC-12 is assumed to be eliminated by 2005 and HCFC-22 by 2009. Both are displaced by HFC-134a. Average annual emission factors over the lifetime of the equipment are assumed to be 20% for CFCs and HCFCs and 15% for HFC-134a equipment.

Given the importance of properly functioning refrigeration in the production of a perishable commodity, it is likely that systems would be well-maintained and serviced frequently. If there is no recovery and recycling during servicing, this would increase average annual lifetime emission factors.

Estimated emissions are shown in Table 58. In 2000, approximately 10 gigagrams CO_2 -e is emitted, and this is projected to increase to 28 gigagrams in 2005, and to 42 gigagrams in 2010.

Vear	Number of	Emissions (tonnes)			CO2-e
ICal	dairies	CFC-12	HCFC-22	HFC-134a	emissions (Gg)
1990	15396	62			
1991	14986	60			
1992	14760	59			
1993	14624	58			
1994	14510	58			
1995	14166	51	6		
1996	13888	44	11		
1997	13753	39	17		
1998	13478	32	13		
1999	13156	26	11	4	5
2000	12888	21	15	8	10
2005	11841		14	21	28
2010	10878			33	42
2015	9994			30	39
2020	9182			28	36

Table 58. Number of dairies and estimated emissions

Source: ABARE (2001; p.10) for number of dairies 1990 to 2000; other data estimated.

8.4 HOTELS, PUBS AND CLUBS

The estimates for hotels, pubs and clubs are indicative only because they are based on limited data and guesses. Numbers of establishments, the average quantity of gas per establishment and average losses per establishment for 1990 are taken from Price Waterhouse (1997). An approximation of 7000 hotels represented by the Australian Hotels Association in 2000 is used to derive a growth rate from 1990 to 2000. This growth rate has been applied to all establishments to estimate establishments for each year to 2020. The proportion of gases used by establishments were derived based on some information provided by an individual familiar with the industry. It is assumed that:

- in 1990, CFC-12 is 70% of the bank and HCFC-22 is 30% of the bank. In hotels, ice banks based on HCFC-22 replaced beer temprites using CFC-12 from about 1988
- by 2000, the bank is 40% CFC-12, 20% HCFC-22 and 40% HFC-134a with HFC-134a introduced from 1995
- all CFC-12 equipment is retired by 2005 and all HCFC-22 equipment is retired by 2009, at which time all equipment uses HFC-134a.

Estimated numbers of establishments and emissions by gas are shown in Table 59. Emissions in 2000 are estimated to be 70 gigagrams CO_2 -e, which increase to 118 gigagrams in 2005, and to 157 gigagrams in 2010.

Year	Number of estab	lishments	Eı	Emissions (tonnes)		
	Hotels and pubs	Clubs	CFC-12	HCFC-22	HFC-134a	emissions (Gg)
1989	6155	3680	110	47	0	
1990	6229	3724	111	48	0	
1991	6304	3769	112	48	0	
1992	6379	3814	114	49	0	
1993	6456	3860	115	49	0	
1994	6533	3906	116	50	0	
1995	6612	3953	81	40	10	13
1996	6691	4000	68	41	20	27
1997	6771	4048	62	41	26	34
1998	6853	4097	56	42	31	41
1999	6935	4146	49	28	48	62
2000	7000	4196	43	29	54	70
2005	7430	4454		30	91	118
2010	7887	4728			121	157
2015	8372	5018			128	166
2020	8886	5327			136	177

Table 59. Emissions from hotels, pubs and clubs

8.5 CONCLUSION

Commercial and transport refrigeration have the potential to become a significant source of emissions of HFCs. Commercial refrigeration is a far more significant source than transport refrigeration, and it is a major contributor to industrial process emissions.

Having displaced CFCs and ultimately displacing HCFCs, the HFCs that will penetrate the market have high GWPs ranging from 1300 for HFC-134a to 3260 for R-404A (an HFC blend). Sound substance conservation practices were adopted during the phase-out of CFCs and are understood to continue in the transport refrigeration sector. It would be straightforward to ensure similar practices are applied generally in the use of HFCs. Recovery and recycling practices along with manufacturers and contractors placing an emphasis on minimising losses through seals and joints would be effective in significantly reducing emissions both now and in the future.

With regard to transport refrigeration, an important factor when considering substitutes is vehicle design in terms of thickness of insulation that is achievable within existing standards for trailer widths, and the extent to which greenhouse advantages from new refrigerants are compromised by greater energy resulting from less efficient refrigerants and insulation of trailers.

Under a business-as-usual approach emissions are projected to increase to 957 gigagrams CO_2 -e in 2005 and to 1230 gigagrams in 2010. This would increase emissions from industrial processes by at least 10%.

Recovery and recycling practices would be effective in reducing average annual emission factors by reducing losses when equipment is serviced and recovering substances when equipment is scrapped. During servicing, if there is a need to evacuate the equipment, the substance should be recovered. Improved seals and brazed rather than flared joints would further reduce losses. For example, if the only loss is due to around 5% leakage per year rather than an average annual emission factor of 20%, emissions would fall by 75% over a 10-year life.

9 INTERNATIONAL DEVELOPMENTS

Following the Kyoto Protocol to the Framework Convention on Climate Change, more attention has been paid to the implications of the phase-out of ozone depleting substances for the adoption of synthetic greenhouse gases. Of concern is the rate at which synthetic greenhouse gases are replacing ozone depleting substances, and the development of new substances and blends to replace ozone depleting substances. Also important is the extent to which an analysis of trends in the use of ozone depleting substances can be used to predict later trends in the replacement synthetic greenhouse gases. Encompassed in the overall analytical approach is the development of not-in kind substitutes and more extensive application of substances that are not halocarbons.

So far Denmark is the only country that has introduced a stringent policy targeting synthetic greenhouse gases. In 2000, Sir John Harman, the Chairman of the United Kingdom Environment Agency, in commenting on the United Kingdom's draft climate change program was pleased to note the clear signal to industry that HFCs have no long-term future. This view is yet to be reflected in policy measures either introduced or proposed in the United Kingdom. Nonetheless, the United Kingdom's Climate Change Strategy strongly emphasises the intentions stating that:

The key elements of the Government's new position on HFCs are set out below:

- HFCs are not a sustainable technology in the long term the successful phase out of ozone depleting substances is being achieved with a range of technologies, and HFCs are only necessary to replace ozone-depleting substances in some applications. The Government believes that continued technological developments will mean that HFCs may eventually be able to be replaced in these remaining applications;
- HFCs should only be used where other safe, technically feasible, cost effective and more environmentally acceptable alternatives do not exist;
- HFC emission reduction strategies should not undermine commitments to phase out ozone-depleting substances under the Montreal Protocol;
- *HFC emissions will not be allowed to rise unchecked.* (DETR 2000; p.51)

9.1 OVERVIEW OF PHASE-OUT OF OZONE DEPLETING SUBSTANCES

The success of the phase-out of ozone depleting substances in developed countries is reflected in the rapid fall in ozone depleting substance production since the phase-out commenced.

As can be seen from Figure 16, production of the main ozone depleting substances (CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115) has declined sharply since 1990. To some extent this has been offset by growth in production of three of the transitional substances, HCFC-22, HCFC-141b and HCFC-142b. The data indicate that the phase-out has been more rapid than mandated under the Montreal Protocol. Coverage of the Alternative Fluorocarbon Environmental Acceptability Study (AFEAS) survey does not include countries such as China, India and Russia. AFEAS estimate that their estimates of CFC production are around 40% of total world CFC production in 1998. The reliability of the production data is greater in earlier years when CFC production was predominantly located in the AFEAS survey countries. Since the Montreal Protocol and the decision to phase-out ozone depleting substances in the developed countries combined with industrial development and increasing affluence in the larger developing countries, strong growth in ozone depleting substance production in these countries has occurred. AFEAS data are considered to represent 93% of non-feedstock HCFC

production and 100% of HFC-134a production (the other substance reported by AFEAS).

The AFEAS data are limited to the substances shown in Figure 16, plus HFC-134a. It does not include HCFC-123, a substance that is known to be used as a drop-in replacement for CFC-11 in some commercial airconditioners. In Australia it has been suggested that up to 50% of CFC-11 chillers were retrofitted with HCFC-123. HCFC-123 is an acceptable substitute for CFC-11 centrifugal chillers under the US EPA's SNAP program as of 8 June 1999. This means that at least some of the fall in production of CFC-11 would have been compensated for by an increase in production of HCFC-123 from at least 1994 when occupational health and safety assessments led to it being certified as safe. Following reports of health effects from an incident in Belgium, the US Department of Energy reaffirmed that, 'The use of HCFC-123 as a substitute refrigerant, when handled according to established practices, is a safe and efficient chemical for chiller use' (US DOE 1997). In the case considered, the HCFC-123 was used in a blend with HCFC-124 that is not an acceptable substitute in the US.





Source: AFEAS Data. Annual data for CFC-113, CFC-114 and CFC-115 are not available prior to 1980.

UNEP (1998c; p.57) data support the contention that over time the proportion of production in AFEAS survey countries has fallen substantially relative to developing countries not included in the survey. ODP-weighted proportions are shown Table 60 for 1989 to 1996.

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Data	ODP-weighted production of CFCs ('000 tonnes/year)							
source	1989	1990	1991	1992	1993	1994	1995	1996
AFEAS	859	587	544	481	405	221	136	77
UNEP	1042	763	678	591	484	342	249	160
%AFEAS	82	77	80	81	84	65	55	48

Source: UNEP (1998c; p.57)

The UNEP data show that since 1989 production in China, India, Korea and Romania as a group has increased from 33000 ODP tonnes to 85000 ODP tonnes (158% increase). UNEP (1998c; p. 56) observe that, 'If Article 5(1) Parties continue to produce approximately 110 ODP-kilotonnes per year in 1997-1999, non-Article 5(1) exports may decrease rapidly as Article 5(1) Parties reduce consumption after 1999, as required by the Protocol'. Note that Article 5(1) Parties are developing countries and non-Article 5(1) Parties are developed countries.

Data on HCFC production discloses a different situation with the majority of production concentrated in AFEAS Survey countries. Table 61 shows the ODP-weighted data from the AFEAS Survey and UNEP. Despite the inconsistencies in the data shown in that table, namely AFEAS survey production survey data being in some cases substantially greater than the UNEP total production estimate, the data indicate that the vast majority of HCFC production is located in AFEAS Survey countries (Argentina, Brazil, Canada, European Union, Japan, United States and Venezuela). Both data sets confirm the rapid growth in HCFC production since 1989 with AFEAS data showing growth of 142% over the period and UNEP data showing growth of 107%. UNEP's estimate for China, India, Korea and Romania shows that from 1992 to 1996 production increased from 731 ODP tonnes to 1831 ODP tonnes, an increase of 150%. This is of a similar magnitude to the increase in ODP-weighted production of CFCs. By contrast, Eastern European production of CFCs and HCFCs has declined rapidly over the same period.

Data source	ODP-weighted production of HFCs (tonnes/year)						
	1989	1992	1993	1994	1995	1996	
AFEAS	12743	16969	20197	24618	28422	30822	
UNEP	13867	13942	20875	27266	30180	28674	
%AFEAS (Developed)	89	118	95	89	93	106	

Table 61. ODP-weighted production data for HCFCs from AFEAS Survey and UNEP

Source: UNEP (1998c; p.61)

9.2 UNEP ASSESSMENT OF OZONE DEPLETING SUBSTANCE PHASE-OUT AND AVAILABILITY OF SUBSTITUTES

In April 2000, UNEP's Technology and Economic Assessment Panel published a summary report of the state of ozone depleting substance phase-out and the availability of substitutes for ozone depleting substances (UNEP 2000). The following discussion is derived from the report.

9.2.1 Refrigeration and airconditioning

UNEP recognise that the data for refrigeration and airconditioning needs to be updated to reflect the introduction of new refrigerants, predominantly blends. This work is expected to be undertaken over the period 2000 to 2002 as part of the next assessment of the Refrigeration Technical Options Committee.

Domestic refrigeration

Once the decision to phase-out ozone depleting substances was made, CFCs were eliminated quickly from domestic refrigeration. CFC-12 was replaced with HFC-134a and the foam blowing agent, CFC-11, was replaced in some cases with the transitional substance, HCFC-141b. In turn, HFCF-141b was replaced with the isopentane or cyclopentane. There has also been significant replacement of HFC-134a by hydrocarbons (isobutane, HC-600a) in some markets. In Europe, 40% to 50% of domestic refrigerators use HC-600a as the refrigerant (Sicars 1999; p. 194) although there are significant regional

differences. Around 98% of domestic refrigerators in Germany contain HC-600a. The same trend is not yet evident in Japan and the US (UNEP 2000; p. 72).

Despite the switch to non-ozone depleting substance substances, there remains a large residual stock of CFC-12 containing refrigerators with foam insulation blown with CFC-11. The remnants of this stock will continue in service for at least the next 10 to 15 years with disposal emissions of ozone depleting substances contributing to atmospheric loadings. Early action to recover historically used ozone depleting substances, particularly CFC-12, immediately prior to final product disposal would have significant environmental benefits.

Changes to refrigerant gases have implications for the energy efficiency of the system with a requirement to optimise the design of the system including insulation, heat exchangers and compressor efficiency. Isopentane-cyclopentane blends are the preferred insulation blowing agent but research is continuing into vacuum panels, silica gels, and better HFC blowing agents, HFC-245fa (pentafluoropropane, $C_3H_3F_5$) and HFC-365mfc (pentafluorobutane, $C_4H_5F_5$).

Developed country servicing is kept to a minimum and Europe will ban service use at short notice, whereas in developing countries there is a need for further evaluation of servicing practices.

Commercial refrigeration

In Northern Europe, there is some use of HFC-134a and hydrocarbons for stand-alone equipment. Worldwide the vast majority of equipment has been taken over by the zeotropic blend, R-404a (HFC-143a/HFC-125/HFC-134a). There is also widespread use of HCFC-22 in commercial refrigeration. Use of the zeotropic blend, R-407c (HFC-32/HFC-125/HFC-134a), and the azeotropic blend, R-507a (HFC-143a/HFC125), is much smaller. Early phase-out of HCFCs in new and existing equipment in Europe implies that recovery efforts will not be profitable and will not be undertaken. This would result in the venting of the HCFC bank of refrigerant.

