The Use of Alternatives to Synthetic Greenhouse Gases in Industries Regulated by the Montreal Protocol

Report Prepared for the Australian Greenhouse Office
By ICF Consulting

September 2003

Australian Government

Australian Greenhouse Office

Published by the Australian Greenhouse Office, the lead Commonwealth agency on greenhouse matters.

ISBN: 1 876536 89 6

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Executive Summary

Background

Under the National Greenhouse Strategy the Australian Government has committed itself to limiting net greenhouse gas emissions.

The most potent greenhouse gases—synthetic greenhouse gases—include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). While these synthetic (or high global warming potential) gases are used and produced in a variety of industries, one of their most significant and rapidly growing uses are as substitutes for ozone depleting substances (ODS), including in the refrigeration and air-conditioning (RAC), aerosols, foams, solvents, and fire protection sector.

The Australian Government is working with industry to develop environmental strategies for managing all three classes of synthetic greenhouse gases. This particular study was undertaken to provide the Government with a sound understanding of the status of HFC use in five key sectors, as well as the future prospects for transition to alternatives to synthetic greenhouse gases. This report summarises the views of Australian industry on the commercial availability, technical/cost effectiveness, and overall viability of alternatives.

The Study

This study was based on industry surveys distributed to national industry leaders and experts in the RAC, aerosols, foams, solvents, and fire protection industries in the Australian autumn/winter of 2002. It is acknowledged that, while the responses received are useful indicators of the range of opinions, these are not necessarily representative of all industry views.

The greatest number of survey responses was received from the RAC sector, the largest of the five industrial sectors that use synthetic greenhouse gases in Australia. In total, 44 responses were received from diverse stakeholders in the RAC sector, including major equipment manufacturers, distributors, and private mechanics. Industry input from the other industrial sectors was smaller, with five survey responses received from the aerosols sector (including two from associations), two survey responses received from the fire protection sector (one of which was from a national association), and one survey response received from the foams sector. No survey responses were received from the solvents sector. While the findings of this report are based primarily on official survey responses, industry feedback was also obtained and considered through an industry review of the draft report. Reviewer comments were received from industry participants in each sector, all of which have been addressed in this final report.

General Observations

Overall, the survey results revealed several common characteristics affecting the viability and market uptake of alternatives to synthetic greenhouse gases by industry. Across all sectors, the preferred options are those that bring reduced capital costs, improved performance, and enhanced energy efficiency. Table ES-1 summarises the most popular options identified by industry, on a sector-by-sector basis. Options that are not expected to receive substantial market success are those with high capital costs, technical constraints, or health/safety risks. Other noted impediments include issues associated with the market, including limited availability of product information and lack of supply for the proposed substitute.

Table ES-1. Most Promising Options for Reducing Greenhouse Gas Emissions in 2020, as Indicated by Industry

Sector	Alternative	Expected Market Penetration
Refrigeration/Air-Conditioning [a]		
Commercial AC/ Chillers	Ammonia	11-20%
	Secondary loop systems[b]	> 10%
Cold Storage	Secondary loop systems	21-50%
	Carbon dioxide	21-50%
	Distributed systems[c]	> 10%
Retail Food	Secondary loop systems	21-50%
	Hydrocarbons	21-50%
	Carbon dioxide	11-20%
Industrial Process Refrigeration	Ammonia	> 50%
	Hydrocarbons	11-20%
	Carbon dioxide	11-20%
Household Refrigeration	Hydrocarbons	> 50%
MVACs (Motor vehicle air-conditioning)[d]	Hydrocarbons	> 50%
Transport Refrigeration	Hydrocarbons	21-50%
Fire Protection (Total Flooding)	Inert gas	21-50%
Solvents	Not available	
Aerosols (Non-MDI)	Hydrocarbon aerosol propellants	>50%
Foams	Carbon dioxide/water	21-50%
	Lower permeability facings	21-50%
	Recovery/recycling	21-50%

[a] Because of the large number of survey responses received from the RAC sector, projected market penetration ranges for some options varied widely. The estimates provided in this table represent the most popular market penetration ranges selected by survey respondents. Additional information for each option is provided in the Refrigeration and Air-Conditioning chapter.
[b] Secondary loop systems use synthetic greenhouse gases and/or natural refrigerants.
[c] Distributed systems use multiple compressors connected to a single cooling unit often with a synthetic greenhouse gas charge.
[d] Although not included in the industry survey or specifically identified by industry respondents, the use of HFC-152a or enhanced HFC-134a systems—both still in the research and development phase—may represent promising options to reduce future HFC emissions from MVACs.

Sector-by-Sector Observations

Based on survey results, the following observations can be drawn for the individual sectors:

Refrigeration and Air-Conditioning.

There is a broad range of views on future uptake of alternatives to HFCs within the different subsectors. In commercial and industrial applications, including cold storage and retail food applications, preferred alternatives tend to be very needs-specific, with secondary loop systems, ammonia, carbon dioxide, and distributed systems all having industry support for certain applications. Hydrocarbons are seen as presenting the area of greatest potential uptake for household products, motor vehicle air-conditioning and transport refrigeration, if safety concerns can be satisfactorily addressed.

Even though expected uptake rates of many alternatives were up to 50 percent, there is also a perception that both the level of industry awareness of non-HFC refrigerants and technologies, and the level of industry outreach information to promote the manufacture and use of non-HFC refrigerants in Australia, are low to moderate. Some industry participants stressed the importance of improved training, information, and education on the use of natural refrigerants (e.g., ammonia, hydrocarbons, carbon dioxide) to overcome current attitudinal barriers to their use. It was also suggested that more direct government intervention may be necessary to encourage the adoption of such alternatives. Finally, much of Australia's refrigeration and air-conditioning equipment is imported, and it was suggested that overseas manufacturers may be directing most of their efforts in marketing alternatives towards those countries that have policies that explicitly favour uptake of alternatives to HFCs.

Fire Protection.

Overall, the fire protection sector is reasonably open to the adoption of non-HFC alternatives in total flooding applications. By 2020, inert gas systems using argon, nitrogen and/or carbon dioxide are expected to replace a large portion of the total flooding applications where HFCs are currently being used.

Industry believes that HFC technologies in Australia have reached a technical peak, whereas their second-generation substitutes are still under development. It was expected that second-generation alternatives, once they become available for commercial use, would initially be more expensive than HFC technologies. Currently, the level of awareness about alternatives for total flooding applications within the industry is believed to be high, but the level of industry efforts to promote their manufacture and use is viewed as being only low to moderate.

Solvents.

HFC emissions from the solvents sector can be eliminated or reduced through several technologies and practices, including recovery/recycling, improved system design, substitution of high-Global Warming Potential (GWP) gases with low- or non-GWP alternatives, and/or the use of not-in-kind technologies. However, because no survey responses were received from industry representatives in the solvents sector, limited information is available to characterise this industry in Australia, or to assess the feasibility and market penetration of abatement options.

Aerosols.

Aerosols used in consumer applications have easily transitioned to non-HFC alternatives in most non-medical applications, with hydrocarbons being the preferred choice for most locally filled non-metered dose inhalers (non-MDI) applications. However, greater challenges are faced in medical applications. While dry powder inhalers (DPIs) and nebulisers are being used successfully by some respiratory patients, they do have not dominated the medical MDI market. Furthermore, while DPIs are expected to continue to penetrate the MDI market, MDI manufacturers in Australia generally feel that reducing emissions during manufacturing remains the best option for reducing HFC emissions from this application. Already, most MDI manufacturers in Australia have instituted recovery practices to lower HFC emissions during production.

Foams.

The key alternative blowing agents in the Australian polyurethane (PU) foam sector are carbon dioxide/water, hydrocarbons and carbon dioxide, although only the larger companies in Australia have begun to convert to these alternatives.

The relatively high cost of HFCs and their associated environmental concerns have led PU manufacturers to minimise HFC use and emissions in the manufacture of their products. However, some applications continue to use HFCs where no feasible alternatives are yet available (e.g., certain PU spray and pour foam applications). The industry is expected to make further progress by replacing HFCs with hydrocarbons, and by reducing HFC emissions by using lower permeability facings and recovery/recycling practices during production and at decommissioning.

1 Introduction

The Australian Government has committed itself to taking measures to limit emissions of greenhouse gases in support of its commitments under the United Nations Framework Convention on Climate Change. These gases include engineered chemicals, namely hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). While these synthetic (or high-global warming potential) gases are used and produced in a variety of industries, arguably the most significant of the uses of HFCs and to a far lesser extent PFCs, is as substitutes for ozone depleting substances (ODS). Use and emissions of these synthetic gases are growing rapidly, and many sectors are only now in the process of transitioning their manufacturing and servicing operations away from ODS (Burnbank, 2002; U.S. EPA, 2001). This makes the prospect of further development of new technology, including alternatives to synthetic gases, especially challenging.

Many of the most cost-effective options, such as better management practices, training, recovery and recycling, and responsible use, are being addressed by the Australian Government for those industries regulated by the Montreal Protocol—namely refrigeration and air-conditioning, aerosols, foams, solvents, and fire protection. There exist numerous other options, particular to each end-use, that can build on the emission reduction efforts already attained, to further reduce emissions from these sectors. Identifying these options and evaluating their effectiveness can help Australia reach its emission reduction goals.

This study was developed to help ensure that Australian decision makers have a thorough and balanced understanding of industry's knowledge of the commercial availability and technical/cost effectiveness of alternatives to synthetic gases used by the five industrial sectors of interest, as well as any technical, structural and practical impediments to their use. To this end, this study examines alternative substances, not-in-kind alternatives, and other replacement strategies for each of the industrial sectors in Australia regulated by the Montreal Protocol, including both the advantages and market impediments to their adoption. The study also provides detailed information on the perceptions of industry towards the use and feasibility of alternatives.

The use of synthetic greenhouse gases is normally accompanied by the consumption of energy, through either the creation of equipment that contains synthetic gases or the use of that equipment. The possible sources of energy and their different greenhouse implications (e.g., electricity generated from the use of coal or from renewable recourses) are complex matters in their own right, which fall outside the scope of this study. For similar reasons, no attempt was made to assess life cycle performance or the Total Equivalent Warming Impact (TEWI) of alternatives to the use of synthetic gases. However, where appropriate and feasible, the indirect greenhouse gas emissions of synthetic greenhouse alternatives are noted in each chapter.

The findings of this study are based on industry surveys that were distributed to Australian industry leaders and experts in all five sectors. The surveys were distributed in the second half of 2002. Information on the number of respondents and the nature of their involvement in the Montreal Protocol industries is provided in each of the chapters of this report. While industry responses are useful indicators of the range of opinions, the responses were sought on a voluntary basis and are not necessarily representative of all industry views.

The remainder of this report is organised as follows:

- Chapter 2 presents information on the refrigeration and air-conditioning sector, including domestic and commercial refrigeration and air-conditioning and motor vehicle air-conditioning;
- Chapter 3 describes the fire protection sector, with a focus on the total flooding subsector;

- Chapter 4 provides information on the solvents sector, including metal and electronics cleaning, precision cleaning, and carrier fluid applications;
- Chapter 5 discusses the aerosols sector, including metered dose inhalers (MDI) and non-MDI aerosol propellants; and
- Chapter 6 presents information on the foam sector, with a focus on the polyurethane subsector.

Each chapter provides information on the historical, current, and projected uses of synthetic greenhouse gases within the sector, and the associated emissions by sector. Each chapter also describes the survey participants and identifies key options for reducing greenhouse gas emissions within the specified sector—as well as the major market advantages and impediments to adoption for each option.

2 Refrigeration and Air-Conditioning (RAC) Sector

The refrigeration and air-conditioning (RAC) sector includes the following end-uses:

- Domestic refrigeration (household refrigeration);
- Commercial refrigeration (cold storage, retail food, transport refrigeration);
- Industrial process refrigeration;
- Motor vehicle air-conditioning (cars, trucks, buses); and
- Domestic and commercial air-conditioning (including chillers).