Cold storage and industrial refrigeration

The phase-out of ozone depleting substances in Europe has seen ammonia further strengthen its position in the cold storage and food processing sub-sector. There is negligible use of HCFC. New systems have been developed using carbon dioxide as a secondary refrigerant. Ammonia charge is reduced by 90% without any loss in efficiency. Ammonia has displaced HCFCs in fishing vessels and factory ships in Northern Europe. Developments are taking place with the use of carbon dioxide as a secondary refrigerant.

There is some use of R-404A and R-507A for smaller industrial systems up to 200–300 kilowatts refrigerating capacity. R-410A (HFC-32/HFC-125) has been identified as the most promising HFC for industrial purposes, especially for low temperature freezing. Market penetration was slowed because it is a high pressure refrigerant but the recent development of new compressors is expected to promote greater use of R-410A. Combinations of HFCs with carbon dioxide as a secondary (or primary) refrigerant are being evaluated.

Industrial chillers for process cooling continue to favour HCFC-123 and HCFC-22. Use of HFC-134a is increasing and low charge ammonia chillers have increased their market share. Hydrocarbon chillers have been available in Europe for some time but have not achieved widespread application.

Overall, ammonia is expected to increase in market share with HCFC-22 remaining the most popular refrigerant until such time as changes in equipment and refrigerants must be made.

Unitary airconditioning

HCFC-22 remains the refrigerant of choice in unitary airconditioning. There has been movement towards non-ODP technologies in Japan with R-407C and R-410A replacing HCFC-22 in approximately 15% of unitary products. In the USA, some residential ducted products have been produced with R-410A but development of non-ODP technologies has been occurring at a much slower pace. European markets face stronger pressures from the phase-out schedule for new products and servicing. Adoption of non-ODP technologies is more rapid with hydrocarbon and HFCs being used as replacements, and there is the possibility that R-407C will be preferred. Adequate data on which to base an overall assessment are not available. Propane (R-290) and to a lesser extent, ammonia, are seen as the most likely alternatives to HFCs in the mid-term. For larger systems this would imply the application of secondary loops with related energy efficiency impacts.

Chillers

HCFC-123 has become the preferred refrigerant for chillers following the phase-out of CFC-11. In the USA, HCFC-123 is the most widely used substance in new centrifugal chillers. The primary non-ODP alternative in chillers is HFC-134a with some use of R-407C for smaller water chillers.

The popularity of HCFC-123 chillers is due to the fact that they offer very good energy efficiency and a very low net (refrigerant release and energy related) global warming impact. Despite this advantage, HCFCs will be phased-out and alternatives to HCFC-123 will need to be developed, although it is likely that further debate and controversy might arise.

The prospect of controversy is reflected in the Joint IPCC/TEAP Meeting Report on Options for the Limitation of Emissions of HFCs and PFCs (IPCC and UNEP TEAP 1999) as follows:

The working group addressed the question of refrigerant selections for large chillers. The majority of new centrifugal chillers currently use HCFC-123 as a replacement for CFCs. The next most common refrigerant in this application is HFC-134a (ODP 0 and GWP 1300); neither ammonia nor hydrocarbons are used in centrifugal chillers for safety and performance reasons. Data from peer reviewed journal publications were presented to show that the phase-out of HCFC-123 will increase net impacts on global warming by 14–20% (above non-HCFC chiller applications), owing primarily to its efficiency advantage, as contrasted to less than a 0.001% increase in peak bromine-chlorine loading. There was strong controversy in the working group on whether to consider an HCFC (an ozone depleting substance) as an alternative to avoid increased use of HFCs. There was also controversy on whether energy related impacts should be addressed at this meeting. The working group voted to note that HCFC-123 use warrants examination for chillers based on its negligible impact on ozone depletion and strong benefit in reducing global warming.

(IPCC and UNEP TEAP 1999; p. 32)

Certain high pressure HFC (HFC-134a) equipment may also take over the low pressure market in the future (or in those countries with very stringent short-term HCFC regulations). Continued improvement of emission reductions for both low and high pressure equipment is anticipated.

Transport refrigeration

HFC-134a and R-404A have largely displaced CFC refrigerants in transport applications with HFC-134a used in smaller capacity units and R-404A used in larger capacity units. As yet there appears to be no consensus on the level of acceptable risk for secondary loop systems using flammable refrigerants.

There remain systems on reefer containers using CFC-12, but the European Union countries plan to forbid the use of certain equipment containing CFC-12 in the near future. R-410A is expected to be one

of the most important refrigerants in transport refrigeration. In developing countries, the use of HCFC-22 is expected to continue in the foreseeable future eventually being displaced by HFC-134a.

Mobile airconditioning

By the end of 1994, all developed countries had converted from CFC-12 to HFC-134a for mobile airconditioning. A substantial CFC-12 containing stock of vehicles existed at the time and these will continue in service for several more years until they are retired or scrapped. Over this period they will lose most of the charge and increasing scarcity of CFC-12 will limit servicing. CFC-12 continues to be used in developing countries.

Heat pumps (heating only and heat recovery)

HCFC-22 is still the most important HCFC refrigerant for the heat pump industry in terms of volume. Most European Union countries have regulations on HCFCs in order to phase them out more rapidly than has been agreed under the Montreal Protocol.

HFCs are currently the most important alternative refrigerants, both for new installations and for retrofits, although retrofits are being carried out at a lower rate than expected. Small units are permitted to run their lifetime with the original refrigerant, and are replaced only when they breakdown. HFC-134a is applied for retrofitting larger, existing heat pumps that use CFC-12, and for charging new large and medium scale installations. HFC-134a heat pump technology is considered fully mature for new systems, but too expensive for use in smaller systems.

R-407C, R-410A and R-404A are the most promising HFC blend alternatives to replace HCFC-22 for heat pump applications. Units with R-404A and R-407C have been on the market for a few years. Although a few units with R-410A are already available, several manufacturers now using R-407C have indicated a shift to R-410A within the next three to five years.

Ammonia has a small but growing share of the market. Hydrocarbon blends and hydrocarbons like propane and propylene are used in residential heat pumps mainly in Europe. Carbon dioxide units have been developed with the first heat pump water heaters installed and available from the manufacturer.

Option	Advantages	Disadvantages
Use of hydrocarbon refrigerant	No HFC emissions Commercially available Broad availability of proven technologies in most applications	Higher investment costs for secondary systems Flammability issues for primary systems Often increased energy consumption for secondary systems, if needed Potentially higher maintenance costs
Use of ammonia	No HFC emissions Commercially available Especially high energy efficiency in freezing applications Broad availability of proven technologies in most applications	Higher investment costs for secondary systems Flammability and toxicity issues for primary systems Often increased energy consumption for secondary systems, if needed Potentially higher maintenance costs Objectionable aroma
Use of alternative technology (i.e. absorption)	No HFC emissions No validation issues	Often higher energy consumption Most common working pairs, involving water, cannot operate at temperatures below freezing
Reduction of leakage rates through improved design and quality of components	Potentially very cost effective	Depends on service training and motivation Enforcement critical for systems too small to be profitable and to avoid low-quality after-market parts
Reduction of leakage rates through improved maintenance	Potentially very cost effective	Enforcement critical for systems too small to be profitable
Recovery during service and disposal	Highly profitable for large systems, very cost effective for systems over 0.5 kilograms	Depends on service training and motivation Enforcement critical for systems too small to be profitable
Minimising charge of HFC refrigerant	No flammability issues No significant increase of costs for primary systems	Increased energy consumption for secondary systems Higher investment costs for secondary systems Increasing service requirement
Reduced demand for refrigeration and air conditioning	Energy savings	Often requires integrated solutions in e.g. architecture, logistics and agricultural policy

Table 62. Advantages and disadvantages of emission reduction options – refrigeration and airconditioning

Source: UNEP (2000; p. 85)

Restrictions in the European Union

In the European Union, a new regulation will ban sales and service of CFCs in equipment by the end of 2001. A similar ban is planned for HCFCs for 2007. These bans could have the effect of leading to CFCs and HCFCs being vented to the atmosphere unless proper control measures are implemented. Existing and proposed controls on ozone depleting substances in the European Union are shown in Table 63. The controls apply to production and consumption, except for HCFCs where consumption only is restricted. The proposed regulation envisages a phase-out of HCFC production by 2026 (Oberthur and Pfahl 2000; p. 16).

Substances (baseline)	Montreal	Regulation (EC)	Proposed regulation
	Protocol	3093/94	(common position)
CFCs-11, 12, 113-115 (1986)	1996:-100%	1995:-100%	Banned
Halons 1211, 1301, 2402 (1986)	1994:-100%	1994:-100%	Banned
CFCs-13, 111, 112, 211-217 (1989)	1996:-100%	1995:-100%	Banned
Carbon tetrachloride (1989)	1996:-100%	1995:-100%	Banned
Methyl chloroform (1989)	1996:-100%	1996:-100%	Banned
HCFCs (1989 plus 2.8% of 1989	1996: freeze	Baseline: cap of	1999: freeze
CFC consumption ("cap"))	2004:-35%	2.6%	2001: freeze (cap of 2%)
	2010:-65%	1995: freeze	2002:-15% (cap of 2%)
	2015:-90%	2004:-35%	2003:-55% (cap of 2%)
	2020:-99.5%	2007:-60%	2004:-70% (cap of 2%)
	2030:-100%	2010:-80%	2008:-75% (cap of 2%)
		2013:-95%	2010:-100%
		2015:-100%	
HBFCs	1996:-100%	1996:-100%	Banned
Methyl bromide (1991)	1995: freeze	1995: freeze	1999:-25%
	1999:-25%	1998:-25%	2001:-60%
	2001:-50%		2003:-75%
	2003:-70%		2005:-100%
	2005:-100%		
Bromochloromethane			Banned

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Source: Oberthur and Pfahl (2000; p. 16)

9.2.2 Foams

There are a range of different types of foams designed for different purposes and blown with different blowing agents. Table 64 shows the regional breakdown of current blowing technology. There is no use of CFCs in North America, Europe and Japan, but they continue to be used in Latin America, India and China. There are no data on use in other regions of the world. HCFCs are still popular as foam blowing agents in all regions although use in Europe is small.

Table 64. Regional breakdown of current blowing technology

Blowing agent	North	Europe	Japan	Latin	India	China
	America			America		
CFCs	No	No	No	30%	Yes	20%
HCFCs	Yes	<5%	25%	50-60%	Yes	30%
C-pentane/iso-pentane (70/30)	No	35%	No	Yes	Yes	No
HFC-134a	Yes	Yes?	Yes?	No	No	No
C-pentane/isobutane (80/20)	No	<15%	No	No	No	No
C-pentane	No	50%	75%	10-20%	Yes	50%

Source: UNEP (2000; p. 59)

Methylene chloride is the major ozone depleting substance phase-out technology for polyurethane slabstock foams. Liquid carbon dioxide is growing in use. Low index additives are being used in box foams where liquid carbon dioxide is not used.

Carbon dioxide as CO_2 (water) is the most widely used replacement technology for moulded foams. Flexible integral skin foams are inclined towards the use of HFCs to meet process safety requirements of the automotive industry amongst others. The cost of modification for hydrocarbons is excessive and CO_2 (water) systems do not have the required mechanical properties.

Rigid appliance foams are blown with HCFCs and hydrocarbons (for example, domestic refrigerators) along with increasing interest shown in HFC hydrocarbon blends. Research into liquid HFCs is being undertaken in the USA and Europe with two promising HFCs identified, HFC-245fa and HFC-365mfc. It is possible that the USA will prefer HFC-245fa (developed by General Electric – formerly Allied Signal acquired by Honeywell and since acquired by General Electric) and Europe will prefer HFC-365mfc (developed by a group headed by Atofina – formed through a merger between Elf Atochem and Total Fina). Hydrocarbons are less common in the USA than in Europe due to differences in product design and energy performance criteria. Around 60% of developing countries are adopting hydrocarbons with the balance choosing HCFCs.

Rigid flexible faced laminate producers are pursuing a dual strategy to convert some lines to HFCs and other lines to hydrocarbons. HFC blends of liquid HFCs and HFC-134a are gaining in popularity where flammability issues are pronounced. The non-azeotropic blend of HFC-365mfc and HFC-134a can become flammable if the HFC-134a evaporates prematurely. Careful handling will minimise the risk of accident. Thermal efficiency requirements are also leading to the evaluation of the use of HFC and hydrocarbon blends. These blends are less expensive than those using liquid HFCs.

Spray foams continue to rely on HCFCs. Hydrocarbons, CO₂(water) and HFC blends incorporating some of the liquid HFCs (245fa and 365mfc) are being evaluated. The cost and availability of liquid HFCs have caused uncertainty and these issues are yet to be resolved.

Extruded polystyrene continues to rely upon HCFC-142b and blends of HCFC-142b/HCFC-22 as the primary blowing agents due to their strong insulation properties. Viable zero ODP alternatives are:

- HFC-152a
- blends of HFC-142a and 134a
- HFC-134a and an organic co-blowing agent (for example, ethanol)
- carbon dioxide and an organic co-blowing agent
- 100% carbon dioxide

Although HFC-152a produces foam with reasonably low density, it needs careful handling due to its flammability, it has a somewhat lower insulation value than HFC-134a, and polystyrene has a relatively high permeability to HFC-152a.

HFC-134a cannot be used alone because of its very low solubility in polystyrene and requires a coblowing agent such as ethanol. Blended with HFC-152a, HFC-134a has the potential to achieve a balanced set of functional properties and a Swedish company has successfully used HFC134a/HFC152a blends since 1996.

Carbon dioxide with an organic co-blowing agent has been developed and refined and could grow in significance. The foam demands longer curing times to disperse the ethanol which rapidly diffuses out of the foam creating potentially flammable mixtures. Long-term insulation performance is 15% to 20% worse than for foam where the HFC-134a content is maximised.

Use of carbon dioxide alone imposes performance penalties for a given thickness and density, and cost penalties for increasing thickness to maintain thermal resistance. In some applications carbon dioxide foams can and do compete with HFC foams.

9.2.3 Aerosols, sterilants, miscellaneous uses and carbon tetrachloride

Aerosol products (other than metered dose inhalers) in developed countries no longer use CFCs, and there are no technical impediments to the replacement of CFCs in aerosols in other countries. Substances used in aerosols perform two functions – to operate as a propellant and to dissolve or hold in suspension the substance that it is desired to deliver by way of the aerosol. Appropriate combinations of aerosol substances promote consistent delivery of a fine spray at a constant pressure during the life of the product. Substitutes for CFCs need to maintain the desirable attributes which accounts for continued use of CFCs in metered does inhalers and aerosols for chronic obstructive pulmonary disease.

With the exception of metered does inhalers and aerosols for chronic obstructive pulmonary disease there are several substitutes for all aerosol applications (Table 65). Hydrocarbon aerosol propellants (HAPs) are the principal substitutes for CFCs. The limitation of HAPs is flammability which impacts on siting of plants and storage facilities and requires careful management of manufacturing facilities.

Alternative propellants	Alternative solvents	Alternative delivery systems		
Hydrocarbons and blends (propane,	Water	Finger pumps, trigger		
n-butane, isobutane)	Alcohols (ethanol, 1so-propanol,	pumps, and air sprays		
Dimethyl ether	n-propanol)	Sticks (deodorants and		
Compressed gases (air, CO ₂ , N ₂ , N ₂ O)	Chlorinated (methylene chloride,	antiperspirants, insect		
HFCs (152a, 134a, 227ea, 236fa)	trichloroethylene,	repellents)		
HCFCs (22, 142b)	perchloroethylene)	Roller ball, brush, cloth, etc.		
	Pentane, hexane, white spirits,	Powder inhalers and		
	acetone, methyl ethyl ketone,	nebuliser systems		
	methyl iso-butyl ketone, glycols,	(pharmaceutical products)		
	etc.	Bag-in-can systems and		
	HCFC-141b, HFC-43-10-mee,	piston-can systems		
	HFC-245fa, hydrofluoroethers, etc.			

Table 65. Substitutes for CFCs in aerosol products

Source: UNEP (2000; p. 44)

Dimethyl ether has become increasingly popular in Europe and the USA. It is used as a combination propellant and solvent replacement. It is a flammable liquefied propellant that requires careful handling. Additional safety measures need to be implemented where contact with electrical equipment could occur.

HFC-134a, HFC-152a, HFC-227ea and HFC-43-10mee are among several HFCs that are being commercialised for aerosol use. HFC-236fa and HFC-245fa are other HFCs that could find application in aerosols. HFC-134a and HFC-152a are the least expensive of the HFCs and this will influence the extent of adoption.

HFC-152a is very slightly flammable, has a medium vapour pressure, no ODP and the lowest GWP of the HFCs. These characteristics increase its acceptability as a propellant and it is estimated that around 10000 tonnes per year are used in the USA. Compared with HAPs, HFC-152a is expensive and would not be used in the absence of volatile organic compound controls.

HFC-134a is replacing CFC-12 in metered dose inhalers. It is also the main non-flammable propellant in certain industrial products. Note that in metered dose inhalers, CFC-12 is used as the propellant and CFC-11 is used as the vapour depressant and solvent. HFC-134a usage is projected to be modest. Total use in the USA is estimated to be 5000 tonnes for aerosol applications (including metered dose inhalers).

HCFC-22 and HCFC-142b can be used propellants, but use is restricted in the European Union and the USA. HCFC-141b is an aggressive solvent once considered to be a replacement for CFC-113. It needs to be mixed with milder solvents when used in electronics or other sensitive applications.

Compressed gases (air, molecular nitrogen, carbon dioxide, and nitrous oxide) normally produce coarser spray patterns unless special valves are used. They produce a wet spray, and pressure decreases because they expand while the can is emptied. This causes the spray pattern quality to lower. Filling technology and quality control for compressed gases is much more demanding than for liquefied propellants. Compressed gases are used in about 5% to 9% of all aerosol products.

Methyl chloroform, CFC-113 and carbon tetrachloride have all been used as solvents in aerosol formulations, and continues to be used in developing countries and countries with economies in transition. Carbon tetrachloride and methyl chloroform have very high solvency power whereas CFC-113 has very low power. CFC-113 was used as a solvent in non-aerosol applications for drycleaning. Methyl chloroform has low exposure levels and carbon tetrachloride is a known carcinogen. Neither substance is considered acceptable for continued use.

Apart from metered dose inhalers, medical aerosol products and industrial and technicality specialities have posed the main difficulties for aerosol reformulation. These other medical products include nasal preparations, local anaesthetics, wound sprays, antibiotics, antiseptics, ancillary products and traditional Chinese medicine. Topical sprays can use HAPs, dimethyl ether or nitrogen, and nasal and throat products can use HFC-134a. Not-in-kind alternatives such as pump sprays, powders, liquids and creams can also be considered.

Industrial and technical specialities that have experienced problems with reformulation include electronic cleaners, dusters, fault detectors, mould releases, aircraft disinfectants and insecticides, weld anti-spatter, polyurethane foams, and aerosol horns. Where flammability is a concern HFC-134a is close to a direct substitute for CFC-12. HFC-152a can be used, but it is slightly flammable. HCFC-141b can be mixed with CFC-113 for electronic cleaners, but the mixture needs to be carefully controlled due to the solvency power of HCFC-141b, which can damage sensitive plastic materials. HFC-43-10mee, volatile silicones and hydrofluoroethers could replace CFC-113 but are very expensive.
Metered dose inhalers for asthma and chronic obstructive pulmonary disease remain as the use where substitutes are more difficult to develop. The trends from the Essential Use Nominations for CFCs for metered dose inhalers are:

- recent CFC requirements in Essential Use Nominations appear to be much closer to actual use than earlier estimates in 1996 and 1997
- total CFC use for metered dose inhalers for essential uses has fallen by 9.5% from 8290 tonnes in 1996 to an estimated 7501 tonnes in 1999
- while the overall trend is for a reduction in CFC use, occasional local increased use by a Party usually reflects a change in regional circumstances; for example relocation of CFC-metered dose inhaler manufacture from Canada to USA
- from these data it would appear that the reduction in CFC use for metered dose inhalers is slower than anticipated. Of the estimated 450 million metered dose inhalers manufactured worldwide in 1999 approximately 380 million are CFC based metered dose inhalers and 70 million HFC metered dose inhalers.

In most developed countries, approvals have been given for at least one HFC based metered dose inhaler. One company has developed a metered dose inhaler with isobutane propellant and there are continuing investigations of dry powder inhalers. UNEP (2000) comment that experience indicates that a coordinated approach between health and environmental authorities is needed to:

- ensure the development of national strategies for transition to CFC-free alternatives
- ensure that the transition process is perceived as both an environmental and a health priority, not an environmental priority alone.

Global factors that require consideration include:

- the flow of CFC based metered dose inhalers from exporting countries to importing countries both to assure that importing countries have access to essential products and to prevent the unnecessary exportation of CFC based metered dose inhalers to countries where CFC alternatives are available
- the likely need for metered dose inhaler manufacturing companies to move their bulk CFC supplies in order to manage effectively the tail of the transition – Montreal Protocol controls and national regulations may not currently permit this
- the importance of assuring the continued availability of pharmaceutical grade CFC for essential use production throughout the entire transition process which is occurring at a different pace in different geographical regions. Potential difficulties in maintaining supply of pharmaceutical grade CFC at the tail of the transition are anticipated and consideration should be given to this issue.

The experience with transition to date is that it is occurring seamlessly and without significant adverse effects. The phase-out of CFC-12/ethylene oxide mixtures in sterilisation is effectively complete.

Carbon tetrachloride is still being used as a feedstock in the production of CFCs and this is the primary source of emissions. Emissions also arise from carbon tetrachloride use as a solvent and for laboratory and analytical purposes. These emissions originate mainly in developing countries and countries with economies in transition.

9.2.4 Halons

Developing country phase-out of halons is substantially completed. Some essential uses continue in military and aircraft applications, and in shipping. Alternatives have been developed but long lead times in procurement mean that a few systems are still being procured with halon systems. It is also probable that all hand-held halon systems installed in buildings have not been decommissioned. This is expected to be very small and will further diminish as systems are subjected to compulsory routine checks. Developing countries continue to produce and install halons systems, although production has fallen in China and Russia indicated that halon-2402 production will cease in the summer of 2002. China still produces halon-1301 and halon-1211. The shipping industry has not settled on a universally available substitute. Halon concentrations in the atmosphere continue to increase contrary to the expectations of the Montreal Protocol.

9.2.5 Solvents

Detailed assessment of solvents is provided in UNEP (1998b) with a brief update in UNEP (2000). CFCs have largely been eliminated in solvent applications where there are no technical reasons for continued use. They are still used in some aerosol preparations and in the aerospace industry. With the exception of residual uses from private stockpiles, if any, CFC-113 and methyl chloroform have disappeared from drycleaning applications, and are now replaced by perchloroethylene or hydrocarbon solvents.

Methyl chloroform has almost been completely eliminated from adhesive applications in developed countries, but it continues to be used in some developing countries. Alternatives to CFC-113 and methyl chloroform are available for most metal cleaning applications and have been adopted. In developing countries there is some high risk use of carbon tetrachloride.

There are several choices available to replace CFC-113 in electronics cleaning. These range from 'no clean' soldering technologies, solders based on water soluble chemistry, saponifier defluxing, to hydrocarbon surfactant. Hydrocarbon surfactant has not fulfilled its initial promise and straight hydrocarbon defluxing is rare due to flammability concerns.

Precision cleaning has presented several challenges. Aqueous and semi-aqueous cleaning have been proven successful in some applications, and HCFCs, HFCs, and HFEs have been shown to be useful in precision cleaning.

UNEP (1998b) expressed concerns about the marketing of some substances that have not been properly assessed, foremost amongst these being n-propyl bromide and chlorobromomethane. These two substances are also blended into solvent mixtures that are sold under many trade names. Both substances have been assigned ODPs, and n-propyl bromide is not recommended as a substitute for other ODP solvents. Chlorobromomethane was added to the list of controlled substances by the Beijing Amendment to the Montreal Protocol.

UNEP (2000) highlights several developments in specialist technical applications as follow:

- parachlorobenzotrifluoride is being used as a replacement for methyl chloroform used for some speciality paints and coatings
- blasting carbon dioxide pellets is showing good results in cleaning titanium surfaces
- flakes have been adopted by some organisations for cleaning sensitive optics.

With regard to the aerospace industry:

- major aircraft manufacturers still rely on the use of stockpiled CFC-113 as a lubricant and coolant in certain drilling and riveting operations, particularly for wing assemblies; complete elimination of CFC-113 for such application is being sought
- HFE-7100 is being used successfully to clean up hydraulic fluid from systems with complex configurations
- although CFC-113 is still prescribed in the specifications of some manufacturers for oxygen systems maintenance, HFE-7100 is being successfully used for all cleaning operations including elimination of fluorinated greases
- methyl chloroform or CFC-113 is still being used for critical bonded joints of aerospace assemblies.

UNEP (1998b; p. ES-1) observed that cost of alternative solvents was an issue. Unlike the ozone depleting solvents, the alternatives market is made up of many suppliers with numerous alternatives, many of which are variations or blends marketed under trade names of the same alternative. The dispersed nature of this market has made the economies of scale realised in the past impossible today. Therefore, alternatives in general remain expensive relative to the ozone depleting solvents they replace, particularly for speciality uses.

UNEP's comment is not entirely accurate in its reference to economies of scale. Economies of scale could still be achievable in the production of blend components. Product differentiation in terms of a proliferation of trade names and blends is likely to lead to market confusion and increase the search costs associated with obtaining substitutes. Further, it could lead to situations where users obtain ozone depleting substances rather than an ozone depleting substance substitute as a result of a lack of information and transparency in the marketplace.

9.3 SALES OF CFCS, SELECTED HCFCS AND HFC-134A

Table 66 through to Table 75 show sales for selected substances by sector of use. These data are compiled by AFEAS and have the same degree of coverage as the production data referred to above. Overall the sales data exhibit the pattern that would be expected where substances are being eliminated from non-essential uses.

9.3.1 Sales of CFCs

CFC-11

A slightly anomalous aspect of the data is that there appears to be continued use in applications that are not expected. Most of the CFC-11 production is used in closed cell foam (61% in 1999), the dominant use prior to phase-out, and most CFC-12 production is used in refrigeration and airconditioning (77% in 1999), again the dominant use prior to phase-out. Further CFC-11 use for closed cell foam has grown each year from 1996 to 1999 (4186 tonnes in 1996 to 7824 tonnes in 1999). This situation prevails because the production and sales data include some countries that have not been subject to the same phase-out schedule as the developed countries.

Table 66 . Sales of CFC-11

Year	Refrigeration and air	Closed cell foams	Open cell foams	Aerosol propellant	All other uses	Total sales
	conditioning (tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	20242	144438	38938	18245	11053	232916
1991	20002	148034	27620	11238	6592	213486
1992	17773	137941	17538	8154	5028	186434
1993	16860	106792	11146	7007	5326	147131
1994	12469	35109	7612	4182	860	60232
1995	9253	14259	4562	4102	507	32683
1996	6917	4186	5220	3730	2070	22123
1997	6209	6818	2250	2456	844	18577
1998	3777	6777	1637	1607	802	14600
1999	844	7824	1145	918	2140	12871
Total	114346	612178	117668	61639	35222	941053

Source: AFEAS (2001)

CFC-12

Table 67. Sales of CFC-12

Year	Refrigeration and air	Closed cell foams	Open cell foams	Aerosol propellant	All other uses	Total sales
	conditioning	(termes)	(to man)	(town co)	(termos)	(10,000,00)
	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	161670	23023	4391	30449	11417	230950
1991	174976	18673	1370	19296	10490	224805
1992	177405	13723	543	14712	9824	216207
1993	189052	7668	784	12080	5080	214664
1994	119039	3265	658	7879	2759	133600
1995	71159	1099	658	8618	1288	82822
1996	41188	600	1090	3951	2027	48856
1997	24899	593	867	4532	2009	32900
1998	26885	576	631	2957	2220	33269
1999	21109	489	470	1220	3844	27132
Total	1007382	69709	11462	105694	50958	1245205

Source: AFEAS (2001)

CFC-113

CFC-113 sales have been virtually eliminated. The main short-term use was as a solvent (in aerosols and otherwise) and these data indicate that alternatives have displaced CFC-113 across all of the countries that report to the AFEAS Survey including developing countries. Minor uses were as a blowing agent, and as a refrigerant and heat transfer fluid.

Year	Short lifetime	Long lifetime	All other uses	Total sales
	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	173290	1511		174801
1991	146394	1221	10	147625
1992	104461	3045	1	107507
1993	47122	883	32	48037
1994	28960	548	39	29547
1995	23024	225	72	23321
1996	5497	470	40	6007
1997	2998	10		3008
1998	1466	2	121	1589
1999	945	2	53	1000
Total	534157	7917	368	542442

Table 68. Sales of CFC-113

Source: AFEAS (2001)

CFC-114

Short lifetime uses of CFC-114 comprised aerosols, cleaning and drying, blowing agent in open cell foam and closed cell polyolefin foam and as a solvent. Long lifetime uses comprise as a refrigerant (including extensive use in airconditioning where high ambient temperatures were prevalent) and blowing agent in closed cell foam except closed cell polyolefin foam. As with CFC-113, sales of CFC-114 are very small relative to the period when the phase-out commenced.