The domestic refrigeration industry in Australia has consolidated over the past 30 years, with the number of local manufacturers decreasing from nine in the 1970s to two in 2000. Email and Fisher & Paykel are currently the sole domestic producers of refrigerators. Email acquired many of the manufactures in operation, ending with the acquisition of Southcorp in 1999, while Fisher & Paykel founded a new plant in 1990. Despite industry restructuring, production has continued to increase. Other traditional Australian brand names are now imported from Korea. Industry reports that appliances imported from Southeast Asia tend to be lower cost and lower performance (i.e., having low energy efficiency and high leakage rates), leading to a difference in the level of performance between some of the domestic appliances used in Australia and those used in the European Union, Japan, and the United States.

Commercial refrigeration equipment is used in the retail food sector in businesses such as supermarkets, convenience stores, and small retail outlets. Data on the number of retail food establishments in Australia is limited and fragmented. Since 1990, large supermarkets have grown, at the expense of smaller and independent supermarkets. It is likely that the prevalence of small and medium-sized supermarkets will continue to decline. This trend is more likely to entrench itself as a result of the recent entry of the German supermarket, Aldi, into the market. Two large companies—Coles-Myer and Woolworths dominate the commercial refrigeration sector. These two supermarkets comprise an estimated 70 to 80 percent of the supermarket sector.

Industrial process refrigeration includes complex, often custom-designed, refrigeration systems used within the chemical industry, petrochemical industry, pharmaceutical industry, oil and gas industry, metallurgical industry, and sports and leisure facilities. Charge size ranges on average from 650 to 9,100 kilograms, and average lifetime is 25 years (UNEP, 1999a).

Motor vehicles that are produced in Australia use imported air-conditioning units that are charged at the supplying manufacturing plant. There are four manufacturers of motor vehicles in Australia: Ford, Toyota, General Motors Holden, and Mitsubishi. Domestic motor vehicle production has exhibited a slight downward trend of 0.53 percent per year since 1965. Motor vehicle air-conditioners, or MVACs, however, have increased dramatically—what was a luxury in the 1970s has been a standard feature since the 1990s. By 2010, it is expected that virtually all cars sold in Australia will have air conditioning installed.

Domestic and commercial air-conditioning is a significant market in Australia, compared to its Asia-Pacific neighbours, reflecting Australia's relative affluence. There are currently no air-conditioning manufacturers in Australia, with the vast majority of imports originating from Southeast Asia. Industry reports that like the domestic refrigeration equipment, the domestic air-conditioning equipment imported from Southeast Asia tends to be lower cost and lower performance. There is substantial volatility in imports, since air-conditioner demand is closely linked to variations in climatic conditions. Ignoring climate-induced changes in demand, the domestic air-conditioner market is linked to general economic conditions, since air-conditioning is viewed as a luxury. Imports of air-conditioning units have grown from 1989 to 1999, with a surge in 1998 and 1999. This trend is consistent with that of the overall global market for air-conditioning units.

2.1 Use of HFCs in the RAC Sector

Each of the refrigeration and air-conditioning end-uses are composed of a variety of different equipment types that have historically used ozone-depleting substances (ODS) such as chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs). As the ODS phase out is taking effect under the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) in Australia and other developed countries, equipment is being retrofitted or replaced to use HFC-based substitutes or intermediate substitutes, namely HCFCs. These will eventually need to be replaced by non-ozone depleting alternatives, including HFCs, in order to comply with national ODS phase out schedules.

Today, a number of HFCs and HFC blends are used in the RAC sector, including HFC-134a, R-404A, R-407C, R-410A, and R-507.[1] Emissions of HFCs can occur during product and equipment manufacturing, as a result of component failure, leaks and purges during operation, unintentional releases during servicing, unintentional releases from disposal of equipment or used refrigerant containers, and intentional venting of refrigerant. The use of refrigeration and air-conditioning equipment also generates "indirect" emissions of greenhouse gases (primarily carbon dioxide) from the generation of power required to operate the equipment. It should be noted that in future, cutting-edge technologies and state-of-the-art design may reduce reliance on HFC refrigerants in air-conditioning systems. For example, by relying on natural ventilation and shading devices, architects and engineers have successfully reduced heat gain in built environments, rendering traditional cooling systems obsolete. For the purposes of this report, the major categories of refrigeration and air-conditioning end-uses have been separated into eight categories:

- Commercial air-conditioning/chillers
- Cold storage
- Household refrigeration
- Industrial process refrigeration
- Motor vehicle air-conditioning
- Residential air-conditioning
- Retail food
- Transport refrigeration

Currently, use of non-HFC refrigerants is low in most end-uses, but market penetration is expected to increase significantly by 2020, as CFCs, HCFCs, and blends containing these chemicals are replaced by HFC alternatives.

In each end-use, various alternative refrigerant and technologies exist to lower projected HFC emissions (see section 2.3). A further means of reducing emissions from the RAC sector is through minimising refrigerant venting through the implementation of efficient refrigerant recovery practices when servicing RAC equipment and disposing of refrigerant.

Based on industry responses to the questionnaire, estimates of current recovery levels (at service and at disposal) vary significantly. Disparate estimates from within the chillers/commercial air-conditioning, cold storage, industrial process refrigeration, and retail food, subsectors indicate a great

[1] R-404A is composed of R-125 (44%), R-143a (52%), and R-134a (4%); R-407C is composed of R-32 (23%), R-125 (25%), and R-134a (52%); R-410A is composed R-32 (50%) and R-125 (50%); and R-507 is composed of R-125 (50%) and R-143a (50%).

deal of uncertainty in the industry about the percentage of jobs that involve the handling of refrigerant in which refrigerant is actually recovered.

Table 2-1 presents the industry-estimated recovery rates for the household, MVACs, Residential Air-Conditioning and Transport subsectors, covering both ozone depleting substances and HFCs. Nevertheless, it should be noted that the figures contained in these tables are basic estimates only. While industry responses are useful indicators of the range of opinions, the results below are not necessarily representative of all industry views. The Australian Government has recently entered into an agreement with industry for the development of a comprehensive reporting framework to produce robust estimates of emissions while protecting the confidential data and commercial interests of industry participants.

Table 2-1. Estimated Levels of Refrigerant Recovery with Industry Consensus

End-Use	Percent Recovery	
	At Service	At Disposal
Household	0-10	0-20
MVACs	0-50	[a]
Residential AC	[a]	95-100
Transport	[a]	0-20

[a] Estimated levels of recovery varied widely by survey response.
Source: Industry responses to AGO questionnaire (2002).

2.2 Description of Survey Participants

RAC comprised the bulk of survey responses received, reflecting the size of the industry sector and the large number of participants. Altogether, 18 respondents participated in the *Request for Information* questionnaire and 26 participants replied to the *Questionnaire for Industry Experts* survey. Those contacted range from private refrigeration and air-conditioning mechanics to refrigeration equipment manufacturers and distributors. Among the respondents are Austral Refrigeration Pty Ltd., Australia's largest manufacturer and supplier of commercial refrigeration, and HyChill Australia Pty Ltd, the country's largest manufacturer and distributor of hydrocarbon refrigerants. The participants, and a brief description of each, are listed in Table 2-2.

Table 2-2. Survey Participants and Descriptions

ACMV Design Consultants	Small consulting firm specialising in energy efficient building design and energy storage systems.
AT Consulting Energy Auditors	Small engineering consulting firm specialising in energy audit work.
Austral Refrigeration Pty Ltd	Australia's largest manufacturer and supplier of supermarket and convenience store refrigeration, having a 43% market share. Employs over 400 people and has revenue of approximately $100 million annually.
Burchett, Carl	Self-employed refrigeration and AC mechanic.
Cold Rae Pty Ltd	Small/medium refrigeration and AC contractors – installation and maintenance. Prominent member of Refrigeration and Air-conditioning Contractors Association.
Connell Mott MacDonald	Large building engineering firm operating in Australia and the UK. Projects include office blocks, sports stadiums, airport terminals, hospitals and hotels.

Frigrite Refrigeration Pty Ltd	Medium to large Australian company involved in the installation and maintenance of commercial air-conditioning, refrigeration and mechanical ventilation systems. One of the first companies in Australia to have engaged in the 'CFC retrofit' market. Employs over 100 technicians.
Gordon Brothers Industries Pty Ltd	Medium to large Australian manufacturer and distributor of industrial refrigeration and specialised AC equipment. Operates across Australia and in SE Asia.
Greenchill Technology Association	Advocacy organisation promoting the use of natural refrigerants and systems. Members include manufacturers, contractors, consultants, and environmentalists.
Honeywell Polymers (Australia)	Australian division of multinational manufacturer of specialty chemicals, control systems and electronic materials. It is a major manufacturer of HFCs and HCFCs.
HyChill Australia Pty Ltd	Australia's largest manufacturer and distributor of hydrocarbon refrigerants.
Inter-Chillers Pty Ltd	Medium sized Australian company involved in the maintenance and service of refrigeration and air-conditioning equipment, including for ships, hotels and other commercial applications.
Mayekawa (Mycom) Australia Pty Ltd	Australian division of large Japanese manufacturer of residential AC systems. Claims to have recently developed the world's first building AC system using CO_2. Market share in Australia unknown but likely to be significant.
MINUS40 Pty Ltd	Small refrigeration engineering design and consulting firm specialising in industrial and commercial refrigeration. Claims to have an objective of promoting environmentally-friendly and efficient technologies but will remain '*neutral and pragmatic in the current heated debate regarding alternative refrigerants*'.
Refrigerant Reclaim Australia	Non-profit refrigeration industry body established in 1993 to promote the recovery, and reclamation, recycling and disposal of refrigerants. Members include most of major industry organisations involved in the manufacture and use of fluorocarbons.
Refrigeration Engineering Pty Ltd	Designs and builds industrial thermal process systems, including industrial process refrigeration. Subsidiary of Stolway Holdings which manufacturers a broad range of industrial and commercial heating, air-conditioning and refrigeration equipment. Size and market share unknown but operates throughout Australia and in South East Asia.
Sanyo Air-conditioning Australia	Australian division of multinational Japanese company manufacturing residential and commercial AC systems. Market share unknown but likely to be significant.
Scantec Refrigeration Technologies Pty Ltd	A medium sized industrial refrigeration engineering, contracting and service company, with offices throughout Australia and the South Pacific.
Supermarket Energy Consultants	A small business providing energy management advice to supermarkets, primarily in the Sydney region.
Trane Australia	Australian division of large international manufacturer and distributor of residential, commercial and industrial AC systems.

Vehicle Air-Conditioning Specialists of Australia	Major industry association representing manufacturers, wholesalers, service centres and technicians involved with the installation and repair of vehicle air-conditioning systems.

In addition to the responses of these industry participants, we received further information from individual industry experts through the discussions organised by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH).

2.3 Use of HFC Alternatives in the RAC Sector

Options for reducing HFCs in the RAC sector include the use of alternative refrigerants and technologies—such as ammonia, carbon dioxide, hydrocarbons, liquid carbon dioxide, liquid nitrogen, ice slurry, absorption systems, geothermal technology, secondary loop systems (SLS) using both synthetic (e.g., HFC) and natural (e.g., ammonia, carbon dioxide, hydrocarbons, etc.) primary refrigerants,[2] distributed systems, and desiccant systems. Table 2-3 presents the applicability of all alternative refrigerant and technology options by end-use. Descriptions of abatement options, including the possible advantages and disadvantages associated with each are provided in Appendix 1.

Although there are options for reducing HFC emissions within each end-use, industry will employ options based on efficiency, cost effectiveness, and associated risk. Survey respondents provided feedback on their preferences for abatement options and their perceptions of current and future market share of each.