Year	Short lifetime	Long lifetime	All other uses	Total sales
	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	5336	2973	2	8311
1991	4270	2381	7	6658
1992	2958	1732	1	4691
1993	2979	1587	10	4576
1994	1820	1385	2	3207
1995	978	2156	1	3135
1996	422	291		713
1997	530	611	55	1196
1998	1173	26		1199
1999	252	40		292
Total	20718	13182	78	33978

Table 69. Sales of CFC-114

Source: AFEAS (2001)

CFC-115

CFC-115 was used predominantly in long lifetime uses comprising as a refrigerant, blowing agent for closed cell foam, and dielectric fluid. Sales of CFC-115 in 1999 were 3.5% of sales in 1990 and have declined rapidly since 1993. CFC-115 was used as part of a zeotropic blend, R-502 (CFC-115 (51%) and HCFC-22 (49%)), that was an important low temperature refrigerant. In addition, R-502 was used in transport refrigeration.

Year	Short lifetime	Long lifetime	All other uses	Total sales
	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990		11325	22	11347
1991		12249	27	12276
1992		10667	44	10711
1993		11391	20	11411
1994	3	6786	45	6834
1995		3651		3651
1996		2019		2019
1997		836		836
1998	7	915		922
1999		396		396
Total	10	60235	158	60403

Table	70.	Sales	of	CFC	-115
Inon	10.	Juico	v_{I}	CI C	, 110

Source: AFEAS (2001)

9.3.2 Sales of HCFCs

In most cases, sales of HCFCs have continued to grow since 1990. These are important transitional substances and availability and suitability has facilitated the rapid phase-out of CFCs. Examination of annual changes in sales do not provide substantial evidence that consumption of HCFCs is declining rapidly, although in most cases sales appear to have stabilised from around 1996. Sales of the high volume substances, HCFC-22 and HCFC-142b, have grown less in the 1990s than in the 1980s. From 1980 to 1989, sales of HCFC-22 grew by 74% whereas from 1990 to 1999 sales grew by 18%. In the case of HCFC-142b, sales grew almost fourfold from 1981 to 1989, and by 226% from 1990 to 1999. The most spectacular growth in sales has occurred with HCFC-141b with sales increasing from 99 tonnes in 1990 to 132355 tonnes in 1999. Sales of HCFC-141b have grown continuously from 1990 to 1999 (Table 72).

Table 71. Sales of HCFC-124

Year	Refrigeration and air conditioning	Closed cell foams	Medical aerosols	Solvent applications	Other short- term uses	Total sales
	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1991					17	17
1992	1	15			83	99
1993	423	10			109	542
1994	797	30			85	912
1995	2020	20			1057	3097
1996	2351				2514	4865
1997	1681	25			2652	4358
1998	4763	20			469	5252
1999	2281	20			704	3005
Total	14317	140	0	0	7690	22147

Source: AFEAS (2001)

Year	Refrigeration	Closed cell	Medical	Solvent	Other short-	Total sales
	conditioning	TUallis	de105015	applications	term uses	
	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	3	83		8	5	99
1991	1	1228		260	18	1507
1992	48	10547	13	2418	228	13254
1993	451	34682	131	7596	431	43291
1994	577	67236	6	12501	911	81231
1995	898	94338	48	16564	1306	113154
1996	2617	106057	555	11274	586	121089
1997	557	110317		11468	14	122356
1998	578	114048	770	11408	1557	128361
1999		120655	18	11616	66	132355
Total	5730	659191	1541	85113	5122	756697

Table 72. Sales of HCFC-141b

Source: AFEAS (2001)

When analysing sales of most of the HCFCs (HCFC-141b excepted) a factor that needs to be borne in mind is that these substances are blended with HFCs, PFCs and hydrocarbons in the refrigerant market. The R-400 series of refrigerants, of which there are several, include around 10 zeotropic blends that use HCFCs as part of the blend. It is likely that the stabilisation in sales from around 1996 is due to increasing market penetration of blends that include HCFCs and those that use HFCs only.

Isolation of trends due to increases in refrigerant demand, replacement of CFCs, and adoption of blends as part of moving from CFCs to HCFCs to HFCs is impossible without data on sales of blends and HFCs. AFEAS are unable to collect and collate data unless there are at least producers each producing 1000 tonnes or more per year. This explains the omission of HCFC-123 from the AFEAS datasets, and constrains the time period over which data on HFCs might be expected to become available as part of the AFEAS Survey.

Year*	Refrigeration and air	Closed cell foams	Medical aerosols	Solvent applications	Other short- term uses	Total sales
	conditioning					
	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1993	6	31163	671	240	1602	33682
1994	36	36282	537		1506	38361
1995	412	34636			3663	38711
1996	651	34989			2471	38111
1997	635	38757			1210	40602
1998	637	37092			245	37974
1999	924	41325		61	106	42416
Total	3301	254244	1208	301	10803	269857

Table 73. Sales of HCFC-142b

*Data for earlier years are classified by lifetime of the use; Source: AFEAS (2001)

Table 74. Sales of HCFC-22

Year	Short lifetime	Long lifetime	All other uses	Total sales
	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	31016	180849	1849	213714
1991	27135	201946	7731	236812
1992	30288	206763	8664	245715
1993	22746	204337	13536	240619
1994	24864	207515	7065	239444
1995	27781	203199	12488	243468
1996	32776	230361	8106	271243
1997	16602	230659	3847	251108
1998	9216	241139	10820	261175
1999	12130	231620	8625	252375
Total	335144	3627986	84341	4047471

Notes:

Short Lifetime (<1 year) – for example: aerosols, open cell foams, plus fugitive emissions Medium Lifetime (1-10 years) – for example: refrigeration, heat pumps, air conditioning Long Lifetime (>10 years) – for example: closed cell thermoset foams Total sales equals sales for dispersive uses plus fugitive emissions Source: AFEAS (2001)

9.3.3 Sales of HFC-134a

Table 75. Sales of HFC	-134a
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Year*	Refrigeration and air conditioning	Closed cell foams	Medical aerosols	Solvent applications	Other short- term uses	Total sales
	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)	(tonnes)
1990	77				112	189
1991	2129	1	28		40	2198
1992	5967	102	71	1	263	6404
1993	24526	291	279	102	1328	26526
1994	46111	1461	535	16	2277	50400
1995	61291	1981	1531	28	8938	73769
1996	71044	2658	630	25	9317	83674
1997	90930	3579	2643	46	4739	101937
1998	96611	9087	1336	71	5130	112235
1999	111221	8108	2112	2010	10211	133662
Total	509907	27268	9165	2299	42355	590994

Source: AFEAS (2001)

9.3.4 Comparisons of sales data and emissions

Another way of analysing the AFEAS data is to examine the relationship over time between emissions and sales (Figure 17). An increasing ratio of emissions to sales would be expected for substances as they are being phased-out, if they are predominantly used for activities that are not directly emissive.

Substances in medium-term and long-term uses would tend towards ratios greater than one. Substances that are being introduced to the market would exhibit initial ratios of much less than one as the majority of sales would be contained in original equipment, and emissions would comprise fugitive emissions and equipment and product manufacturing emissions (for example, losses on charging or foam blowing). As market penetration increases, all other things equal, it is expected that the ratio would tend towards a constant value as sales for servicing and sales in original equipment begin to reflect the trend growth in market demand for equipment, and emissions from charging, operation and disposal.





Source: Derived from AFEAS (2001).

Examination of Figure 17 shows that the emissions to sales ratio of the established products is relatively stable throughout the 1980s up until the early 1990s. From around 1993, the ratios for those products that are used in medium and long term applications rises sharply. Higher ratios up to 1999 are associated with CFC-11, CFC-12, CFC-115, CFC-114. The trend increase for CFC-113 is less volatile and sharp than for the other substances, reflecting the dominant use as a solvent – a directly emissive use. The majority of CFC-11 and CFC-12 was used in medium to long term applications and high emissions to sales ratios mirror the fact that there are continuing substantial emissions arising from the bank of equipment (refrigeration and airconditioning) and products (foams).

Data on HCFCs and HFC-134a (Figure 18) exhibit a similar pattern of emissions to sales as that for CFCs in the 1980s.

HCFC-22, the highest volume HCFC, varies within a relatively narrow band with a low of 0.83 in 1990, to a high of 0.94 in 1997 (0.93 in 1999).

HCFC-142b also shows a relatively stable ratio from a low of 0.22 in 1991 to a high of 0.35 in 1992 (0.28 in 1999).

HCFC-141b is the second highest volume HCFC and varies from 0.25 in 1990 to 0.41 in 1999, with a growing trend. Although the dominant use for HCFC-141b and HCFC-142b is closed cell foam, there is significant use of HCFC-141b as a solvent (around 9% of sales).

HCFC-124 is more volatile probably as a result of its use as a component of the blend R-416A (FR-12) that was used in automotive airconditioning for a relatively short period but failed to achieve sufficient market acceptance. HCFC-124 is also a component of R-401A (HCFC-22/HFC-152a/HCFC-124), which is used in refrigeration and airconditioning.

The ratio of emissions to sales of HFC-134a increases from a low of 0.11 in 1991 to a high of 0.54 in 1999 and shows an increasing trend from 1991. This is because HFC-134a is the main ozone depleting substance replacement substance with consistent rapid growth in production. That this ratio is likely to continue to grow because of its initial and continuing use in motor vehicle airconditioning and refrigeration airconditioning, both as a single gas and as part of the blends R-404A (HFC-143a/HFC-125/HFC-134a) and R-407C (HFC-32/HFC-125/HFC-134a), along with developing uses in aerosols and foam blowing.





Source: Derived from AFEAS Survey sales and emissions data (AFEAS 2001)

9.4 INTERNATIONAL ESTIMATES OF HFC EMISSIONS

A report on estimated emissions in the United Kingdom (DETR 1999) projected increasing total HFC emissions under a business-as-usual scenario. The report ignored emissions of HFC-23 from HCFC-22 production and projected an increase of 656% in HFC emissions from 1.26 megatonnes CO₂-e in 1995 to 9.53 megatonnes CO₂-e 2010, (Table 76). The main sources of emissions are projected to be refrigeration and airconditioning (4.65 megatonnes) and foams (2.17 megatonnes). Controls on production and consumption of HCFC-22 will substantially eliminate by-product emissions of HFC-23 by 2010. General aerosols and metered dose inhalers are expected to contribute 1.18 megatonnes and 1.12 megatonnes to emissions respectively.

Market segment	HFC	emissions (Mt CO ₂ -e)	% of total
	1995	2010 (business-as-usual)	emissions in 2010
Refrigeration/airconditioning	0.84	4.65	45
Foam	0.00	2.17	21
General aerosols	0.41	1.18	11
Metered does inhalers	0.00	1.12	11
Solvents	0.00	0.32	3
Losses from HFC manufacture	0.01	0.05	0.5
Fire-fighting	0.00	0.04	0.4
HFC emissions (subtotal)	1.26	9.53	92
HFC-23 from HCFC-22 manufacture	13.95	0.82	8
Total HFC emissions	15.21	10.35	100

Table 76. United Kingdom HFC emissions under a business-as-usual scenario

Source: DETR (1999; p. 49)

The technical opportunities for emission reduction measures can be split into four categories DETR (1999; p. 63):

- 1. minimise emissions throughout the life cycle of a product (for example, reduce leakage rates from refrigeration systems)
- 2. use a zero or low GWP alternative fluid (for example, use carbon dioxide to blow expandable polystyrene foam)
- 3. use an alternative or 'not in kind' technology (for example, use dry powder inhalers instead of metered dose inhalers)
- 4. minimise indirect emissions of carbon dioxide from energy used by users (for example, improve the efficiency of domestic refrigerators).

Some of the measures considered in DETR (1999) are low impact and some are high impact. Low impact measures are based on assumptions such as partial uptake of a zero GWP alternative fluid or a small improvement in leakage rates (for supermarket refrigeration, from 10% to 7%). High impact measures are based on assumptions such as significant uptake of a zero GWP alternative fluid or a large improvement in leakage rates (for supermarket refrigeration from 10% to 5%).

DETR (1999) evaluated the impact on business-as-usual emissions of low impact measures and high impact measures. Included in DETR's full analysis are sulphur hexafluoride from magnesium and electrical insulation, and PFCs from aluminium production and electronics applications.

DETR (1999; p. 65) conclude that the overall emission reduction technical potential from the 2010 business-as-usual outcome is as follows:

- for low impact measures there is an emission reduction potential of 33%, from 12.0 to 8.1 megatonnes CO₂-e in 2010
- for high impact measures there is an emission reduction potential of 53%, from 12.0 to 5.6 megatonnes CO₂-e in 2010.

These results are not distorted by the contribution of HFC-23 from HCFC-22 manufacture or sulphur hexafluoride and PFC emissions because the contribution of these market segments under business-asusual is small. The main market segments with the greatest emissions and the greatest scope for emissions reductions are (in order of importance) supermarket refrigeration, mobile airconditioning, general aerosols and metered dose inhalers.

Compared with 1995 emissions, the business-as-usual emissions are 31% less, the low impact measures achieve a reduction of 54%, and the high impact measures result in emissions falling by 68%. Elimination of HCFC-22 production with the associated HFC-23 by-product emissions is a substantial contributor to the business-as-usual emission reductions.

An earlier report on emissions in the European Union (March Consulting Group 1998) used the same analytical approach that was adopted in DETR (1999). Excluding HFC-23 from HCFC-22 manufacture, the report projected that CO₂-e emissions of HFCs will increase from 5.7 megatonnes in 1995 to 56.3 megatonnes in 2010, an increase of 890%. Emissions from refrigeration and airconditioning are projected to increase from 4.3 megatonnes to 28.2 megatonnes. Substantial emissions are also projected to arise from foams, general aerosols, and metered dose inhalers. Evaluation of the outcomes from low and high impact measures suggested an overall emission reduction potential from the 2010 business-as-usual scenario as follows (March Consulting Group 1998; p. 44):

- for low impact measures there is an emission reduction potential of 41%, from 66.0 to 38.6 megatonnes CO₂-e
- for high impact measures there is an emission reduction potential of 66%, from 66.0 to 22.4 megatonnes CO₂-e.

Market segment	HFC	emissions (Mt CO ₂ -e)	% of total
	1995	2010 (business-as-usual)	emissions in 2010
Refrigeration/airconditioning	4.3	28.2	42.7
Foam	0.00	13.6	20.6
General aerosols	1.3	7.0	10.6
Metered does inhalers	0.00	4.8	7.3
Solvents	0.00	2.0	3.0
Losses from HFC manufacture	0.1	0.5	0.8
Fire-fighting	0.00	0.2	0.3
HFC emissions (subtotal)	1.26	56.3	85.3
HFC-23 from HCFC-22 manufacture	35.0	9.7	14.7
Total HFC emissions	40.7	66	100

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Source: March Consulting Group (1998; p. 32)

It is clear from the analysis that low impact measures would achieve a 5% reduction on 1995 emissions. High impact measures would give a 45% emission reduction. Low impact measures do not achieve the European Union reduction target under the Kyoto Protocol of 8%.

Harnisch and Hendriks (2000) reviewed the estimates of March Consulting Group (1998) while compiling new estimates and undertaking an economic evaluation of emission reductions of HFCs, PFCs and sulphur hexafluoride in the European Union. Their estimates are higher, largely due to different estimates for motor vehicle airconditioning. Harnisch and Hendriks' (2000; p. 51) estimate for 1995 is 34.5 megatonnes compared with the March Consulting Group (1998) estimate of 40.7 megatonnes, and in 2010 their estimate is 72 megatonnes whereas the March Consulting Group's (1998) estimate is 66 megatonnes (p. 53).

Irrespective of which study is used, emissions are projected to increase by a substantial amount. Harnisch and Hendriks (2000; p.59) conclude that emissions of HFCs in 2010 will still be far from saturation. This is because banked amounts of HFCs in airconditioning and refrigeration will still be far from maturity and most emissions associated with the decommissioning of equipment will not yet be relevant due to the young equipment population. The amount of HFCs banked in foams will also be far below maturity by 2010. Emissions in the subsequent commitment periods of the Kyoto Protocol are thus likely to be significantly above the values for the 2008–2012 period.

Table 78 shows estimates of baseline emissions for the USA for 2000, 2005 and 2008. Unlike most other countries, the USA expresses emissions in million metric tonnes of carbon equivalent (C-e) rather than CO_2 -e. To compare CO_2 -e estimates with C-e requires the C-e to be multiplied by 3.67. The USA's emissions are forecast to increase by around 100% from 2000 to 2010 with a 174% increase in emissions arising from the use of ozone depleting substance substitutes (18.6 megatonnes C-e to 51.0 megatonnes C-e).

Sources of high GWP gases	Fore	ecast emissions (Mt	C-e)
	2000	2005	2010
HFC-23 from HCFC-22 production	9.3	8.5	7.0
Electricity transmission and distribution (SF ₆)	7.4	8.2	9.0
Magnesium (SF ₆)	3.0	3.1	3.8
Aluminium (PFCs)	3.0	3.2	3.2
Semiconductors (PFCs)	3.5	7.8	15.7
Ozone depleting substance substitutes	18.6	36.3	51.0
Total high GWP gases	44.8	67.1	89.7

Table 78. Baseline forecast of US high GWP emissions without the Climate Change Action Plan

Source: Harvey (2000; p.i-4)

In 2000, about 68% of the ozone depleting substance substitute emissions are estimated to be HFCs from refrigeration and airconditioning (Table 79). The share of refrigeration and airconditioning sector increases to around 75% in 2010. Emissions from these uses is forecast to increase by 202% from 2000 to 2010 (12.66 megatonnes to 38.22 megatonnes). The main sources of emissions from these end uses in 2010 are motor vehicle airconditioning (16.9 megatonnes), retail food (9.8 megatonnes), residential airconditioning (4.6 megatonnes), and refrigerated transport (2.9 megatonnes). With the exception of residential airconditioning which continues to rely upon HCFC-22, these are the largest sources of emissions in 2000.

End use	20	000	2005		2010		
	Quantity	% of total	Quantity	% of total	Quantity	% of total	
Chillers	1.12	9	1.49	6	1.36	4	
Retail food	2.55	20	4.60	17	9.80	26	
Cold storage	0.13	1	0.27	1	0.46	1	
Industrial process	0.24	2	0.60	2	1.11	3	
Commercial AC	0.01	0	0.25	1	0.85	2	
Residential AC	0.07	1	1.42	5	4.63	12	
Refrigerated	1.20	9	2.45	9	2.89	8	
transport							
Other appliances	0.10	1	0.16	1	0.21	1	
Mobile AC	7.25	57	15.76	58	16.92	44	
Total	12.66		27.01		38.22		

Table 79. Estimated HFC emissions from the refrigeration and airconditioning (AC) sector in the US by end use

Source: Harvey (2000; p. 6-3)

Harvey (2000) considers HFC emission reduction opportunities for all of the sectors specified Table 79. Focusing on refrigeration and airconditioning, some of the most widely recognised approaches to reducing refrigerant emissions include:

- reducing leak rates
- increasing recovery, recycling, and reclaiming
- ensuring proper refrigerant disposal
- use of alternative refrigerants
- use of alternative refrigeration and airconditioning technologies (ibid. p. 6-3).

Table 80 shows the estimated emission reductions in refrigeration and airconditioning from adopting a range of practices.

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1 able 80.	Emission	reauctions	for	selectea	mitiş	zation	options

Mitigation option	Incremental emission		Cumula	ative emission
	reductio	ons	re	ductions
	% reduction	Mt C-e of	Mt C-e	% of baseline
	from 2010 base	2010 base		emissions
Minor repairs	6.49	2.48	2.48	7
Replace major system components	2.44	0.93	3.41	9
Replace minor system components	3.27	1.25	4.66	12
Equipment modification (low emission purge units)	3.83	1.46	6.12	16
Alternative system (ammonia system low cost)	2.65	1.01	7.13	19
Alternative system (ammonia or hydrocarbons for industrial process applications)	0.31	0.12	7.25	19
Alternative system (ammonia system high cost)	0.29	0.11	7.36	19
Alternative system (hydrocarbons for residential refrigeration)	0.08	0.03	7.39	19
Alternative system (CO ₂ system for motor vehicle AC)	5.56	2.13	9.52	25
Alternative system (hydrocarbon for residential unitary AC)	1.51	0.58	10.10	26
Total			10.10	26

Source: Harvey (2000; p. 6-8)

Harvey estimates that emission reductions of around 26% are achievable if all of the practices were to be adopted by the market. It is notable that 16% of emission reductions can be achieved without changing refrigerants or technologies. These reductions are obtained through minor and major system component replacement, and ensuring purge units have low leakage. Surprisingly, Harvey does not make reference to recovery, recycling, reuse or destruction.

9.5 IPCC Special Report on Emissions Scenarios (SRES)

The IPCC published SRES in 2000 (IPCC 2000b). Emissions of synthetic substances are considered in the report under several 'scenario families', which are described in relation to synthetic greenhouse gases as follows (ibid. p. 4):

- 1. The A1 storyline and scenario family describes a future of world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.
- 2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- 3. The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with a reduction in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- 4. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Emissions of HFCs for the years 2000 and 2010 for each scenario family are shown in Table 81.

The scenarios result in increases in emissions ranging from 175% to 193%. The main substance emitted is HFC-134a, followed by HFC-245ca. HFC-245ca is a possible refrigerant that is not yet used in large quantities. According to the IPCC, it is expected to be adopted rapidly and to be used in substantial quantities.

Table 81. Estimated HFC emissions of OECD90* member states

Substance	Unit**	A	1	A	.2	l	31	E	32
		2000	2010	2000	2010	2000	2010	2000	2010
HFC-23	kt	11.9	13.5	11.9	13.7	12.0	13.8	11.8	13.3
HFC-32	kt	0.0	2.3	0.0	2.2	0.0	2.1	0.0	2.0
HFC-43-10	kt	0.0	6.2	0.0	6.0	0.0	5.4	0.0	5.3
HFC-125	kt	0.0	7.6	0.0	7.2	0.0	7.1	0.0	6.9
HFC-134a	kt	55.0	111.0	55.0	105.3	55.0	106.3	55.0	103.2
HFC-143a	kt	0.0	5.8	0.0	5.5	0.0	5.1	0.0	5.0
HFC-152a	kt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFC-227ea	kt	0.0	8.4	0.0	7.7	0.0	8.7	0.0	8.5
HFC-236fa	kt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HFC-245ca	kt	0.0	41.1	0.0	39.2	0.0	40.9	0.0	39.7
Total HFC	kt	66.9	195.9	66.9	186.7	67.0	189.4	66.8	183.9

*OECD90: OECD member states in 1990; **kt = kilotonnes

Source: IPCC data updated since the publication of IPCC (2000)

Table 82 shows the CO₂-e emissions. In 2000, emissions estimates range from 210 megatonnes CO₂-e to 212 megatonnes. By 2010, the range of projected emissions is 383 megatonnes (scenario B1) to 402 megatonnes (scenario A1).

Substance	Unit**	A	<u>A1 A2 B1 B2</u>		A2 B1				
		2000	2010	2000	2010	2000	2010	2000	2010
HFC-23		139551	157928	139103	160289	140444	160908	138263	155999
HFC-32	Gg CO ₂ -e	0	1505	0	1435	0	1334	0	1295
HFC-43-10	Gg CO ₂ -e	0	8004	0	7743	0	7072	0	6851
HFC-125	Gg CO ₂ -e	0	21344	0	20107	0	19772	0	19199
HFC-134a	Gg CO ₂ -e	71500	144270	71500	136907	71500	138141	71500	134162
HFC-143a	Gg CO ₂ -e	0	21996	0	20978	0	19499	0	18931
HFC-152a	Gg CO ₂ -e	0	0	0	0	0	0	0	0
HFC-227ea	Gg CO ₂ -e	0	24411	0	22203	0	25344	0	24791
HFC-236fa	Gg CO ₂ -e	0	0	0	0	0	0	0	0
HFC-245ca	Gg CO ₂ -e	0	23003	0	21960	0	22911	0	22257
Total HFC	Gg CO ₂ -e	211051	402463	210603	391621	211944	394982	209763	383485

Table 82. Estimated HFC CO₂-e emissions of OECD member states

If the emissions are allocated based on population, assuming Australia's share of the OECD90 population is 1.7% and remains constant to 2010, the estimates in Table 82 imply a range of emissions for Australia of 3555 to 3577 gigagrams CO₂-e in 2000, and 6500 to 6821 gigagrams CO₂-e in 2010.

9.6 CONCLUSION

Internationally, the phase-out of CFCs has been successful. There remain issues as to whether HCFC phase-out will proceed as smoothly given that there is no apparent decline in sales and HCFC-141b sales are continuing to grow. This is attributable to the fact that HFC substitutes are not widely available, particularly for foam blowing, and substitution of HFCs in some applications require new technologies. For example, compressors for use with R-410A need to be designed for that purpose. As equipment is scrapped and new units are purchased, market penetration of HFCs will increase with a consequent reduction in sales of HCFCs. This trend is not expected to be observed for several years.

All analyses of market penetration of HFCs demonstrate that they are likely to become a major contributor to greenhouse gas emissions. In the absence of policies designed to limit emissions with an

emphasis on the importance of continuation of good practices adopted during the phase-out of ozone depleting substances, emissions of HFCs are projected to more than double in most developed countries between 2000 and 2010.

10 CFC, HCFC AND HFC REFRIGERANTS: TRENDS AND MELBOURNE REGIONAL EMISSIONS DEDUCED FROM AGAGE GC-ECD AND GC-MS DATA FROM CAPE GRIM, TASMANIA

10.1 INTRODUCTION

The major refrigerant gases world wide, and in Australia, are CFC-12, HCFC-22 and HFC-134a. From the time of their introduction (CFC-12 in 1930; HCFC-22 in 1940; HFC-134a in 1990) to 1998, the refrigeration and air-conditioning industries have been responsible for about 40%, 90% and 70% respectively of these gases in the background atmosphere. In 1998 these industries accounted for 93%, 95% and 78% respectively of CFC-12, HCFC-22 and HFC-134a emissions (AFEAS 2000).

This chapter summarises the past and current levels of CFC-12, HCFC-22 and HFC-134a in the background atmosphere as measured on the AGAGE (Advanced Global Atmospheric Gases Experiment) GC-MS (gas chromatography-mass spectrometry) and GC-ECD (gas chromatography-electron capture detector) instruments at Cape Grim, Tasmania (Prinn *et al.* 2000). The chapter also examines their expected future behaviour.

Presented here are emissions of these and other minor refrigerants, HFC-125 and HFC-152a, in the Melbourne region, as deduced from AGAGE GC-MS and GC-ECD data using inter-species correlation techniques.

10.2 REFRIGERANTS IN THE BACKGROUND ATMOSPHERE

The past, current and possible future levels of the major refrigerants CFC-12, HCFC-22 and HFC-134a in the background atmosphere at Cape Grim, Tasmania, are shown in Figure 19.

The growth of CFC-12 has slowed in recent years due to the Montreal Protocol restrictions on consumption in the developed world (Cunnold *et al.* 1997). Global emissions of CFC-12 peaked in the mid-1980s at about 500 kilotonnes per year and were in 1998 about 150 kilotonnes per year, 75% of which was from developed countries (Prinn *et al.* 1999, 2000; AFEAS 2000). Despite significantly reduced emissions, CFC-12 concentrations are expected to reach a maximum by about 2010 that is 5% to 10% above current levels, followed by a slow decline as the CFC-12 atmospheric destruction process (photolysis) removes CFC-12 from the atmosphere at a rate of about 1% per year. However, the 1998–1999 Cape Grim data suggest that CFC-12 concentrations may peak earlier and at a lower level than predicted.



Measurements observed at Cape Grim Tasmania (♦) and in Antarctic firn air (♦) (Oram et al. 1996; Cunnold et al. 1997; Miller et al. 1998; Prinn et al. 1999; P. Fraser, G. Sturrock and D. Etheridge, CSIRO Atmosphereic Research, unpublished data).

Solid lines are scenarios for CFC-12 and HCFC-22 (A3, Madronich et al. 1999) and for HFC-134a (A2, Ehhalt at al. 2000).