Table 2-3. Applicability of Options, as Indicated by Industry

Options / end-use	HFC Alternatives							HFC Minimisation Options				
	Ammonia	CO_2	HCs	Ice Slurry	SLS (natural primary refrig.)	Liquid CO_2	Liquid Nitrogen	Absorption Systems	Geothermal	SLS (HFC primary refrig.)	Distributed Systems	Desiccant Systems
Commercial AC/ Chillers	✓	✓	✓		✓			✓	✓	✓		✓
Cold Storage	✓	✓		✓	✓			✓		✓	✓	
Household			✓					✓				
Industrial Process	✓	✓	✓	✓	✓			✓	✓	✓		
MVACs*		✓	✓									✓
Residential AC	✓		✓					✓	✓			✓
Retail Food		✓	✓		✓					✓	✓	
Transport		✓	✓		✓	✓	✓			✓		

✓ = Technically feasible today/expected to be technically feasible in near future.
* Although not specifically identified by industry respondents, HFC-152a and enhanced HFC-134a systems are HFC minimisation options currently being researched and developed for use in MVACs.

Regarding the characterisation of the current market, respondents cited very few end-uses in which they perceive HFC alternatives to hold a *significant* (>10%) or *substantial* (>20%) market share. Two notable exceptions are in cold storage, in which distributed systems were assessed by respondents as having a significant market share, and in industrial process refrigeration end-use, in which ammonia was assessed as having a substantial market share.

[2] Secondary loop technologies can use a wide variety of fluids in the primary loops and secondary loops (e.g., ice slurry, water, organic and non-organic salts, alcohols, and others). While the cost, efficiency, and overall environmental benefit of each SLS varies, the industry surveys focused on SLS using HFCs and ammonia as primary refrigerants and ice slurry as a secondary refrigerant—all of which are described in Appendix 1. In addition, Austral Refrigeration Pty. Ltd. provided information on a new SLS technology, which uses a mixture of propylene and distilled water as the secondary refrigerant. This new technology is also described in Appendix 1, though it was not specifically addressed in any survey responses received.

In addition to distributed systems and ammonia refrigerant in these two end-uses, several options were cited by industry as holding a 5 percent share of the current market. Table 2-4 presents the options that are believed to currently hold a 5 percent share of the market or more.

In terms of future market penetrations of options (i.e., in 2020), industry responses by end-use varied, but general trends were apparent. Hydrocarbons are generally the preferred future alternatives to HFCs in residential and transport applications. The preferred future options for commercial and industrial applications tend to be very needs-specific, with secondary loop systems, ammonia, carbon dioxide, and distributed systems all having support within industry for certain applications.

Table 2-4. Current HFC Alternatives with >5% Market Share

End-Use	HFC Alternative with >5% of Market	Industry Responses
Cold Storage	Distributed Systems	1 response: 6-10% 1 response: 21-50%
Retail Food	SLS (HFC primary refrigerant)	2 responses: 1-5% 1 response: 6-10% 1 response: 11-20%
	Distributed Systems	2 responses: 1-5% 1 response: 11-20%
Industrial Process Refrigeration	Ammonia refrigerant	1 response: 11-20% 2 responses: 21-50%
	Hydrocarbons	2 responses: 1-5% 2 responses: 11-20%
MVACs	Hydrocarbons	2 responses: 1-5% 1 response: 11-20%

2.4 Impediments to Employing HFC Alternatives

In some end-uses, there is significant uncertainty associated with the future penetration of many alternatives. The uncertainty surrounding these options and markets appears to reflect, to a significant extent, disparate views regarding the advantages and disadvantages of options and the preferred choice of future refrigerant. Despite the growing popularity of these options, several impediments including availability of information, costs, market accessibility, stand as market barriers against the adoption of many non-HFC alternatives for many end-uses. The following list summarises the major barriers to market entry/penetration of the most popular option in each end-use, as described by survey participants.

Commercial air-conditioning/chillers. There is disagreement about the potential for alternatives to gain future market share. The major barriers to the adoption of ammonia refrigerant systems is the need to overcome health and safety concerns, a lack of knowledge and specialist training, and the absence of local equipment manufacturers and suppliers.

Cold storage. For ammonia secondary loop systems, barriers to be overcome include high capital costs and efficiency penalties. Health and safety hazards, real or perceived, also represent a significant barrier to the adoption of ammonia secondary loop systems. One respondent noted that 'uncertainty with regard to insurance costs and availability' may have the effect of pushing operators into considering safer design, which is likely to encourage increased use of secondary systems and carbon dioxide.

Retail food. Respondents did not agree on the relative future market shares of secondary loop systems as well as for distributed systems. Low energy efficiency was cited as a primary disadvantage for all of these options. Safety and health hazards and market unavailability were cited as impediments for ammonia secondary loop systems as well as a lack of training and expertise in the design, installation, and maintenance of the systems and a lack of component availability in Australia. For ice slurry, cost and training requirements were cited as major barriers to adoption. For distributed systems, technical feasibility and the need for costly and disruptive maintenance were cited as drawbacks. However, one industry representative noted that the market penetration of distributed systems is likely to increase in future, as supermarkets consider the installation of new technologies. One respondent argued that costly and disruptive conversions are the greatest barriers in the retail food industry, causing it to be the most challenged of all RAC sectors in terms of transitioning to more greenhouse-friendly systems.

Industrial process refrigeration. Ammonia is, and has historically been, the refrigerant of choice in industrial process refrigeration applications. Because ammonia is already the industry standard in this end-use, HFCs are typically selected for systems for which health and safety concerns are an issue. Thus, health and safety hazards are viewed as significant market barriers for adopting ammonia as a replacement to HFCs in existing industrial process refrigeration applications. Limiting charge quantities by using secondary loop systems are seen as means of overcoming these concerns.

Household refrigeration. Hydrocarbons (HCs) are clearly the preferred alternative for household refrigeration, but real or perceived health and safety hazards amongst consumers are viewed as a major market barrier. A number of respondents argue that consumers are being misinformed about the extent of these hazards.

MVACs. Future market share of hydrocarbons is uncertain. The market barriers cited for the use of hydrocarbons include 'unfair and unwarranted' regulatory restrictions in NSW and Queensland, as well as the reluctance of vehicle manufacturers to challenge the opposition of MVAC manufacturers to hydrocarbons (HCs). However, other respondents argue that hydrocarbons will fail to achieve market share due to safety issues and because internationally, manufacturers are 'not progressing with hydrocarbon technology.' One respondent has also noted that the 'blending' of different refrigerants in MVAC systems has led to contamination of 55 percent of vehicle fleet systems, greatly limiting recovery efforts, system efficiency, and performance. International research is also being conducted on carbon dioxide and HFC 152a systems.

Transport refrigeration. For hydrocarbons in the transport refrigeration sector, perceived health and safety hazards are viewed as a major market barrier. Some respondents argue that these hazards are more perceived than real and that the ban on retrofit of HFC/CFC systems with hydrocarbons is an unwarranted market impediment.

Residential AC. Relative future market shares of hydrocarbons and absorption systems are not agreed upon. For hydrocarbons, it is primarily safety and health hazards that threaten the success of this option. For absorption systems, cost was cited is the primary impediment to market adoption. One respondent has stressed that the Australian market is currently flooded with relative inexpensive, imports from Southeast Asia and there is no incentive for consumers to purchase the more efficient, environmentally benign systems. Another industry representative noted the viability of evaporative (water filter-based air-conditioners), suitable for use in areas without high levels of humidity.

Table 2-5 presents the expected future options by end-use, as indicated by industry and the main reported advantages associated with each alternative.

Table 2-5. Future HFC Alternatives with Greatest Expected Market Penetration (2020)[a]

End-Use	HFC Alternative	Reported Advantages[b]
Commercial AC/ Chillers	(1) Ammonia refrigerant	Low cost refrigerant, low capital costs, improved energy efficiency, improved performance.
	(2) SLS (ice slurry secondary refrig.)	Low cost refrigerant, low capital costs, improved energy efficiency, improved performance.
	(3) Absorption Chillers	Low cost refrigerant, improved energy efficiency, improved performance.
Cold Storage	(1) SLS (ammonia primary refrig.)	Low cost refrigerant, improved performance.
	(2) Carbon Dioxide	Improved performance, improved energy efficiency, lower cost of refrigerant.
	(3) Distributed Systems	Lower cost refrigerant, lower capital cost.
	(4) SLS (ice slurry secondary refrig.)	Low cost refrigerant, improved performance, improved energy efficiency.
	(5) SLS (HFC primary refrig.)	Lower cost refrigerant, improved energy efficiency, improved performance.
Retail Food	(1) SLS (HFC primary refrig.)	Improved performance.
	(2) Hydrocarbons	Increased energy efficiency, lower capital costs, increased performance.
	(3) Carbon Dioxide	Lower refrigerant cost, increased energy efficiency, improved performance.
	(4) SLS (ammonia as primary refrig.)	Lower refrigerant cost, improved performance, lower capital cost.
Industrial Process Refrigeration	(1) Ammonia refrigerant	Lower refrigerant cost, improved performance, increased energy efficiency.
	(2) Hydrocarbons	Lower cost refrigerant, increased energy efficiency, improved performance.
	(3) Carbon Dioxide	Lower cost refrigerant, improved performance.
	(4) SLS (ice slurry secondary refrig.)	Increased energy efficiency, improved performance.
Household Refrigeration	Hydrocarbons	Increased energy efficiency, lower capital cost, lower refrigerant cost, improved performance, drop-in replacement for HFCs/CFCs.
MVACs	Hydrocarbons	Increased energy efficiency, lower refrigerant cost, lower capital cost, less noise.
Transport Refrigeration	Hydrocarbons	Increased energy efficiency, lower capital cost, lower refrigerant cost, improved performance, drop-in replacement for HFCs/CFCs.
Residential AC	(1) Hydrocarbons[c]	Lower cost of refrigerant, improved energy efficiency, lower capital costs, improved performance.
	(2) Desiccant Cooling Systems[d]	Lower cost of refrigerant, improved energy efficiency
	(3) Absorption Systems[e]	Improved energy efficiency, lower cost refrigerant, improved performance.

[a] Only options projected to have more than 10 percent market share are presented in this table.
[b] Benefits are listed in order of importance, based on industry responses to the questionnaire.
[c] Only 2 survey participants estimated future market penetration of this option; one participant estimated market penetration to be 0 percent, while the other participant estimated it to be between 21 and 50 percent.
[d] Only 2 survey participants estimated future market penetration of this option; one participant estimated market penetration to be between 1 and 5 percent, while the other participant estimated it to be between 6 and 10 percent.
[e] Only 2 survey participants estimated future market penetration of this option; one participant estimated market penetration to be between 1 and 5 percent, while the other participant estimated it to be between 11 and 20 percent.

While the future market penetration of the options discussed above remains to be seen, several options were clearly identified as non-starters—as having an insignificant market share (<5 percent) both today and in the future. Options that are unlikely to see significant market penetration are presented in Table 2-6 by end-use. The reasons for the unpopularity of these options (i.e., barriers to market adoption) are also presented.

Table 2-6. Alternatives Expected to Have Insignificant Market Share (<5%) in 2020

End-Use	Options Expected to Penetrate <5% of the Market	Major Barriers to Market Adoption
Commercial AC/ Chillers	Carbon Dioxide	-High capital cost -Safety hazard
Industrial Process Refrigeration	Geothermal Technology	-High capital cost -Commercially unavailable -Not technically feasible
	Absorption Systems	-High capital cost
MVACs	Carbon Dioxide	-High capital cost -Not technically feasible
	Desiccant Cooling Systems	-NA
Transport Refrigeration	Evaporation/Expansion of Liquid Nitrogen	-High capital costs -Safety hazard -Not technically feasible
	SLS (ice slurry secondary refrig.)	-Not yet technically feasible/ Unavailable outside metro areas
	Carbon Dioxide	-High capital cost -Safety hazard -Decreased energy efficiency -Not technically feasible/ Unavailable in remote locations
Residential AC	Ammonia	-Safety/Health hazards
	Geothermal Technology	- High capital cost

NA = Not available; primary impediments to market penetration were not specified by industry experts.