HCFC-22 continues to grow approximately linearly in the background atmosphere (Miller *et al.* 1998; Prinn *et al.* 2000). However, it was expected that HCFC-22 growth would accelerate in the late 1990s. HCFC-22 concentrations were predicted to reach about double 1998 concentrations by about 2015 and then decline quickly, as oxidation by hydroxyl radical can remove HCFC-22 from the atmosphere at a rate of about 8% per year. Emissions of HCFC-22 have stabilised, but perhaps only temporarily, at about 230 kilotonnes per year in 1998 (Kurylo *et al.* 1999; Prinn *et al.* 1999; AFEAS 2000). If HCFC-22 emissions remain approximately stable, peak concentrations reached over the next decade will be significantly lower than currently predicted. More than 95% of HCFC-22 emissions are from the developed countries.

HFC-134a first appeared in the atmosphere in the mid-1990s (Oram *et al.* 1996) and the concentration is now increasing rapidly in the background atmosphere and is expected to continue to grow throughout the twenty-first century. Global (developed countries) emissions of HFC-134a were about 30 kilotonnes per year in the mid-1990s (Kurylo *et al.* 1999) and were about 60 kilotonnes per year in 1998 (Ehhalt *et al.* 2000; AFEAS 2000). Oxidation by hydroxyl radicals can remove HFC-134a from the atmosphere at a rate of about 7% per year.

The current concentrations and increases of CFC-12, HCFC-22 and HFC-134a in the atmosphere are due largely to past and present emissions from operational refrigeration and air-conditioning systems in the developed world. However the future growth of CFC-12 and HCFC-22 will depend on the extent and type of their use in the developing world allowed under the Montreal Protocol. Illegal use of CFCs and HCFCs probably will not have a significant impact on future atmospheric levels (Fraser 2000). The future growth of HFCs in the background atmosphere will depend critically on

possible emission controls introduced under the Kyoto Protocol, the extent of global recycling of HFCs and the possible development of near zero-emission refrigeration and air-conditioning technologies.

10.3 MELBOURNE REFRIGERANT EMISSIONS

The major refrigerants measured at Tasmania's Cape Grim are CFC-12, HCFC-22, HFC-134a, as well as the minor refrigerants HFC-125 and HFC-152a (Sturrock *et al.* 1999; Prinn *et al.* 1999). In this section a technique using inter-species correlation techniques for estimating total emissions of these species from all sources in Melbourne is described.

CFC-12 emission estimates for Melbourne have been made by using the known Melbourne emissions of carbon monoxide (EPA 1998) and correlating CFC-12 and carbon monoxide measurements on air masses that pass over Melbourne and are transported to Cape Grim.

This technique is particularly suited to CFC-12 and carbon monoxide as about 85% of carbon monoxide emissions in Melbourne are due to motor vehicles (EPA 1998) and 90% of 1998 CFC-12 emissions in the developed world are from motor vehicle (non-hermetically sealed) airconditioning systems (AFEAS 2000). It is reasonable to assume that the majority of carbon monoxide and CFC-12 emissions from Melbourne in the past have come from the same source – motor vehicles. Because motor vehicles are widely distributed over Melbourne, the ratio of the enhancements above baseline of CFC-12 to carbon monoxide should be relatively independent of the air mass trajectory path over Melbourne. However it is expected that the CFC-12 source distribution in Melbourne will change with time. Increasingly CFC-12 emissions will be from hermetically sealed, domestic, refrigeration systems. The source will still be widely distributed over Melbourne, but will shift from cars to buildings and other residences. For correlations involving species with very different source distributions in Melbourne, the enhancement ratios will not be as precisely defined as they are for CFC-12:carbon monoxide, but they still should be useful to calculate approximate emissions strengths of other chemical species emitted in the Melbourne and Port Phillip region.

10.4 THE MELBOURNE CARBON MONOXIDE AND DICHLOROMETHANE INVENTORIES

The annual emission of carbon monoxide from the Melbourne and Port Phillip region has been estimated at 677 kilotonnes per year for 1995–1996 (EPA 1998). The carbon monoxide emissions are seasonal, being 25% higher in winter than in summer. Despite a growing number of motor vehicles in Melbourne, carbon monoxide emissions are reported to be declining – they were 740 kilotonnes in 1990. The same is true for the national carbon monoxide emissions in the transport and manufacturing sectors (the sectors that best represent Melbourne carbon monoxide emissions), which are reported to have declined from 4.9 megatonnes in 1990 to 2.9 megatonnes in 1998 (AGO 2000) (Figure 20).



The long-term decline in carbon monoxide emissions in Melbourne is supported by data on the trend in maximum 8-hour carbon monoxide levels observed in Melbourne at EPA sites (Figure 21, EPA 2000). However the EPA data do not show a decline in maximum carbon monoxide levels over the recent period 1995–1999.



Figure 21. Maximum 8 hour carbon monoxide concentrations in Melbourne (EPA 2000)

Observations of Melbourne carbon monoxide pollution episodes at Cape Grim show that the average 'area' (concentration multiplied by time) of the carbon monoxide pollution episodes in 1998–1999 is about 25% larger than in 1995-1996, although the difference is not statistically significant (Figure 22). This assumes that this calculated 'area' is proportional to the average carbon monoxide emission strength in the Melbourne – Port Phillip region (Figure 22).

Carbon monoxide observations in Melbourne and at Cape Grim provide no justification for concluding that carbon monoxide emissions in Melbourne are less in 1998–1999 than they were in 1995–1996. In this report it is assumed that they are the same (680 kilotonnes) or 25% higher (850 kilotonnes). These carbon monoxide emissions, once adjusted for seasonality, that are used to derive CFC-12 emissions from Melbourne by inter-species correlation during 1998-1999.

Figure 22. Average annual area of CO pollution episodes observed at Cape Grim¹



Note: measured using the AGAGE in situ instrument (B. Dunse, University of Wollongong, unpublished data).

The annual emission of dichloromethane from the Melbourne and Port Phillip region has been estimated at 500 tonnes per year for 1995–1996 (EPA 1998). Dichloromethane is used as a solvent in a number of industries in Melbourne – petrochemicals, mineral processing, textile and machinery manufacturing – and a small quantity has been used domestically. There is no national inventory for this species and no measurements by the Environment Protection Authority in Melbourne. For this reason a value of 500 tonnes per year is used by inter-species correlation technique to derive emissions of other species from Melbourne during 1998–1999. Import data for dichloromethane should indicate whether these emissions have changed since 1998 and will be investigated.

Neither the Melbourne (Port Phillip region) nor national inventories contain estimates of the uncertainties in their carbon monoxide or dichloromethane emissions. However the national inventory (AGO 2000) does contain estimates of methane and nitrous oxide emissions, with their uncertainties, from the energy and transport sectors. These are the same sectors (and processes such as fossil fuel combustion) that generate most of the carbon monoxide emissions.

An approximate 1σ uncertainty in carbon monoxide emissions of $\pm 25\%$ is assumed, based on the average uncertainty in the transport sector for methane ($\pm 20\%$) and nitrous oxide ($\pm 30\%$) emissions. Because dichloromethane is used as a solvent for which emissions approximately equal consumption, the uncertainty in the emissions of dichloromethane is probably quite low. The overall uncertainty in the emission of carbon dioxide, methane, nitrous oxide and perfluorocarbons in the industrial sector is $\pm 10\%$ (AGO 2000). This is the uncertainty assumed in the calculation of emissions via inter-species correlation, although the real uncertainty in dichloromethane emissions could be lower than $\pm 10\%$.

10.4.1 Chlorofluorocarbon-12 (CCI₂F₂)

CFC-12 has been measured between six and 18 times per day at Cape Grim since 1978 (100000 measurements shown in Figure 23), using GC-ECD (Cunnold *et al.* 1997; Prinn *et al.* 2000).



Figure 23. In situ CFC-12 as measured at Cape Grim, Tasmania

Baseline CFC-12 data at Cape Grim respond to global emissions. The pollution events, with levels significantly elevated above baseline, are due to regional emissions that largely come from Melbourne, as identified by regional modelling and air-mass trajectory studies (Cox *et al.* 2000; Dunse *et al.* 2000, 2001).

The CFC-12and carbon monoxide data show that 1998–1999 Melbourne emissions of CFC-12 are about 100 tonnes per year (see below), but may have been as high as 500 tonnes per year in the early 1980s. CFC-12 emissions from Melbourne have declined over the past two decades by about 9% per year, as indicated by the maximum CFC-12 levels observed at Cape Grim during pollution episodes over the period 1982 to 1999 (Figure 24). This is in response to the phasing-out of CFC-12 in refrigeration and other applications as required by the *Australian Strategy for Ozone Protection* (AEC 1989; ANZECC 1994a). From 1986 to 1999 Australian consumption of CFC-12 fell by 97% (Figure 24) (Environment Australia 2000, unpublished data), but emissions, as indicated by the intensity of the pollution episodes, have not fallen as rapidly as consumption because it typically takes up to 10 years for CFC-12 to be emitted from hermetically-sealed refrigeration systems (AFEAS 2000).



Figure 24. Annual maximum CFC-12 concentrations of Melbourne air masses reaching Cape Grim

The Melbourne influenced pollution events for a range of species at Cape Grim are more obvious in late autumn-winter than at other times of the year (Figure 24, Figure 25). This is probably not due to more intense emissions in winter, which would vary from species to species, but might be a seasonal mixing-depth effect and/or a seasonal transport effect, where the incidences of air masses passing over Melbourne *en route* to Cape Grim are more frequent in winter than in summer. The cause of this seasonality in Cape Grim pollution are being investigated further with a regional transport model.

Figure 25. The total number of occurrences per month, during 1995–1999, of air masses that pass over Melbourne and are transported to Cape Grim, Tasmania, as indicated by CFC-12 pollution episodes.



The seasonality in the Cape Grim pollution events and the seasonality in Melbourne carbon monoxide emissions can be combined to estimate an effective Melbourne carbon monoxide emission that is appropriate for the average of the observed pollution events. Because more winter than summer pollution is observed at Cape Grim, the effective carbon monoxide source is 2% to 3% higher than the 1998 estimate above. After adjustment for this seasonality effect, the average 1998–1999 carbon monoxide emissions for Melbourne used in the inter-species correlation calculations are 695 kilotonnes and 860 kilotonnes, with an approximate 1 σ uncertainty of ±25%.

10.4.2 HCFC-22 and HFC-125, HFC-134a and HFC-152a

Measurements of HCFC-22 and HFCs-134a, -125 and -152a at Cape Grim commenced in early 1998 (4000 measurements of each species are shown in Figure 26), using GC-MSD (Sturrock *et al.* 1998; Prinn *et al.* 2000).

Figure 26. In situ HCFC-22 and HFC-125, -134a and -152a observations at Cape Grim from 1998 to 2000



Atmospheric Research, unpublished data

Pollution events at Cape Grim are clearly observed for all these species which are due largely to emissions from Melbourne. These are superimposed on a seasonally varying baseline, reflecting the global removal of these chemicals by the hydroxyl radical.

The HCFC and HFC Melbourne pollution event concentration data (above baseline) are assumed to correlate linearly with CFC-12 Melbourne pollution event data (above baseline) according to the following relationship (for example for HCFC-22):

 $\Delta \text{HCFC-22} = \alpha * \Delta \text{CFC-12}$

where α is the correlation coefficient. The above equation relates the molar ratio of excess (above baseline) of HCFC-22 to excess of CFC-12. In order to deduce the mass (M) of emissions it is necessary to take into account the molecular weights (MWs) of the trace gases. This equation can be rewritten:

 $M_{HCFC-22}/MW_{HCFC-22} = \alpha M_{CFC-12}/MW_{CFC-12}$

and rearranged to give:

 $M_{HCFC-22} = \alpha * M_{CFC-12} * MW_{HCFC-22} / MW_{CFC-12}$

This last equation can be generalised to other species such as the HFCs. The linear correlation plots, and the α terms, of HCFC-22 and HFCs-125, -134a, -152a with CFC-12 are shown in Figure 27. The linear correlation plots, and the α terms, of HCFC-22, HFCs-125, -134a, -152a and CFC-12 with dichloromethane are shown in Figure 28.

Figure 27. Interspecies correlation plots for HFC-22 and HFCs-125, -134a and -152a deviations above baseline versus CFC-12 deviations above baseline in Melbourne pollution events observed at Cape Grim Figure 28. Interspecies correlation plots for HFC-2, HFCs-125, -134a, -152a and CFC-12 deviations above baseline versus CH₂Cl₂ deviations above baseline in Melbourne pollution events observed at Cape Grim



The interspecies correlation coefficients and the estimated Melbourne emissions of CFC-12, HCFC-22 and HFCs-125, -134a and -152a are shown in Table 83. CFC-12 emissions for Melbourne during 1998-1999, based on independent correlations with carbon monoxide and dichloromethane, range from 105–153 tonnes per year.

The HFC emissions of 90–150 tonnes per year are equivalent to 185–310 kilotonnes of CO_2 -e per year. Assuming that Melbourne (the Port Phillip region) represents the same fraction of HFC emissions as it does for carbon monoxide emissions in the transport manufacturing sector (21%, EPA 1998; AGO 2000), then the national emissions of HFCs are about 430–710 tonnes per year or 900-1500 kilotonnes CO_2 -e per year.

This is the first estimate made on a Kyoto species based on atmospheric abundance data. The HFC national emissions estimate compares to 1400 kilotonnes CO₂-e of PFCs and four kilotonnes CO₂-e of sulfur hexafluoride in the 1998 National Greenhouse Inventory (AGO 2000).

Refrigerant	Correlating Species	а	Emissions
CFC-12	COa	-	105±30
	COb	-	130±35
	$CH_2Cl_2^c$	0.215±0.032	153±38
HCFC-22	CFC-12d	1.919±0.023	144±58
	CFC-12 ^e	1.919±0.023	178±71
	$CH_2Cl_2^c$	0.412±0.026	210±34
HFC-134a	CFC-12 ^d	0.802±0.095	71±28
	CFC-12 ^e	0.802±0.095	88±35
	$CH_2Cl_2^c$	0.202±0.024	121±27
HFC-125	CFC-12 ^d	0.202±0.034	21±9
	CFC-12 ^e	0.202±0.034	26±12
	$CH_2Cl_2^c$	0.040±0.006	28±7
HFC-152a	CFC-12d	0.030±0.004	1.7±0.7
	CFC-12 ^e	0.030±0.004	2.6±0.9
	$CH_2Cl_2^c$	0.006 ± 0.001	2.5±0.6

Table 83. CFC-12, HCFC-22 and HFC-125, -134a and 152a molecular weights, interspecies correlation coefficients and emissions from Melbourne determined from inter-species correlations during Melbourne pollution events observed at Cape Grim

a Carbon monoxide: 1998–1999 emissions 695±170 kilotonnes/year

b CO: 1998–1999 emissions 860±240 kilotonnes/year

c Dichloromethane: 1998–1999 emissions = 500±50 tonnes/year

d CFC-12: 1998-1999 emissions = 105±30 tonnes/year

e CFC-12: 1998–1999 emissions = 130±35 tonnes/year

Other Notes: CFC-12 emissions are estimated from correlation with CO (Dunse *et al.* 2000) and dichloromethane; the HCFC and HFC and emissions are estimated from correlations with CFC-12 and dichloromethane. Uncertainties are 1σ .