2.6 Promotion of HFC Alternatives in the RAC Sector

Based on responses to the *Request for Information*, there is a general perception that the level of industry outreach information to promote the manufacture and use of non-HFC refrigerants in Australia is currently moderate to low. Approximately 84 percent of respondents indicated that current outreach efforts are at low or moderate levels.

Similarly, the level of industry awareness of non-HFC refrigerants and technologies is also regarded as being low to moderate. In descending order, respondents categorised the level of industry awareness as low (47 percent), moderate (42 percent), and high (11 percent). No respondents characterised the level of industry awareness to be non-existent (0 percent). Many respondents stressed the importance of improved training, information and education of natural refrigerants (e.g., ammonia, hydrocarbons, carbon dioxide) to overcoming barriers to their adoption. Others believe that more direct government intervention, in the form of regulation and/or incentives, will be needed to encourage the wholesale adoption of natural refrigerants and systems.

Finally, much of Australia's refrigeration and air-conditioning equipment is imported, and it was suggested that overseas manufacturers may be directing most of their efforts in marketing alternatives towards those countries that have policies that favour uptake of alternatives to HFCs. For example, the European Union and Japan are aggressively pushing HFC alternatives (as well as policies targeting responsible use practices), whereas policies, industry, and public perception in the United States are not perceived to be as open to such alternatives.

2.7 Summary

Table 2-7 summarises industry's projections of HFC alternatives that are likely and unlikely to penetrate the Australian RAC sector by 2020.

Table 2-7. Viability of RAC Options in 2020, as Indicated by Industry

Options / end-use	HFC Alternatives							HFC Minimisation Options				
	Ammonia	CO_2	HCs	Ice Slurry	SLS (natural primary refrig.)	Liquid CO_2	Liquid Nitrogen	Absorption Systems	Geothermal	SLS (HFC primary refrig.)	Distributed Systems	Desiccant Systems
Commercial AC/ Chillers	✓	▪	NA		✓			✓	▪	▪		▪
Cold Storage	▪	✓		▪	✓			▪		✓	✓	
Household			✓					▪				
Industrial Process	✓	✓	✓	▪	✓			▪	▪	▪		
MVACs		▪	✓									▪
Residential AC	▪		NA					✓	▪			▪
Retail Food		✓	✓		✓					✓	▪	
Transport		▪	✓		▪	NA	▪			▪		

✓ = Technically feasible, and expected to capture a significant market share (>10%) in future.
▪ = Technically feasible, but expected to capture an insignificant market share (<10%) in future
NA = Clear articulation of future market popularity is not available, as inadequate or conflicting information was provided by survey.

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3 Fire Protection Sector

Halons have been historically used in fire suppression and explosion protection applications because they are electrically non-conductive, dissipate rapidly without residue, are safe for limited human exposure, and are extremely efficient in extinguishing most types of fires (U.S. EPA, 2001). Although halons were produced in much lower volumes than other ozone depleting substances (ODS), they have extremely high ozone depletion potentials (ODPs) due to the presence of bromine, which reacts more strongly with ozone than chlorine.

Several substitutes for halons have high Global Warming Potentials (GWP). The principal greenhouse gases used in and potentially emitted from fire extinguishing systems in Australia are HFC-227ea (with a GWP of 2,900), HFC-23 (with a GWP of 11,700), and HFC-125 (with a GWP of 2,800). Industry has advised that HFC-227ea has been imported into Australia since 1994, with a total of 235 tonnes imported by 2001. In 2001, the fire protection sector estimated that usage of synthetic greenhouse gases was around 63 tonnes. Use of these gases has stabilised at this level, and may gradually decline as other fire protection technologies are developed and marketed.

Halon applications can be divided into two categories: (1) portable fire extinguishers (streaming) that originally used halon 1211, and (2) total flooding applications that originally used halon 1301 or halon 2402 (U.S. EPA, 2001). Portable fire extinguishers are most frequently used in offices, manufacturing and retail facilities, aerospace/marine applications, and homes. PFCs have not been used in Australia's portable fire extinguisher market, and market penetration of HFCs is believed to have been limited in this use. Moreover, use of HFCs for streaming uses is unlikely to grow in Australia, except in certain specialised applications (e.g., marine, aviation, and military applications). Because of the limited use of synthetic greenhouse gases in this subsector, streaming uses are not discussed further in this report.

Total flooding systems are usually used for fixed-site systems to protect a variety of spaces, including: electronic and telecommunications equipment; military applications; oil production facilities; flammable liquid storage areas; engine nacelles and cargo bays of commercial aircraft; cultural institutions and museums; records storage areas; bank vaults; warehouses; and special facilities, such as research laboratories and military facilities. Internationally, the primary HFC used in the total flooding sector is HFC-227ea, with HFC-23 used to a lesser extent. Use of HFC-125 has been limited to normally non-occupied specialty applications, such as aviation engine nacelles, but may increase in market share over time (U.S. EPA, 2001).

3.1 Use of HFCs in the Total Flooding Sector

HFC-23, HFC-125, and HFC-227ea are the only synthetic greenhouse gases used in Australia's total flooding sector. According to the Fire Protection Association Australia (FPAA), HFC-227ea accounts for approximately 99 percent of current HFC use, with HFC-23 accounting for the remaining 1 percent. HFC-125 accounts for less than 1 percent of the total flooding market and is used in specialty applications only. The FPAA estimates that by 2020, 85 percent of total flooding systems will use HFC-227ea, 5-10 percent will use HFC 125, and up to 5 percent will use HFC-23.

Replacement of halons has not resulted in an equivalent quantity of HCFCs and HFCs being used in fire extinguishing equipment, as a result of replacement with not-in-kind alternatives, such as sprinkler systems, or with no replacements, in cases where fire suppression systems were not needed. While it has been estimated that the base usage of HFCs in 2000 is between 150 and 200 tonnes (Burnbank, 2002), the FPAA maintains that the actual amount in use is significantly lower. The FPAA suggests that only 43 tonnes of HFCs were used for fire protection in 2000 (FPAA, 2002).

3.2 Description of Survey Participants

Two survey responses were received from the fire protection sector: one from the *NSW Fire Brigade,* and the other from the FPAA. The *NSW Fire Brigade* is funded by the NSW State Government and is Australia's largest urban fire service based in and around Sydney. The FPAA survey response represented users, suppliers, and manufacturers of fire extinguishing systems.

3.3 Key Options for Reducing HFC Emissions in the Fire Protection Sector

The *NSW Fire Brigade* and the FPAA identified three viable alternatives to reduce HFC use in the total flooding sector: water mist, inert gas, and carbon dioxide systems. Each of these three options are described briefly below:

- *Water Mist Systems*. Water mist systems use relatively small droplet sprays under low, medium, or high pressure to extinguish fires. These systems use specially-designed nozzles to produce much smaller droplets than are produced by traditional water-spray systems or conventional sprinklers, thereby requiring significantly less water to achieve extinguishment (UNEP, 2001; Wickham, 2002). To date, water mist systems have been used in shipboard accommodation, storage and machinery spaces, combustion turbine enclosures, flammable and combustible liquid machinery, and light and ordinary hazard sprinkler applications (UNEP, 2001). Theoretically, water mist systems can provide equivalent fire protection and life safety/health protection for Class B fuel hazards (i.e., flammable liquids), where low temperature freezing is not a concern.

- *Inert Gas Systems.* Inert gas systems use gases such as argon, nitrogen, carbon dioxide (see further discussion below) or a blend of these gases to extinguish fires (UNEP, 2001). Inert gas systems provide an equivalent level of both fire protection and life safety/health protection in most Class A (ordinary combustible) fire hazards, including electronics/telecommunications applications.

- *Carbon Dioxide Systems.* Carbon dioxide has been used for many decades in total flooding systems. Due to the lethal concentrations at which carbon dioxide is required for use as a fire extinguishing agent, safety standards limit its use in occupied areas (i.e., FPAA System Standard AS4214.3 Part 3) (FPAA website). Some of the types of hazards and equipment that carbon dioxide systems protect are flammable liquid materials; electrical hazards, such as transformers, switches, circuit breakers, rotating equipment, and electronic equipment; engines utilising gasoline and other flammable liquid fuels; ordinary combustibles, such as paper, wood, and textiles; and hazardous solids (NFPA, 1998).

According to the FPAA, water mist sand carbon dioxide systems account for a small percentage of the fire protection market (<5 percent), while inert gas systems account for an estimated 21 to 50 percent. In future, the FPAA estimates the relative market share of inert gas and carbon dioxide systems to remain constant, while water mist systems may increase slightly, as this option is becoming more popular for Class B fire risks. This information is summarised in Table 3-1.

Table 3-1. Current and Future Market Penetration of Key HFC Alternatives in the Total Flooding Sector

HFC Alternative	Current Market Penetration	Future Displacement of HFCs (2020)	Reported Advantages
Inert Gas Systems	21-50%	21-50%	-Lower cost of agent
Water Mist Systems	1-5%	6-10%	-Lower cost of agent
Carbon Dioxide	1-5%	1-5%	-Lower cost of agent

Source: FPAA survey response

3.4 Impediments to Employing HFC Alternatives

Several technical constraints are associated with each of the three HFC alternatives identified. Water mist systems, for example, have not proven effective in extinguishing small fires in large spaces (volumes greater than 2,000 m^3) (IMO, 2001; Wickham, 2002). Additionally, because the relationship between the mechanism of extinguishment of water mist systems is non-linear and not well understood, applications of water mist systems have been limited to those where fire test protocols have been developed, based on empirically-tested system performance. Therefore, new applications may require extensive and costly empirical performance testing prior to the installation of such systems, in order to ensure safety and obtain approval of the proper regulatory or standard setting authority. Many international efforts are being directed at resolving these issues and researchers believe that solutions that would allow these market barriers to be overcome are well within reach (Wickham, 2002).

For inert gas systems, discharge time is significantly slower than the discharge time for HFC systems; discharge time for inert gas systems is on the order of 60 seconds or more, compared to 10 to 15 seconds for HFC systems (Kucnerowicz-Polak, 2002). Inert gas systems are therefore not recommended for areas where a rapidly developing fire can be expected (UNEP, 2001; Kucnerowicz-Polak, 2002). Another factor impeding the use of inert gas systems in lieu of HFCs is that substantially more agent is needed to extinguish fires. The additional space and weight needed to accommodate additional steel cylinders of inert gas may effectively prohibit the retrofit of many existing HFC systems. For example, the retrofit of an HFC system to an inert gas system on small ships or military/commercial aircraft may be practically impossible. Another factor to consider with this option is that, for applications that can accommodate additional space, the need to heat and cool the additional space may lead to negative implications for both cost and energy consumption (U.S. EPA, 2001).

Liability and safety/health concerns impede the use of carbon dioxide systems in the total flooding sector. Because carbon dioxide is an asphyxiant at concentrations at or above 10 percent, proper safety precautions (e.g., proper signs, alarms, worker training) may be required. In addition, as one of the oldest fire extinguishing agents in use, and as a more economical option than HFCs, carbon dioxide has in part developed its own niche market in narrow-use total flooding applications. As a result, the extent to which carbon dioxide can displace future HFC use may be limited.

Table 3-2 summarises the major impediments against the uptake of each of these three HFC alternatives, as identified by members of the FPAA.

Table 3-2. Major Impediments for Key HFC Alternatives in the Total Flooding Sector

HFC Alternative	Reported Disadvantages
Inert Gas Systems	-Safety hazards (slower to reach extinguishing levels) -Not technically feasible; requires large storage area for cylinders
Water Mist Systems	-High capital costs -Not technically feasible in many applications; lacks a wide range of fire approvals for specific applications and fire risks
Carbon Dioxide	-Safety hazards (asphyxiation) -Not appropriate for normally occupied areas

Source: FPAA survey response

In addition to the impediments identified above, the *NSW Fire Brigade* also noted that a key barrier to the adoption of HFC alternatives is that major user groups (e.g., fire services) are not usually involved in the selection of flooding systems, and hence, they cannot influence the adoption of alternative fire extinguishing systems.

3.5 Emerging Alternatives

In addition to the three HFC alternatives mentioned above, other options in the fire protection sector are emerging as potentially viable HFC replacements. These include oxyfluorocarbons/ fluorinated ketones, fine aerosols, inert gas generators, hydrofluoroethers (HFEs), and iodinated alkanes (e.g., trifluoroiodomethane or CF_3I). Based on industry responses received, none of these emerging technologies are expected to significantly penetrate the fire protection market in the short term. However, this section briefly explores these alternatives under development, which may or may not prove to be successful in future fire protection markets.[3]

- *Oxyfluorocarbon/Fluorinated Ketones*. A new product on the market, known by trade name Novec™ 1230, is an oxyfluorocarbon/fluorinated ketone with a very low GWP (between 4 and 7) and an atmospheric lifetime of 15 days. Manufactured by 3M™, it is claimed that this agent is effective in occupied spaces in both standard streaming and flooding applications, where halon alternatives are now being used (3M Specialty Materials, 2002). Initial effectiveness has been demonstrated in military applications (IMO, 2001b). As this agent is so new, sufficient information is not available to fully evaluate at this time on its performance, applicability, and cost.

- *Fine (or powdered) aerosols.* While aerosols are not currently a viable replacement option for HFCs in fire protection, they are being developed for use as extinguishing agents in niche markets in the United States, such as aerospace applications (Wickham, 2002). Much uncertainty exists as to whether or not the associated technical and commercial barriers will be overcome to enable them to become a viable alternative.

- *Inert gas generators* use a solid material that oxidises rapidly, producing large quantities of carbon dioxide and/or nitrogen. While this technology has demonstrated space and weight requirements equivalent to Halon 1301, it has thus far only been used in specialised applications in the United States (e.g., dry bays on military aircraft) (Wickham, 2002). Due to insufficient data on these systems and to the uncertainty associated with their applicability in other fire extinguishing applications, this option may or may not be feasible.
- *Hydrofluoroethers (HFEs) and perfluoropolyethers (PFPEs)* have also been proposed as next generation replacement in the fire protection sector. They show good extinguishing characteristics and low toxicity. They have been approved for use in various streaming and flooding systems in the United States.

- *Iodinated alkanes*. Iodinated alkanes, such as trifluoriodomethane (CF_3I) have been identified as replacement fire protection agents for low-flying aircraft, such as helicopters and other military, civilian, or commercial aircraft that do not fly above 20,000 feet.

3.6 Promotion of HFC Alternatives in the Fire Protection Sector

According to the *NSW Fire Brigade*, the current level of industry efforts to promote the manufacture and use of HFC-alternative fire extinguishing agents is only moderate to low, although the level of awareness of alternatives within the industry is believed to be high. Overall, the *NSW Fire Brigade* regarded the industry as being somewhat open to the adoption of HFC alternatives in total flooding applications, and noted that industry and consumers are particularly open to the use of carbon dioxide as a fire extinguisher.

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[3] Industry has indicated that another option under development is the use of an isomeric blend of HCFC-225 congeners that have a lower GWP than HFC-227ea. The Australian Government does not consider an HCFC a suitable alternative to an HFC, due to the ozone depleting nature of this substance.

While extensive technical and financial investment has allowed HFC technology to reach a technical peak, second generation substitutes are still in development. The FPAA anticipates that when these substances are made available for commercial use, they will initially be more expensive than the incumbent HFC technology.

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4 Solvents Sector

Historically, CFC-113, carbon tetrachloride, and methyl chloroform have been used as solvents for a wide range of cleaning applications including precision, electronics, and metal cleaning (UNEP, 1999). The solvent industry has phased out most of its ozone-depleting substance (ODS) use and continues to research alternative cleaning practices and replacement solvents. Many of these alternatives offer economic, health, and environmental benefits.

The vast majority of the market, primarily the metal and electronics cleaning end-uses, no longer uses high ozone depleting potential (ODP), compounds like CFC-113 and methyl-chloroform, or very high global warming potential (GWP) compounds like perfluorocarbons (PFCs), and perfluoropolyethers (PFPEs). Instead, they use alternative technologies such as no-clean, aqueous and semi-aqueous cleaning; and solvents such as hydrofluorocarbons (HFCs), hydrofluoroethers (HFEs), hydrocarbons, chlorinated solvents, and alcohols. Although climate impact is still a concern using some of these substances, these replacement technologies have some environmental advantages over the higher GWP alternatives.

Conversely, for certain solvent uses, such as precision cleaning and carrier fluid applications, the use of ODP compounds (e.g., HCFC-141b, HCFC-225ca/cb) and higher GWP chemicals (e.g., HFCs) are still necessary because these solvents have high reliability, excellent compatibility, good stability, low toxicity, and selective solvency.

4.1 Use of HFCs in the Solvents Sector

Internationally, common HFCs used in solvent applications include HFC-43-10mee, HFC-365mfc, and HFC-245fa (U.S. EPA, 2001). While various international studies are currently looking at greenhouse gas emissions from solvents, including those in Australia, no baseline emission estimates are yet available.

4.2 Description of Survey Participants

No survey responses were received from the solvents industry.

4.3 Key Options for Reducing HFC Emissions in the Solvents Sector

As no survey responses were received from industry representatives in the solvents sector in Australia, information presented in this section is based on analyses conducted by the International Energy Agency (IEA) and the United States Environmental Protection Agency (U.S. EPA), which assess feasibility and market penetration of abatement options in the solvents sector worldwide. Although these reports do not provide an Australia-specific focus, they are believed to be broadly applicable to the solvents industry in Australia.

HFC emissions from the solvents sector can be eliminated or mitigated through several technologies and practices. Specifically, emissions can be reduced through recovery and reuse of the high-GWP gases; retrofitting or improved system design to enhance containment of the solvents; substitution of high-GWP gases with low- or non-GWP alternatives; and/or through the use of new, not-in-kind technologies. Each of these four approaches for solvent emission reduction are described briefly below (U.S. EPA, 2001; March Consulting Group, 1998 and 1999; UNEP, 1999):

- *Recovery/recycling.* In instances where HFCs continue to be used for performance reasons, emissions can be minimised by implementing recycle and reuse programs (UNEP, 1999). Used solvent may be recovered through a distillation process that can take place in either the degreasing unit or the solvent still (Clement *et al.*). On-site solvent recovery could be utilised and such programs can be cost-effective. Even companies that purchase small, inexpensive solvent reclamation equipment can quickly offset the costs of solvent disposal (UNEP, 1999; U.S. EPA, 2001). One example of successful recovery/recycling of solvent wastes is in the metal cleaning end-use, where used solvents can be recycled in fuel blending programs. However, not all solvent wastes can be recycled (see Section 4.4 for more detail).

- *Retrofit/Improved System Design*. Retrofitting solvent equipment involves adjustments that improve containment and efficiency, and minimise evaporative losses of solvents. Examples of such methods include increasing freeboard height, installing freeboard chillers, using automatic hoists, and improving the design of solvent bath enclosures and vapour recovery condensing systems (U.S. EPA, 2001).

- *Alternative Solvent Fluids.* Ongoing research continues to identify low GWP alternatives that could replace high GWP HFCs. In electronics, metal, and some precision cleaning end-uses, alternative solvents with lower GWPs are now deployed in the industry. Some of these solvents, such as low-GWP HFCs, HFEs,[4] hydrocarbons, alcohols, volatile methyl siloxanes, brominated solvents, and non-ODS chlorinated solvents, can be used as alternatives to CFCs, and HCFCs. Additionally, replacing high-GWP solvents with these compounds can have a major impact on reducing GWP-weighted emissions.

- *Alternative Cleaning Technologies.* In addition to the emission reduction approaches that use improved equipment and cleaning practices, there are several not-in-kind (NIK) technology processes that can be used to substitute for HFC-containing systems. Examples of NIK technologies include water-based cleaning, involving aqueous and semi-aqueous methods, which have already been adopted widely in the metal and electronics cleaning sectors to replace CFC-113, methyl chloroform, and various applications of HCFC-141b. Aqueous cleaning uses a water-based solution often containing detergents to remove contaminants after which the products are rinsed with water. Semi-aqueous cleaning, also called hydrocarbon-surfactant cleaning, uses a cleaning solution to remove contaminants, and is also followed by a water rinse. Both aqueous and semi-aqueous processes have lower material costs than traditional solvent processes due to the low cost of water, but energy costs for aqueous cleaning are comparable to, and in some instances, higher than CFC-113 and methyl chloroform processes. Depending on the level of contamination and local discharge regulations, wastewater treatment may be required before the rinse water is released (U.S. EPA, 2001).

  In addition, "no-clean processes" may also be implemented, which are process modifications that eliminate the need for traditional cleaning, particularly in the electronics sector (March Consulting Group, 1998 and 1999). There are two kinds of processes that could be implemented to switch a manufacturing line to a "no-clean" process: use of low-solids flux or paste, and soldering in a controlled atmosphere (U.S. EPA, 2001).

Table 4-1 summarises the applicability of different cleaning technologies worldwide by solvent end-uses.

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[4] HFEs have no ODP, low toxicity, and are non-flammable. The GWPs of commercially-available HFE-7100 and HFE-7200 are 390 and 55, respectively. HFEs are viable alternatives in critical cleaning applications where compatibility with the substrate to be cleaned is essential. Internationally, HFEs have successfully replaced PFCs, as well as CFC-113, 1,1,1-trichloroethane (methyl chloroform), and HCFCs in certain precision cleaning operations.

Table 4-1. Overview of Cleaning Technologies Used Worldwide in the Solvents Sector

	Applicability to End-Use		
	Metal	Electronics	Precision
Solvent Technologies			
Chlorinated Solvents	X	X	X
HCFC Solvents (HCFC-225 ca/cb and HCFC-141b)		X	X
HFC-43-10mee	X	X	X
HFE Solvents[a]	X	X	X
Hydrocarbons	X	X	X
Alcohol solvents	X	X	X
Brominated Solvents	X	X	X
Methyl Siloxanes	X	X	X
Alternative Cleaning Technologies			
Aqueous Cleaning	X	X	X
Semi-Aqueous Cleaning	X	X	X
No-Clean Processes[b]	X	X	

[a] HFEs are hydrofluoroethers.
[b] No-Clean Processes include the use of low-solids flux or paste and soldering in a controlled, inert atmosphere.
Source: U.S. EPA (2001).

4.4 Impediments to Employing HFC Alternatives

Technical limitations and economic barriers impede wide scale and rapid market penetration of the HFC alternatives in the solvents sector. The following points summarise the key market barriers by option.

Recovery/Recycling. While recovery/recycling offers an excellent opportunity to reduce greenhouse gas emissions, not all solvent wastes can be recycled. For example, solvent wastes from electronics cannot be recycled, since cleaning properties will be diminished. Likewise, recycled solvents are rarely used in precision cleaning, as a result of perceived impurities.

Retrofit/Improved System Design. High quality equipment can be retrofitted in a cost-effective manner; however, this option is not viable for older equipment that may need to be replaced. Retrofitting equipment is occurring worldwide on newer vapour degreasers. Proper employee training on the use of retrofitted equipment and frequent scheduled checks of stabiliser level with adjustments should be implemented to minimise safety risks in the workplace.