10.5 CONCLUSION

The atmospheric accumulation of the major refrigerant gases (CFC-12, HCFC-22) indicate that global consumption of these species is in accord with the Montreal Protocol. Future HCFC-22 levels may be lower than predicted under the Protocol. Another ozone benign refrigerant, HFC-134a, is also accumulating in the atmosphere at a rate consistent with predictions that HFC-134a will replace CFCs and HCFCs in refrigeration and other applications.

Refrigerants are emitted into the Melbourne atmosphere; approximate annual emissions for 1998-1999 are: 105–155 tonnes (CFC-12), 145–210 tonnes (HCFC-22), 70–120 tonnes (HFC-134a), 20–30 tonnes (HFC-125) and two to three tonnes (HFC-152a). Emissions of CFC-12 into the Melbourne atmosphere have declined by a factor of five over the period 1982–1999.

Assuming that emissions are related to population, Melbourne emissions can be used to obtain a broad estimate of national emissions by dividing by 0.18—Melbourne's share of national population. National emissions by species along with CO₂-e and total emissions are shown in Table 84. Emissions of the three species total 841–1311 gigagrams CO₂-e. The estimate obtained from atmospheric measurements is compared with the estimate from equipment in the next chapter.

Species	Correlating species	Emissions (tonnes)	Uncertainty	Emissions (Gg CO2-e)	Uncertainty
HFC-134a	COa	394	156	513	202
	COb	489	194	636	253
	$CH_2Cl_2^c$	672	150	874	195
HFC-125	CFC-12d	117	50	327	140
	CFC-12 ^e	144	67	404	187
	$CH_2Cl_2^c$	156	39	436	109
HFC-152a	CFC-12d	9	4	1	1
	CFC-12 ^e	14	5	2	1
	$CH_2Cl_2^c$	14	3	2	0
Total	CFC-12 ^d	521	NE	841	NE
	CFC-12 ^e	648	NE	1042	NE
	$CH_2Cl_2^c$	842	NE	1311	NE

Table 84. Australia	n emissions	of HFCs	based or	n Melbourne	emissions
		,			

Notes: See notes to table 10.1 for a,b,c,d,e; NE = not estimated

11 ESTIMATED EMISSIONS OF OZONE DEPLETING SUBSTANCES AND SYNTHETIC GREENHOUSE GASES IN AUSTRALIA—SUMMARY

11.1 BANK AND EMISSIONS BY SECTOR

Table 85 through to Table 95 show for each of the sectors analysed in the report the estimated fugitive emissions of HFC-23 from production of HCFC-22; and the bank and emissions of ozone depleting substances and synthetic greenhouse gases. That is, these tables show all emissions estimates and emissions projections for domestic refrigeration, domestic airconditioning, passenger motor vehicles, trucks, buses and light commercial vehicles, transport refrigeration, and commercial airconditioning are derived from estimates of equipment stocks.

Estimates and projections for commercial refrigeration, dairies, hotels, pubs and clubs are derived from establishment numbers assuming an average quantity of substance in installed equipment dependent on the type and size of the establishment. Because of a lack of data none of the estimates or projections are based on gas imports.

Production of HCFC-22

Fugitive emissions of HFC-23 from production of HCFC-22 are shown in Table 85.

Year	HFC-23 emissions (tonnes)	CO ₂ -e emissions (Gg) (GWP = 11700)
1990	96.3	1127
1991	96.3	1127
1992	90.1	1054
1993	123.6	1447
1994	69.4	811.5
1995	61.4	718.8

Table 85. Emissions of HFC-23 from HCFC-22 production

Domestic refrigeration

Estimated emissions from domestic refrigeration are (Table 86):

- 75 tonnes of CFC-12, 11 tonnes of HFC-134a, 358 tonnes of CFC-11 and 77 tonnes of HCFC-141b in 2000
- HFC-134a emissions increase to 40 tonnes in 2005 and 73 tonnes in 2010
- CFC-11 and CFC-12 emissions are spent by 2018
- HCFC-141b emissions peak in 2004 and remain constant until 2016 when they begin to decline.

		5					
Year	Bank (tonnes)	Emission	ns (tonnes)	Foams-emi	issions (tonnes)	
	CFC-12	HFC-134a	CFC-12	HFC-134a	CFC-11	HCFC-141b	
1990	1014		66		304		
1991	1043		68		312		
1992	1072		69		305	15	
1993	1102		72		315	16	
1994	1146		74		323	18	
1995	1072	90	74	1	331	5	
1996	996	182	75	2	340	5	
1997	920	275	76	3	349	27	
1998	843	373	77	4	359	50	
1999	764	481	79	5	371	77	
2000	688	587	75	11	358	77	
2005	370	1082	56	40	284	97	
2010	148	1515	37	73	199	97	
2015	25	1895	16	108	95	97	
2020		2235		143		14	

Table 86. Bank and emissions from domestic refrigeration

Domestic airconditioning

Estimated emissions from domestic airconditioning are (Table 87):

- 468 tonnes of HCFC-22 in 2000
- HFC emissions (R-410A) increase to 189 tonnes in 2005 and 711 tonnes in 2010
- HCFC-22 emissions are spent by 2013.

Table 87. Bank and emissions f	from domestic airconditioning
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Year	Bank (i	tonnes)	Emissions	(tonnes)
	HCFC-22	R-410A	HCFC-22	R-410A
1990	1611		182	
1991	1697		191	
1992	1722		198	
1993	1710		201	
1994	1787		212	
1995	1924		232	
1996	2001		245	
1997	2183		272	
1998	2561		330	
1999	3014		419	
2000	3291		468	
2005	3402	1324	545	189
2010	1030	4886	247	711
2015		7016		1170
2020		8120		1386

Commercial refrigeration

Estimated emissions from commercial refrigeration are (Table 88):

- 23 tonnes of CFCs (R-12/R-502), 107 tonnes of HCFCs (predominantly R-409A), and 152 tonnes of HFCs (R-404A/R-507) in 2000; data are not adequate to allow speciation for the HCFCs and HFCs
- HFC emissions (R-404A and R-507) increase to 222 tonnes in 2005 and 287 tonnes in 2010
- CFC and HCFC emissions are spent by 2008.

Year		Bank (tonne	es)	Em	issions (to	nnes)
	R-12/R-502	HCFCs	R-404A/R-507	R-12/R-502	HCFCs	R-404A/R-507
1990	1650	118		413	30	
1991	1630	118		408	29	
1992	1619	118		405	29	
1993	1616	119		404	30	
1994	1140	348	253	171	52	38
1995	708	657	390	106	98	59
1996	490	1059	689	69	148	96
1997	428	1068	765	60	150	107
1998	343	1035	912	45	135	119
1999	284	1011	1026	37	131	133
2000	195	894	1265	23	107	152
2005	45	308	2220	4	31	222
2010			2871			287
2015			3257			326
2020			3738			374

Table 88. Bank and emissions from commercial refrigeration

Passenger motor vehicles

Estimated emissions from passenger motor vehicles are (Table 89):

- 596 tonnes of CFC-12 and 919 tonnes of HFC-134a in 2000
- HFC emissions increase to 1666 tonnes in 2005 and 2254 tonnes in 2010
- CFC-12 emissions are spent by 2009.

Table 89. Bank and emissions from passenger motor vehicles

Year	Bank	(tonnes)	Emissions (tonnes)				
	CFC-12	HFC-134a	CFC-12	HFC-134a			
1990	3595		1078				
1991	3994		1158				
1992	4345		1217				
1993	4720		1274				
1994	5105		1327				
1995	5316	148	1329	33			
1996	5162	702	1239	158			
1997	4718	1419	1085	320			
1998	4037	2418	888	545			
1999	3411	3268	716	737			
2000	2978	4072	596	919			
2005	1224	7665	184	1666			
2010		10787		2254			
2015		12914		2592			
2020		15223		2929			

Trucks, buses and light commercial vehicles

Estimated emissions from trucks, buses and light commercial vehicles are (Table 90):

- 201 tonnes of CFC-12 and 177 tonnes of HFC-134a in 2000
- HFC emissions increase to 333 tonnes in 2005 and 483 tonnes in 2010
- CFC-12 emissions are spent by 2009.

Year	Bank (tonnes)	Emissior	ns (tonnes)
	CFC-12	HFC-134a	CFC-12	HFC-134a
1990	888		266	
1991	943		283	
1992	995		298	
1993	1039		312	
1994	1130		339	
1995	1173	34	352	7
1996	1154	162	346	32
1997	1047	320	314	64
1998	915	525	275	105
1999	776	709	233	142
2000	670	883	201	177
2005	286	1667	86	333
2010		2417		483
2015		2998		600
2020		3798		760

Table 90. Bank and emissions from trucks, buses and light commercial vehicles

Transport refrigeration

Estimated emissions from transport refrigeration are (Table 91):

- 18 tonnes of CFC-12, five tonnes of R-502 (CFC/HCFC), one tonne of HFC-134a, and 15 tonnes of the HFC blend, R-404A, in 2000
- HFC emissions increase to two tonnes of HFC-134a and 24 tonnes of R-404A in 2005, and to two tonnes and 26 tonnes respectively in 2010
- CFC emissions are spent by 2002.

Year		Ba	nk (tonnes)			Emissions (tonnes)			
	CFC-12	R-502	HFC-134a	R-404A	CFC-12	R-502	HFC-134a	R-404A	
1990	149	37			30	7			
1991	152	38			30	8			
1992	153	38			31	8			
1993	155	39			31	8			
1994	161	40			32	8			
1995	167	42			33	8			
1996	152	38	2	18	30	8	0	3	
1997	137	34	4	37	27	7	1	6	
1998	122	30	6	61	24	6	1	9	
1999	106	27	7	80	21	5	1	12	
2000	91	23	9	100	18	5	1	15	
2005			15	163			2	24	
2010			15	175			2	26	
2015			15	189			2	28	
2020			16	203			2	30	

Table 91. Bank and emissions from transport refrigeration

Dairies

Estimated emissions from dairies are (Table 92):

- 21 tonnes of CFC-12, 15 tonnes of HCFC-22, and eight tonnes of HFC-134a in 2000
- HFC emissions increase to 21 tonnes of HFC-134a in 2005 and 33 tonnes in 2010
- CFC and HCFC emissions are spent by 2008.

Year		Bank (tonno	es)	E	nnes)	
	CFC-12	HCFC-22	HFC-134a	CFC-12	HCFC-22	HFC-134a
1990	308			62		
1991	300			60		
1992	295			59		
1993	292			58		
1994	290			58		
1995	255	28		51	6	
1996	222	56		44	11	
1997	193	83		39	17	
1998	162	65		32	13	
1999	132	53	26	26	11	4
2000	103	103	52	21	15	8
2005		95	142		14	21
2010			218			33
2015			200			30
2020			184			28

Table 92. Bank and emissions from dairies

Hotels, pubs and clubs

Estimated emissions from hotels, pubs and clubs are (Table 93):

- 43 tonnes of CFC-12, 29 tonnes of HCFC-22, and 54 tonnes of HFC-134a in 2000
- HFC emissions increase to 91 tonnes of HFC-134a in 2005 and 121 tonnes in 2010
- CFC and HCFC emissions are spent by 2009.

Year		Bank (tonn	es)	Eı	nnes)	
	CFC-12	HCFC-22	HFC-134a	CFC-12	HCFC-22	HFC-134a
1990	444	190		111	48	
1991	449	192		112	48	
1992	454	195		114	49	
1993	460	197		115	49	
1994	465	199		116	50	
1995	404	202	67	81	40	10
1996	340	204	136	68	41	20
1997	310	207	172	62	41	26
1998	279	209	209	56	42	31
1999	247	141	318	49	28	48
2000	214	143	357	43	29	54
2005		151	606		30	91
2010			804			121
2015			853			128
2020			906			136

Table 93. Bank and emissions from hotels, pubs and clubs

Commercial airconditioning—chillers

Estimated emissions from chillers are (Table 94):

- 78 tonnes of CFC-11, 97 tonnes of HCFC-22, 195 tonnes of HCFC-123, and 19 tonnes of HFC-134a in 2000
- HFC emissions increase to 92 tonnes of HFC-134a in 2005 and 379 tonnes of HFC-134a and 163 tonnes of the HFC blends, R-407C and R-410A, in 2010
- CFC and HCFC emissions are spent by 2009.

Table 94.	Bank and	emissions	from	commercial	aircond	ditioning -	- chillers
			/				

Year	_	Bank (tonnes) Emissions (tonnes					nes)					
	CFC	CFC-	HCFC	HCFC	HFC-	R-407C/	CFC	CFC	HCFC	HCFC	HFC-	R-407C/
	-11	12	-22	-123	134a	R-410A	-11	-12	-22	-123	134a	R-410A
1990	1014	127	127				152	19	19			
1991	1058	132	132				159	20	20			
1992	1105	138	138				166	21	21			
1993	1154	144	144				173	22	22			
1994	1204	151	151				181	23	23			
1995	1100	157	236	79			165	24	35	8		
1996	1109	164	247	123			166	25	37	12		
1997	1109	171	256	171			166	26	38	17		
1998	982	89	357	357			147	13	54	36		
1999	840	93	467	467			126	14	70	47		
2000	779		487	584	97		117		73	58	15	
2005	115		577	1039	462	115	17		87	104	69	17
2010					1897	813					285	122
2015					2224	953					334	143
2020					2577	1104					387	166

Commercial airconditioning—non-chillers

Estimated emissions from chillers are (Table 95):

- 116 tonnes of HCFC-22 in 2000
- HFC emissions increase to 14 tonnes of HFC-134a and 34 tonnes of R-407C/R-410A in 2005, and 48 tonnes of HFC-134a and 113 tonnes of the HFC blends, R-407C and R-410A, in 2010
- HCFC emissions are spent by 2009.