Alternative Solvent Fluids. The identification of viable alternatives for HFCs in some solvent applications, most notably, in precision cleaning end-uses, is challenged by the complexity involved with certain solvent cleaning processes. According to analyses conducted by the U.S. EPA, HFEs are considered a viable substitute particularly for certain HCFCs, but compatibility issues may arise for the implementation of HFEs for some processes that use HFCs due to application-specific requirements. Costs of alternative solvents may present another setback; alternative solvents are more expensive on a per kilogram basis, although efficient work practices and equipment may keep overall costs at reasonable levels (UNEP, 1999).

Alternative Cleaning Technologies. Volatile Organic Compounds (VOCs) often are used in semi-aqueous cleaning applications, which introduces the risk of flammability, a concern that might be rectified by improving equipment design. Economic uncertainties for not-in-kind processes, including aqueous, semi-aqueous cleaning and no-clean, lie in the costs of additional requirements such as wastewater treatment and electric or other utility needs that arise from more energy intensive drying processes, especially for aqueous cleaning (U.S. EPA, 2001).

4.5 Emerging Alternatives

No quantitative or qualitative information was provided on the future solvents market in Australia, therefore, no conclusions can be drawn.

4.6 Promotion of HFC Alternatives in the Solvents Sector

No qualitative information was provided by industry on the current level of industry awareness and/or promotion of alternatives to high-GWP gases in the solvents sector. Therefore, no conclusions can be drawn.

4.7 References

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5. Aerosols Sector

The Aerosols sector includes the following uses:

- Metered dose inhalers (MDIs); and
- Non-MDI aerosol propellants.

MDIs serve as a prescribed inhalation therapy for both asthma and chronic obstructive pulmonary disease (COPD). Asthma and COPD are important public health issues in Australia, with an estimated 2 million Australians suffering from asthma and another 400,000 affected by COPD. These aerosol devices rely on a propellant vapour to deliver the active drug ingredient to a patient's lungs. CFC-11 and CFC-12 originally served as the propellant in MDIs since their development in the 1950s. In response to the Montreal Protocol, the medical industry researched non-CFC alternatives and found only two acceptable alternatives—HFC-134a and HFC-227ea—that are still penetrating MDI markets. During the past year, 15 million medical inhalers (which include MDIs and dry powder inhalers (DPIs)[5]) were sold through retail pharmacies in Australia. Almost 80 percent of these were MDIs, while the rest were DPIs. Where technically feasible and acceptable from a patient health perspective, pharmaceutical companies have reformulated other drug delivery systems formerly using CFCs, such as angina treatments, topical sprays, and nasal inhalants, to non-fluorocarbon technologies.

Non-MDI aerosol propellants are used in various consumer products such as cosmetic, convenience, and technical applications. HFCs used in non-MDI aerosol applications can serve two functions: acting as a propellant, or as a solvent to dissolve and suspend a substance that is to be delivered by way of aerosols.

5.1 Use of HFCs in Aerosol Sector

Concerning MDI aerosol applications, both CFC and HFC have a sizeable market share. According to information received from one survey participant, approximately 9.7 million of the 12 million MDI inhalers sold in Australia in 2002 were HFC MDIs, while the rest (about 19 percent) were CFC MDIs. HFC-134a and HFC-227ea have high GWPs—1,300 and 2,900, respectively. Patient transition away from CFC MDIs is expected to be complete in Australia, Canada, the EU, and Japan by 2005 and all other developed countries by 2008-2010 (IPAC, 2002).

Concerning non-MDI aerosol applications, HFCs currently account for less than one percent by weight of locally filled propellants, according to survey responses. Global consumption and emissions of HFCs in non-MDI products in 1998 was less than 15,000 tonnes (UNEP, 1999). As a result of the Montreal Protocol, CFCs were replaced by a variety of non-HFC alternatives, including hydrocarbons, dimethyl ether (DME), carbon dioxide, nitrogen propellants, and not-in-kind alternative products. For example, hydrocarbons have been adopted as CFC replacements in many polyethylene (PE) or expanding foam spray uses. HFCs are used in aerosol products primarily to comply with technical requirements or environmental regulations. For example, where flammability is a concern, HFC-134a and HFC-152a are employed.

[5] DPI technology is a not-in-kind alternative that does not use HFC propellants or solvents.

5.2 Description of Survey Participants

The survey participants from the aerosol sector, and a brief description of each, are listed in Table 5-1.

Table 5-1. Survey Participants and Descriptions

International Pharmaceutical Aerosol Consortium (IPAC)	The international association of pharmaceutical companies that manufacture medications, including MDIs, for the treatment of respiratory illnesses.
Boehringer Ingelheim Aust.	Australian division of major multinational pharmaceutical company. Market share in Australia is unknown.
Aerosol Association of Australia	Industry advocacy organisation whose membership includes about 50 companies involved in the manufacture and/or marketing of non-MDI aerosol products. It is associated with trade organisations such as the US Consumer Specialty Products and the Fédération Européenne des Aérosols ('FEA') in Europe.
CRC Industries (Australia)	Australian division of multinational manufacturer of specialty chemicals, including aerosols. Market share is unknown.
DIFA Chemical Industries Pty Ltd	No details known.

5.3 Key Options for Reducing HFC Emissions in the Aerosol Sector

There are three options for reducing patient use of MDIs: dry powder inhalers (DPIs), nebulisers, and oral treatments. DPIs and nebulisers provide inhalation therapy without aerosol propellants. Currently, available oral medications are not widely used in the management of asthma and COPD, due to lower effectiveness or increased side effects relative to inhaled therapies. New oral therapies with alternative modes of action are under development for the treatment of respiratory illnesses, but with their safety and effectiveness still to be established, prospects for their future market share remain uncertain.

Controlling the leakage of aerosols during and after the manufacturing process is also an option. According to IPAC, examples of waste minimisation practices employed include: use of a vapour return hoses; redesign of the delivery truck and canister processes; installation of systems to detect and prevent pump failure; and minimisation of mixing vessel waste material. In addition, recovery of the gas from MDI canisters that are rejected from the manufacturing process for insufficient performance also is an option. It is estimated that recovery of rejected canisters could result in an annual savings in the European Union of 0.3 million tonnes of CO_2 equivalent (Enviros March, 2000).

Although non-MDI uses were primarily replaced by options that did not employ HFCs, hydrocarbons and other compressed gases have been implemented as alternative options. Table 5-2 presents advantages of future non-MDI options.

Table 5-2. Main Advantages of Popular Options in the Aerosols Sector

Top Options: 2020	Main Advantages
Hydrocarbon aerosol propellants	-Lower capital costs -Lower cost of agent
Compressed gases	-Lower cost of agent

Due to lengthy and uncertain timelines, the survey response for MDIs did not include estimates of market penetration rates of options for 2020. Current estimations of market penetration are listed in Table 5-3, along with estimates of current and future market shares of options for non-MDI aerosol use.

Table 5-3. Summary of Abatement Options and Estimated Market Share in the Aerosols Sector

Abatement Option	Current Market Share (%)	Future Market Share (%)
Dry Powder Inhalers	11-20	-
Not-in-kind medications	1-5	-
Nebulisers	6-10	-
Hydrocarbon aerosol propellants	>50	>50
Compressed gases	1-5	6-10

5.4 Impediments to Employing HFC Alternatives

Because MDIs are medical devices, substitute propellants must meet far stricter performance and toxicology specifications than would be required in most other end-use products. Inhalation therapy is the preferred means of treating patients with serious respiratory illnesses. There are three types of inhalation delivery systems that are currently available for patient use: MDIs, DPIs, and nebulisers. Neither DPIs nor nebulisers require aerosol propellants. Although DPIs and nebulisers are used successfully by respiratory patients, they have not dominated global MDI markets; each has an estimated 15 percent share. Based on current market analyses, the market share for DPIs is expected to increase naturally over the next several years, even without regulatory measures.

Nebulisers account for a relatively limited market share in Australia (approximately 6 to 10 percent) and are used primarily for treatment of acute exacerbations in hospitals and by young children or elderly patients with asthma or COPD. Nebulisers have three significant drawbacks: complexity of assembling the device; requirement of an independent power source; and the length of time taken to deliver the medication. In addition, the cost per treatment for nebulisers is significantly higher than that for MDIs or DPIs. As a result, health opinion leaders and reimbursement authorities are attempting to restrict the use of nebulisers to only those patients who absolutely require them.

In limited circumstances, oral tablets are used to treat respiratory illnesses. In general, however, inhalation therapies are favoured over oral tablets because they are faster acting and have reduced incidence of systemic side effects.

In light of the significant patient health implications, any proposals to adopt measures that could impact upon medical uses of HFCs should be considered in consultation with health authorities and patient/physician organisations.

Hydrocarbons are the preferred choice of propellant for most locally filled non-MDI applications. Although they have the advantage of being inexpensive, their ability to increase market share is limited by safety concerns. For example, since hydrocarbons are flammable, they cannot be used on "live" circuits or airplanes.

Other compressed gases, such as CO_2 and N_2 currently only have a small market share, but are expected to become more widespread by 2020. These gases also are low cost, but their performance is often inadequate—pressure reduction occurs with the depletion of the can and they are incompatible with certain formulas.

5.5 Summary

While aerosols used in consumer applications have easily transitioned to non-HFC substitutes and alternative options, MDIs face greater challenges as medical applications. From a regulatory perspective, replacing HFCs in MDIs or finding alternative options is more complex since replacements must adequately meet medical standards and regulations. The transition to alternatives is further complicated by the need for medical practitioners to prescribe medication that is appropriate for specific cases, patient acceptance of alternatives, and existing insurance coverage that specifies modes of treatment. Despite these challenges, however, DPIs have been successfully transitioning into the MDI market and are expected to continue to do so.

One survey response noted significant timelines in employing options due to technical barriers in product development and regulatory approval processes. According to survey responses, manufacturers have instituted recovery practices to lower emissions of aerosols during the manufacturing process. When considering timelines of implementation and other barriers, reducing emissions during manufacturing appears to have fewer barriers to implementation than other options.

5.6 References

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6. Foam Sector

Foams are used primarily for insulation purposes across a wide variety of commercial, industrial, and construction applications. Responses to the survey indicate that the foams most widely produced in Australia are polyurethane (PU) foams, which can be sub-categorised further into three primary subsectors: rigid, flexible, and integral skin PU foams. Rigid foams include refrigerator and freezer insulation, appliance, construction and transport (boardstock/flexible-faced lamination and sandwich panels), and spray insulation, as well as other more specialised products. Flexible foams include slabstock foams and moulded foams, while integral skin foams are moulded foams that are manufactured either by injection into closed vented moulds or by pouring into open moulds.

According to industry information received for this study, polyurethane (PU) foams currently cover 11 to 20 percent of the Australian insulation market. Rigid PU foams are manufactured primarily using HCFC-141b, although some HCFC-142b and HCFC-22 are also used. Meanwhile, hydrocarbons are used as CFC substitutes in the domestic appliance sector, while flexible foams use water-blown carbon dioxide (carbon dioxide/water) and methylene chloride systems. Polyolefin foam products and thermal insulating polystyrene foams are not produced in Australia (UNEP, 1998).

6.1 Use of HFCs in Foam Sector

Historically, chlorofluorocarbons (CFCs) such as CFC-11 have been used as the primary blowing agents during the manufacture of foams until they were found to be ozone-depleting substances (ODS). As a result of the initiatives under the Montreal Protocol, it was agreed to phase out CFCs and to use hydrochlorofluorocarbons (HCFCs) as interim substitutes. Australia completely phased out the use of CFCs in 1995 for all but essential uses and is progressing towards an accelerated phase out of HCFCs well ahead of Montreal Protocol requirements (Burnbank, 2002). The production of HCFCs in Australia has ceased, with consumption for essential uses coming from imports and recycling (SOE, 2001). In the foams sector, there continues to be a demand for certain HCFCs for PU foam production, which Australia is permitted to use under the provisions of the Montreal Protocol. Today, HCFCs continue to be used in Australia in the foams water heater industry and in general insulation applications (e.g., spray foam, general purpose pour foams, and rigid slabstock foam) (Huntsman Polyurethanes, 2003).

HFCs, which replace the CFCs and HCFCs, are active greenhouse gases with high global warming potentials (GWPs). The most commonly used HFCs in foam blowing applications are HFC-134a, HFC-152a, and HFC-245fa, have 100-year GWPs of 1,300, 140, and 790 times the warming potential of carbon dioxide, respectively. In addition, HFC-365mfc (with GWP of 890) can now theoretically be used in rigid foam applications, although mixtures of HFC-365mfc and HFC-227ea are more commonly used as a replacement for HCFC-141b (Huntsman Polyurethanes, 2003).

6.2 Description of Survey Participants in the Foam Sector

Only one survey response was received for the foams sector—Chemind Hi Tech Polymers, a large manufacturer of rigid polyurethane foam systems based in Queensland. Its Australian market share is not known, but is likely to be significant. The company is a prominent member of the Plastics and Chemicals Industries Association of Australia. A number of industry stakeholders provided additional information.

6.3 Key Options for Reducing HFC Emissions in the Foam Sector

There are seven options that are employed to reduce HFC emissions in the foams sector, including alternative agents, alternative insulation materials, and practices that directly reduce emissions. Alternative blowing agents that do not consist of HFCs include liquid carbon dioxide (LCD), water-blown (in situ) carbon dioxide (carbon dioxide/water), and hydrocarbons. Direct emission reduction practices include vapour capture, lower permeability facings, and recovery/recycling. Alternative insulating material includes PU vacuum insulation. Although indirect emissions associated with electricity generation may also play a role in the overall climate impacts of options, the inclusion of Life Cycle Analysis (LCA) and/or Total Equivalent Warming Impact (TEWI) analyses was beyond the scope of this report. Where appropriate, however, energy efficiency penalties associated with options are noted. A brief description of each option considered is provided below.

- *Liquid Carbon Dioxide (LCD).* The basic principle by which carbon dioxide (CO_2) blowing agents operate is expansion of liquid CO_2 to the gaseous state. Liquid CO_2 is blended with other foam components under pressure prior to the initiation of the chemical reaction. When decompressed, the CO_2 expands, resulting in the froth foam, which further expands with the additional release from the water/isocyanate reaction.

- *Carbon dioxide/water.* In this process, CO_2 produced from a chemical reaction between water and polymeric isocyanate is used as a blowing agent.

- *Hydrocarbons (HCs).* Hydrocarbons such as propane, butane, isobutane, n-pentane, isopentane, cyclopentane, and isomers of hexane are effective alternatives to HFCs. HCs are inexpensive and have minimal GWP impacts. However, because of their flammability, hydrocarbons are associated with additional safety and handling costs (e.g., ventilation and other controls).

- *PU Vacuum insulation.* Vacuum panels have insulating capabilities significantly better than any foam insulation available today, and offer tremendous potential for the refrigeration industry. They are typically open-celled polyurethane or polystyrene foam encapsulated in a gas barrier. (It should be noted that encapsulation of the panel still requires standard foam and blowing agent.) This assembly is then evacuated to give the panel its insulating properties.

- *Lower permeability facings.* "Facings" refer to plastic or metal skins that enclose foam in some applications. The permeability of a facing refers to the ability of the blowing agent to diffuse out of the foam cells and through the facing, to the atmosphere. Thus, low permeability facings are facings designed to reduce the rate of transmission of blowing agent from the foam to the atmosphere. Lower permeability facings can take many forms, including metal, plastic fiberglass, or multi-layer "plastic bags." If used on equipment containing HFC-blown foams, greenhouse gas emissions can be significantly reduced (Chemind Hi-Tec Polymers, 2003).

- *Recovery/recycling.* HFCs are predominantly used in closed cell foams, and can have low migration rates. As a result, it is possible to recover the majority of the HFCs used in the production of foam, thereby reducing the total amount of HFCs emitted. Australia does not have well developed technologies to recover blowing agents from foams; however, recovery technologies are expected to grow in the future. Current recovery/recycling techniques used during foam production include: (a) the regrinding and redistribution of old foam into virgin foam (a practice operated with flexible foams), and (b) the complete crushing of rigid foam under vacuum.

  Regrinding and redistributing old foam into virgin foam (i.e., using old foam as a filler, thus reducing the need to produce new foam) currently requires costly, specialised grinding equipment. Moreover, the amount of old foam that can be distributed into the virgin foam is limited, meaning that only a partial amount of the old foam can be recycled. Indeed, much of the blowing agent is liberated during the regrinding process. This technology has found greatest application in flexible polyurethane foam sectors.

During the crushing of rigid foam under a vacuum, the gases released are drawn off, recondensed, and then purified. The purified gases can then be resold or destroyed. This technique is very expensive.

- *Vapour capture.* Vapour capture systems could be any combination of hood and ventilation system for the capture and containment of organic vapours for proper disposal.

Based on the results of the survey, the key alternative blowing agents in the Australian polyurethane foam sector at present are carbon dioxide/water, hydrocarbons, and carbon dioxide. According to one industry expert, only the larger companies in Australia have begun to convert to these alternatives (Huntsman Polyurethane, 2003). In the future, where technically feasible, lower permeability facings and recovery/recycling are expected to achieve sizeable market shares of 21 to 50 percent. Table 6-1 lists present and future options for replacing HFCs that are estimated to have a market share higher than 5 percent. The survey respondent noted the necessity of technological improvements for all options except for recovery/recycling in order to bolster the uptake of these options.

Table 6-1. Key Abatement Options for the Foam Sector: Present and Future

Abatement Option	Key Options[a]	
	Current	Future
Alternative Blowing Agents	Carbon dioxide Carbon dioxide/water Hydrocarbons	Carbon dioxide Carbon dioxide/water Hydrocarbons
Direct Emission Reduction	-	Lower permeability facings Recovery/recycling
Alternative Insulating Material	-	PU vacuum panel insulation

[a] Only options estimated to have more than 5 percent market share are reported in this table.

Permeability facing technology is integral to controlling vapour release to the atmosphere. Current facings can result in very high releases of HFCs to the atmosphere over time, but with technology improvement, the amount of emissions should decrease as improved facings are applied. Recovery/recycling is another excellent emission reduction option. Although recovery/recycling policies and efforts are still in the development stages in Australia, they are expected to be widespread by 2020. For example, with further technological development, foam can be encased in impermeable polymeric material to allow foam contained in equipment to be safely removed during equipment decommissioning. The foam could then be incinerated without any atmospheric losses, or reused, if the technology becomes available. Thus, in future, the combination of low permeability facings and recovery/recycling technologies can potentially reduce HFC foam emissions to near zero.

The use of hydrocarbons is another promising alternative, as indicated by industry survey responses. Already, all manufacturers of domestic refrigerators in Australia use hydrocarbon blowing agents, as do several companies in the commercial refrigeration industry. According to one industry estimate, more than 40 percent of foam produced in the rigid foam market is currently blown with hydrocarbons (Huntsman Polyurethanes, 2003). Based on collective industry surveys responses, hydrocarbons are expected to gain an increasing market share over time, possibly reaching 20 percent of the total sector by 2020. Further market growth is likely to be constrained by inherent problems with hydrocarbon-blown foams, such as safety concerns regarding the flammable nature of hydrocarbons (particularly for end-uses that require application in the field), high capital costs associated with engineering controls, and inadequacy as a high performance insulator.

By comparison, the improvement of carbon dioxide/water technology will lead to increases in its rate of use over time. According to some survey respondents, the market penetration currently ranges from 6 to 10 percent, but may rise to the 21-50 percent level in the next 20 years. Neat carbon dioxide is a feasible option, but its application is very limited because the required equipment is expensive and several quality concerns remain unresolved. Its main application is predicted to remain in the manufacture of flexible seating foams, where insulation properties are not important and technical issues have been more easily overcome.

With technology improvements, market share for PU vacuum panels—currently estimated to be below 5 percent—is expected to increase significantly by 2020. Due to the nature of the technology, usage of PU vacuum panels will be limited to specific markets, namely those that require the highest insulation values over a long period of time.

The main advantages of options for reducing greenhouse gas emissions in the foams sector are identified in Table 6-2. The impediments associated with each option are presented in section 6.5.

Table 6-2. Advantages of Key Abatement Options for the Foam Sector, as Indicated by Industry

Abatement Option	Key Options: 2020	Main Advantages
Alternative Blowing Agents	Carbon Dioxide Carbon Dioxide/Water Hydrocarbons	-Low cost -Low cost -Low cost
Alternative Insulating Material	PU Vacuum Panel Insulation	-Lower cost of agent -Improved performance
Direct Emission Reduction Techniques	Lower Permeability Facings (HFCs)	-Improved insulation
	Recovery/Recycling (HFCs)	-Can be implemented for all foam types -Implementation already in progress

6.4 Key Options for Reducing HFC Emissions in the Foams Sector

The foams industry in Australia has made good progress towards voluntarily replacing HCFC-based blowing agents with zero ODS and low or zero GWP agents. Two alternatives, carbon dioxide and hydrocarbons, are each estimated to already represent over 5 percent of the foams market. In future, the market shares of these and other HFC alternatives are expected to grow considerably. Table 6-3 presents the estimated current and future market shares of HFC alternatives in the foam sector, as approximated by the sole survey respondent.

Table 6-3. Estimated Market Share of Abatement Options in the Foam Sector, as Indicated by Industry

Abatement Option	Current Market Share (%)	Future Market Share (%)
Carbon Dioxide/ Water	6 - 10	21 - 50
Carbon Dioxide	1 - 5	6 - 10
Hydrocarbons	6 - 10	11 - 20
PU Vacuum Panels	1-5	11-20
Vapour Capture	1-5	6-10
Lower Permeability Facings (HFCs)	1-5	21-50
Recovery/Recycling (HFCs)	1-5	21-50

Source: Survey response from Chemind Hi Tech Polymers.

However, there are many applications for which there will be major technical/processing advantages to using HFC agents and for which alternatives do not currently exist. At this point in time, and in the foreseeable future, alternatives do not exist for applications that require a high R value (i.e., high insulating value).

6.5 Impediments to Employing HFC Alternatives

The use of alternative blowing agents requires high capital investments for plant conversion and other costs associated with safety and performance. The surveyed foam manufacturer did not consider the availability or accessibility of information as an impediment to employ alternative blowing agents. Other impediments for specific options, as identified by the respondent, are listed below.

- *Liquid Carbon Dioxide (LCD).* The use of LCD technologies in almost all polyurethane foam business sectors is extremely difficult to implement. Financial impediments limiting implementation include the high cost of storage and distribution equipment, and high costs for new foam processing machinery that may be required. In addition, the applicability of LCD is impeded by technical processing problems that limit its use to simple moulding operations (comprising 5 to 10 percent of possible usage), and bulky equipment required for processing, making it unsuitable for end-uses such as spray and pour-in-place foams. Other difficulties encountered include the limited solubility of the chemical mixture, decompression, and distribution of the unavoidable froth (UNEP, 1998). Foams blown with liquid carbon dioxide might suffer from higher thermal conductivity, lower dimensional stability, and higher density vs. HCFC blown foams. To overcome these limitations, carbon dioxide can be blended with hydrocarbons or HFCs (U.S. EPA, 2001).

- *Water-Blown (in situ) Carbon Dioxide (carbon dioxide/water).* According to the survey respondent, very few companies have developed adequate carbon dioxide/water technology. In addition to the high capital costs needed for the conversion and negative past experience with first generation water blown systems, major barriers for significant market penetration of this option include higher initial thermal conductivity, lower dimensional stability, and higher density versus HCFC- and HFC- blown foams. Other industry comment disagrees with this contention and indicates that HCFC and HFC blown foams provide better thermal insulation initially, and over the life of the product.