Year	Bank (tonnes)			Em	Emissions (tonnes)		
	HCFC-22	HFC-134a	R-407C/R-	HCFC-22	HFC-134a	R-407C/R-	
			410A			410A	
1990	514			77			
1991	534			80			
1992	555			83			
1993	578			87			
1994	601			90			
1995	625			94			
1996	650			98			
1997	675			101			
1998	707			106			
1999	739			111			
2000	770			116			
2005	594	91	228	89	14	34	
2010		322	751		48	113	
2015		377	880		57	132	
2020		437	1019		66	153	

11.2 TOTAL EMISSIONS—ODP TONNES AND CO2-EQUIVALENT

Table 96 shows estimated emissions in ODP tonnes for CFCs and HCFCs and CO₂-e for synthetic greenhouse gases. Note that these estimates do not include sectoral emissions for foams (other than domestic refrigeration foams), aerosols, fire extinguishant and solvents. Indicative estimates for aerosols and fire extinguishants are provided in chapter 4. These are too uncertain to include with the aggregate estimates.

Year	CFC and HCFC emissions (ODP Tonnes)	HFC emissions (CO2-e Gg) (including fugitive HFC-23)
1990	2562	1127
1991	2677	1127
1992	2759	1054
1993	2858	1447
1994	2788	936
1995	2731	977
1996	2577	603
1997	2374	907
1998	2087	1311
1999	1829	1695
2000	1617	2085
2005	708	4125
2010	250	6924
2015	111	8631
2020	0	10017

Table 96. Emissions of ozone depleting substances and synthetic greenhouse gases

Emissions of CFCs and HCFCs are projected to be exhausted by 2020. Emissions of ozone depleting substances are estimated to be 1617 ODP tonnes in 2000, falling to 708 ODP tonnes in 2005, and 250 ODP tonnes in 2010. Despite continuing use of HCFCs and the contribution to emissions of ozone depleting substances from that source, CFCs will also continue to be emitted due to long-life uses such as foams.

Emissions of HFCs are projected to increase from 2.1 megatonnes CO₂-e in 2000, to 4.1 megatonnes in 2005, and 6.9 megatonnes in 2010. Large increases will result from more widespread use as a result of the phase-out of HCFCs and replacement of remaining CFC equipment. CFC equipment that is replaced is more likely to switch from CFCs to HFCs rather than HCFCs because HCFC availability will decline due to the phase-out.

The magnitude of projected HFC emissions highlights the need to address a growing and potentially large source of greenhouse gas emissions. Inclusion of aerosols, fire extinguishants, and solvents would further increase emissions and emphasises the possible size of the problem. These sources could add between two and six megatonnes CO₂-e of emissions (see chapter 4). Emissions by species are illustrated in Figure 29 and the total bank is shown in Figure 30.



Figure 29. Emissions of ozone depleting substances and synthetic greenhouse gases by species

Figure 30. Total bank of ozone depleting substances and HFCs



11.3 COMPARISON OF EMISSION ESTIMATES

Comparison of estimates derived from the *Special Report on Emission Scenarios* (IPCC 2000b; see chapter 9 of this report), atmospheric fluxes (see chapter 10 of this report), and the activity and equipmentbased estimates are shown in Table 96 for 2000 (in the case of fluxes the value is for 1998–99) and 2010. The atmospheric flux emissions include three gas species only – HFC-125, HFC-134a and HFC-152a. Significant species that are not included and are used in high proportions in HFC blends are HFC-32 (GWP 650) and HFC-143a (GWP 3800). HFC-143a is used in the blends R-404A and R-507, and HFC-32 is used in the blends R-407C and R-410A. It is assumed that all four of these blends will be used in significant quantities in the future. There are also a number of existing uses and, therefore, emission sources as shown in the earlier tables. Approximate emissions from equipment of HFC-143a added to the flux estimate is included in the table.
The estimate based on IPCC (2000b) is much larger in 2000 than either the equipment estimate and flux estimates. By 2010, the IPCC (2000b)-based estimate and equipment estimates are much closer. This suggests that the rate of adoption of HFCs in Australia is slower than elsewhere or that emission factors are lower. Emission factors in most cases are derived from overseas studies, consequently slower adoption is the more likely explanation.

The uncertainty in the flux estimates for individual species expressed as coefficients of variation (standard deviation as a percentage of the mean) range from 24% to 46% dependent on the correlating species (Table 97). Assuming independent approximately normal distributions for the flux observations, the uncertainty in the total expressed as coefficients of variation range from 29% for the minimum to 17% for the maximum. This implies 95% confidence intervals of ±58% and ±34%. The correlating species for the minimum is CFC-12 and the correlating species for the maximum is dichloromethane.

Estimation method	Emissions in 2000	Emissions in 2010
	(Gg CO ₂ -e)	(Gg CO ₂ -e)
Activity/equipment	2070	6922
SRES IPCC	3577	6821
Atmospheric fluxes	841-1311	
Atmospheric flux plus equipment	1159-1629	
estimate of HFC-143a (approximation)		
95% confidence interval (minimum)	667-1651	
95% confidence interval (maximum)	1182-2076	

Table 97. Estimated emissions derived using different approaches

Source: See chapter 10 of this report

Given the high level of uncertainty in the estimates, differences between the equipment estimates and the flux estimates (with HFC-143a included) are not unreasonably large. In the early stages of use of substances, equipment estimates based on average annual emission factors that include venting on servicing and equipment disposal are expected to be higher than flux estimates. Flux estimates have a different time profile and measure the amount of substance that is present in the atmosphere. As the use of a substance becomes mature, the estimates are likely to converge initially and then the flux estimates should periodically exceed the equipment estimates. Flux estimates will capture emissions at the time when equipment is vented (on servicing or disposal) whereas equipment estimates distribute these emissions over time.

To summarise, emissions of HFCs in 2000 are:

- unlikely to be less than 667 gigagrams CO₂-e
- unlikely to be greater than 2077 gigagrams CO₂-e.

In 2010, emissions are unlikely to exceed 7112 gigagrams CO₂-e from the uses analysed in detail in this report.

12 CONCLUSIONS

Major problems with obtaining data and information were encountered when doing the research for this report. Industry data on equipment imports, production sales and characteristics, and bulk gas imports proved difficult to obtain. Alternative comprehensive data sources do not exist. Australian Bureau of Statistics data from published documents are sparse and limited data only are available for purchase. Some import data along with data on motor vehicle registrations were purchased from the Australian Bureau of Statistics.

Despite these problems, it is considered that the estimates give a reasonably comprehensive picture of the use of ozone depleting substances and synthetic greenhouse gases, as well as the projected use of synthetic greenhouse gases. This has been achieved through combining a variety of disparate data sources supplemented by valuable assistance from several individuals familiar with the industry sectors.

12.1 SECTORAL EMISSIONS

12.1.1 Ozone depleting substances and miscellaneous potential HFC uses

Australia no longer produces any ozone depleting substances and does not produce any HFCs. HCFC-22 production as a source of fugitive emissions of HFC-23 ceased in 1995. CFCs are still imported for use in metered dose inhalers pursuant to an essential use exemption. Ultimately, these substances will be replaced and the main substitutes are likely to be HFC-134a and HFC-227ea. Dependent on the mix of substances used, emissions could range from:

372 to 830 gigagrams CO₂-e in 2005 and 387 to 863 gigagrams CO₂-e in 2010.

There are substantial imports of HCFCs with the highest volume substances being HCFC-22 and HCFC-141b. The HCFC blend, R-409A, is the next highest volume import. HCFC-22 is used in refrigeration and airconditioning, HCFC-141b is used in foam blowing and as a solvent, and R-409A is used as a retrofit interim replacement for CFC-12 and R-500 in low and medium temperature refrigeration. There are indirect imports contained in equipment, particularly, domestic and small commercial packaged air conditioning.

Halon consumption is small. There are several essential use exemptions, and supply for these uses is controlled through the National Halon Bank. Holdings by organisations apart from the National Halon Bank are around 50 tonnes much of which is awaiting destruction. HFC alternatives are imported into Australia but the quantity is unknown. Estimates of emissions indicate that emissions could range from:

498 to 2083 gigagrams CO₂-e in 2005 and 581 to 2426 gigagrams CO₂-e in 2010.

The lower bound assumes all extinguishant is HFC-125 and the upper bound is based on use of HFC-23. It is improbable that such high levels of emissions will be realised, although uncontrolled use could lead to the development of a significant emissions source.

Consumption of carbon tetrachloride and methyl chloroform and stocks of these substances are negligible. It was suggested that there was a stockpile of methyl chloroform in South Australia but no further information was obtained. There are no reliable data on which to base sound estimates of the extent to which methyl chloroform uses as a cleaning solvent that have been replaced by other technologies, might in turn be replaced by HFCs. Using consumption of methyl chloroform in 1990 as

a guide, if HFC-43-10mee was used in similar quantities this would equate to emissions of six megatonnes CO₂-e. This level of emissions is unlikely to eventuate, but there is the potential for a large market for HFCs to arise provided that the economics justify attempts to expand the market.

Imports and consumption of HFCs are largely unknown. Australian Bureau of Statistics import data show that 2355 tonnes of HFC-134a was imported in 2000. No other data are available, either from the Australian Bureau of Statistics or from the importers of bulk substances.

12.1.2 Domestic refrigeration

Domestic refrigeration is a relatively minor source of emissions of ozone depleting substances and synthetic greenhouse gases. Most emissions from this source arise on disposal of equipment from residual compressor gas and foams. The insulation contains a large stock of substance (ozone depleting substances and synthetic greenhouse gases) that will be emitted after disposal. The quantity of gas available from foam is far in excess of that available from compressors. Measures to reduce direct emissions from this source will need to focus on recovery and recycling of refrigerant gas on equipment disposal, and destruction of gas contained in the insulation.

12.1.3 Motor vehicles

Motor vehicle airconditioning is the most significant actual and potential source of emissions of synthetic greenhouse gases.

The estimates indicate that in 1999, motor vehicle emissions contributed approximately 1.1 megatonnes CO₂-e. This is projected to increase to 2.6 megatonnes in 2005 and 3.6 megatonnes in 2010. Motor vehicle airconditioning is the fourth largest source of greenhouse gas emissions in the industrial processes sector. Measures to control or limit emissions are essential to ensure that growth in Australia's greenhouse gas emissions remain within a reasonable targeted range whether that is the current Kyoto target or a revised target that is agreed to in any future negotiations. Problems that might exist with ratification of the Kyoto Protocol should not be seen as a signal to increase emissions where sensible environmental management policies that will restrain emissions growth can be implemented.

The emissions estimates are based on conjectures about average emission factors supplemented by information from individuals that recovery and recycling practices implemented during the phase-out of ozone depleting substances are no longer strictly observed when HFC-134a systems are serviced. Standards and Codes of Practice that applied during the phase-out of ozone depleting substances should be reinforced with the possibility of legislative backing. Motor vehicle manufacturers should be encouraged to continually improve fittings that minimise leakage from systems. A requirement to report annual use along with the quantity contained in charged imported equipment and system characteristics (losses on charging and leakage rates) is an essential component of any program to monitor, estimate, and limit emissions. The marginal cost of reporting would be trivial given that the information sought should be readily available to manufacturers. Reporting by major vehicle importers should also be required.

12.1.4 Domestic and commercial airconditioning

Domestic and commercial airconditioning have the potential to become an important source of greenhouse gas emissions as HFCs penetrate the market. At present most domestic systems use HCFC-22, and commercial systems operate on CFC-11, CFC-12, HCFC-22, HCFC-123, and HFC-134a. It is expected that in the future HFC-134a and HFC blends, R-407C and R-410A, will become the dominant substances in commercial airconditioning. The HFC blends, R-407C and R-410A, are also

expected to displace HCFC-22 in domestic airconditioning equipment, with R-410A being the main substance. In 2005, domestic airconditioning could contribute 326 gigagrams CO₂-e emissions increasing to 1227 gigagrams in 2010.

Commercial airconditioning has the potential to contribute 193 gigagrams CO₂-e emissions in 2005, and 1003 gigagrams in 2010. This gives a total of 519 gigagrams in 2005 and 2230 gigagrams in 2010. Recovery and recycling practices combined with installations that are designed to minimise leakage such as brazed rather than flared joints in pipework, would reduce emissions significantly. Ammonia (R-717) is an alternative that could be used if appropriate means of managing its toxicity and flammability can be developed.

12.1.5 Commercial and transport refrigeration

Commercial refrigeration is a significant potential source of emissions of HFCs and a major contributor to industrial process emissions. Transport refrigeration is a relatively minor future emission source. The HFCs that will penetrate the market having displaced CFCs, and ultimately displacing HCFCs, have high GWPs ranging from 1300 for HFC-134a to 3260 for the HFC blend, R-404A. Sound substance conservation practices were adopted during the phase-out of CFCs, and it would be straightforward to ensure similar practices are applied in the use of HFCs. Recovery and recycling practices along with manufacturers and contractors placing an emphasis on minimising losses through seals and joints would be effective in significantly reducing emissions both now and in the future.

Under a business-as-usual approach emissions are projected to increase to 957 gigagrams CO₂-e in 2005 and 1230 gigagrams in 2010. This would increase emissions from industrial processes by at least 10%. Recovery and recycling practices would be effective in reducing average annual emission factors by reducing losses when equipment is serviced and recovering substances when equipment is scrapped. During servicing, the substance should be recovered if there is a need to evacuate the equipment. Improved seals and brazed rather than flared joints would further reduce losses. For example, if the only substance that is lost is around 5% leakage per year rather than an average annual emission factor of 20%, over a 10 year life emissions would fall by 75%.

12.1.6 International developments

Internationally, the phase-out of CFCs has been successful. There remain issues as to whether HCFC phase-out will proceed as smoothly given that there is no apparent decline in sales and HCFC-141b sales are continuing to grow. This is attributable to the fact that HFC substitutes are not widely available – particularly for foam blowing – and substitution of HFCs in some applications require new technologies. For example, compressors for use with R-410A need to be designed for that purpose. As equipment is scrapped and new units are purchased, market penetration of HFCs will increase with a consequent reduction in sales of HCFCs. This trend is not expected to be observed for several years.

All analyses of market penetration of HFCs demonstrate that they are likely to become a major contributor to greenhouse gas emissions. In the absence of policies designed to limit emissions with an emphasis on the importance of continuation of good practices adopted during the phase-out of ozone depleting substances, emissions of HFCs are projected to more than double in most developed countries between 2000 and 2010.

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