- Carbon dioxide/water technologies also are limited by certain legislation controlling energy efficiency requirements in Australia. The respondent cites Australia's Minimum Energy Performance Standards (MEPS), which base thermal energy efficiency requirements for insulated appliances on their initial thermal performance rather than using a life cycle analysis. The poor initial thermal performance of carbon dioxide/water therefore limits its compliance with MEPS. According to the survey respondent, this is misleading because over time, all foams—including PU, styrene, and other polymers—undergo a reduction in thermal efficiency as the blowing agent diffuses out of foam cells through the cell walls. It also occurs in appliances where the foam is enclosed between metal or plastic skins, such as refrigerator walls, hot water service tanks, and outer liners of other appliances, goods, or structures. The end result is that after three to five years, the appliance insulation is not as effective as it was initially and foams blown with HCFC or HFC will have a thermal efficiency similar to that of one blown with carbon dioxide/water.

In some PU foam applications, one concern associated with using carbon dioxide/water systems is that the polymeric isocyanate content must be increased, which cannot be accommodated by some spray foam equipment. The technology required to overcome factors that limit the application of carbon dioxide/water blowing agent in Australia is not highly developed, and the surveyed manufacturer assumes that the general attitude towards carbon dioxide/water will be negative.

- *Hydrocarbons (HC).* Since HCs are volatile organic compounds, there are unresolved safety and liability concerns associated with their use. Key technical issues associated with hydrocarbons are flammability and performance.

  HCs require stringent safety precautions in manufacturing, storage, handling, transport, and customer use. These factors require factory upgrades and employee training. In order to reduce fire risks, some applications might also require the use of a larger quantity of flame-retardants and/or the use of a more expensive fire-retardant. Flammability concerns are especially emphasised in "field" end-uses such as spray foams, pour-in-place foams and moulding foams where the required flameproof safety equipment cannot be used, creating safety-hazards and consequently increasing insurance rates. These end-uses make up about 70 percent of the PU industry of Queensland, Western Australia, Tasmania, and the Northern Territory. Besides increasing insurance costs to the manufacturer, processed PU foams that use this technique run the risk of being classified as a flammable solid causing them to be less marketable. However, if proper steps in handling are introduced, flammability can be managed (Huntsman Polyurethanes, 2003).

  Additionally, like other HFC substitutes already discussed, some HC-based foams are associated with energy efficiency penalties. HC-based foams typically yield approximately 85 percent of the insulating value of those blown with HCFC-141b or other HFCs, such as HFC-245fa or HFC-365mfc. Higher performance insulation is currently being used in Australia, however, in the manufacture of domestic refrigerators and freezers. These systems yield approximately 5 percent lower insulation performance than comparable HCFC-141b systems (Huntsman Polyurethanes, 2003). Producing a thicker foam can compensate for energy-efficiency penalties, but will increase the cost of production and may not be technically viable in some applications, due to size/space limitations.

- *Lower Permeability Facings.* Lower permeability facings are crucial in controlling releases of HFCs (as well as CFCs and HCFCs) to the atmosphere. The success of this technology is dependent on the improving the percentage released through the development of less permeable facings.

- *PU Vacuum Panel Insulation.* The future potential of PU Vacuum Panels is limited by improvements in vacuum proof membrane technology that would allow long-term panel evacuation to be maintained. In addition, the vacuum panel end-use is limited to appliance, panel, and sheet insulation. Employing vacuum panel insulation into other end-uses would require potentially expensive appliance redesign.

- *Recovery/Recycling.* Recovery/recycling practices are still in their nascent stages in Australia, but are expected to become a standard part of the appliance recycling process in the future. Research and development efforts are now being taken on the recycling of flexible foams. This technology has already been demonstrated, although at relatively low concentrations (Huntsman Polyurethane, 2003).

6.6 Summary

The relatively high cost of HFCs and their associated environmental concerns have led developers of PU systems to seize opportunities to reduce greenhouse gas emissions in the manufacture of their products.

There are cases, however, where technology improvements are necessary in order for lower GWP options to penetrate the market. For example, carbon dioxide/water technology is employed for some uses, but its initial thermal properties, which are less efficient than those of other technologies, limit its use. Some technical hurdles that have not been overcome require the use of HFCs or HFEs to make PU foams viable in certain applications. Despite barriers, the industry is expected to make noticeable progress.

Hydrocarbons, lower permeability facings, and recovery/recycling are all expected to achieve sizeable market shares of 11-20 percent, but the impediments to employing hydrocarbons are significant. Small end users of hydrocarbons are expected to be unable to afford the safety process equipment such as flame proofing/isolation, and automation of their manufacturing process that would prevent possible combustion of the blowing agent (totalling between $50,000 and $1 million depending on business size). Foam industry stakeholders also fear that the legislated use of hydrocarbon blowing agents could result in many small to medium PU foam processors going out of business due to associated costs and increased retail pricing of end products to the consumer, thereby increasing competition from imports.

Limitations presented by legislation also are pertinent, especially in the case of carbon dioxide/water technology. As the survey responder points out, some industry performance standards do not recognise the entire lifetime of a product and therefore ignore the deterioration of thermal efficiency of all foam products while focusing on the inefficiency of carbon dioxide/water blown foams. A life cycle analysis (LCA) would recognise this change and would allow carbon dioxide/water to be a competitive option.

Lower permeability facings have the potential to result in a very significant reduction in emissions since, according to the survey respondent, it is “the most crucial element” controlling HFC releases. Current technology can lead to high emissions, but expected technological developments should decrease emissions.

In its nascent stages in Australia, recovery/recycling of blowing agents will become a standard element of the appliance recycling process in Australia. Since recovery/recycling practices are already in place to a small extent and are becoming more widespread, they should result in a steady reduction of emissions from the foam sector. This practice also has immediate potential since it is independent of the foams market, but may require additional economic incentives to push it forward.

6.7 References

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Appendix 1: Description of HFC Alternatives in the RAC Sector

- *Ammonia.* Alternative refrigerants such as ammonia can be used in place of HFC refrigerants in a variety of applications. Ammonia has many market advantages, including lower cost of refrigerant, increased energy efficiency, and improved performance. The major disadvantages associated with the use of ammonia include safety and health hazards and the need for safety equipment and training.
  Theoretical applicable end-uses: commercial air-conditioning/chillers, industrial process refrigeration, residential air-conditioning, cold storage.

- *Carbon Dioxide.* In motor vehicle air-conditioners, a transcritical vapour cycle using carbon dioxide as the refrigerant represents a potentially significant emission reduction opportunity. Transcritical carbon dioxide systems are under study and development by many vehicle manufacturers in cooperation with global component and system suppliers. Transcritical carbon dioxide systems have potential energy efficiency that is comparable to HFC-134a systems vehicles and the lowest GWP of any candidate refrigerant (Andersen et al., 2000). The arrangement of components of such a system would need to accommodate the extremely high pressure levels of supercritical carbon dioxide (about 2,000 psig). Research and development is also underway to develop "low-pressure" carbon dioxide, a compression/sorption hybrid system (Alliance, 1999).

  Carbon dioxide systems can be used only in low-temperature refrigeration applications (-30ºC to -56ºC), while CO_2/ammonia systems can be used for higher temperature refrigeration (+35ºC to -54ºC) (Roth and König, 2002). Combination CO_2/ammonia cascading systems are being tested in industrial process refrigeration applications. Benefits associated with these systems may include lower refrigerant and capital costs and improved energy efficiency. In addition, carbon dioxide systems are now in use in several large retail food operations, as well as transport refrigeration systems (Kauffeld et al., 2002). Combination carbon dioxide/propane systems are also under development for use in retail food applications (Kauffeld et al., 2002).

  Several risks and uncertainties are associated with this option, varying by end-use. The major concerns include safety, cost of designing and purchasing equipment, potential loss of operational efficiency (and the associated increase in indirect emissions), refrigerant containment, long-term reliability, and compressor performance (Environment Canada, 1998; ACGIH, 1999). However, benefits can also be associated with CO_2 systems, including lower refrigerant costs, and possibly, improved performance and increased energy efficiency
  Theoretical applicable end-uses: commercial air-conditioning/chillers, cold storage, industrial process refrigeration, MVACs, residential air-conditioning, retail food, transport refrigeration.

- *Hydrocarbons***.** Alternative refrigerants such as hydrocarbons (HCs) can be used in place of HFC refrigerants in a variety of applications. Different blends of HC refrigerants (typically cyclopentane and isobutane) can replace HFC refrigerants in new manufactured household refrigerators and freezers, among other uses. Hydrocarbon refrigerants are safe when proper precautions are taken, and those used in household refrigerators are quickly gaining popularity. The first Australian hydrocarbon refrigerator (a small bar refrigerator) was produced by Email in 1995. Likewise, since 1995, hydrocarbons have been used in MVACs in Australia, although some industry participants still harbour concerns about the flammability of hydrocarbons. Today, HyChill hydrocarbon refrigerants are used all over Australia as a direct replacement for both old and new refrigerants in most air-conditioning and refrigeration applications (HyChill informational pamphlet). Benefits of HC refrigerants vary by end-use and technology but may include increased energy efficiency, lower capital costs, lower refrigerant costs, and improved performance. Market impediments include safety and health hazards—real or perceived.

Theoretical applicable end-uses: household refrigeration, industrial process refrigeration, MVACs, residential air-conditioning, retail food, transport refrigeration.

- *Liquid Carbon Dioxide.* Liquid carbon dioxide is well suited for transport refrigeration since it enables food distributors with multiple stops to increase cooling capacity while addressing food safety and environmental concerns. In addition to rapid temperature pull-down, the systems contain fewer moving parts than conventional equipment, resulting in reduced noise levels and lower maintenance requirements (Powell, 2002). However, the conversion of fleets to liquid carbon dioxide requires extensive and expensive modifications to the systems.
  Theoretical applicable end-use: transport refrigeration.

- *Liquid Nitrogen.* In addition to the environmental benefits of using liquid nitrogen in transport refrigeration end-uses, other attributes include high, variable refrigerating power, simple operation, and the complete absence of noise (Messer website). The limitations of liquid nitrogen in transport refrigeration include high costs, safety and health hazards, and, for many types of transport refrigeration, technical feasibility.
  Theoretical applicable end-use: transport refrigeration.

- *Absorption Systems.* An absorption system uses water, ammonia, or lithium bromide as the refrigerant. The system can range from very simple (small refrigerator) to complex (commercial freezer). This type of system is used in domestic and industrial refrigeration and air-conditioning applications. Because of the high pressure (400 psi), welded steel tube construction must be used throughout the system. Also, because of the reaction between ammonia and copper or brass, a set of steel manifold gauges are needed (Integrated Publishing website). Gas-fired (as opposed to electrically powered) absorption water chillers are sold in the United States and are common in Japan where electricity costs are high and waste energy is available. Although absorption chillers are far less efficient than competitive systems if waste heat is not available, the technology is feasible and, under some economic circumstances, compares favourably with centrifugal chillers using fluorocarbon refrigerants. Market success will be determined by factors such as the relative costs of natural gas and electricity (these units are rarely cost-effective without low natural gas prices or high electricity rates and significant amounts of available waste heat), peak load charges, and purchase costs. In addition, absorption chillers typically have higher capital costs than vapour compression equipment, such that significant operating cost savings would be necessary to make their purchase economically-competitive.
  Theoretical applicable end-uses: commercial air-conditioning/chillers, cold storage, household refrigeration, industrial process refrigeration, residential air-conditioning.

- *Geothermal Technologies.* Geothermal cooling systems may be viable alternatives for some residential and commercial spaces. Geothermal technology transfers heat between the system and the earth and can provide both space heating and cooling. Installation costs are typically higher than conventional systems, but annual costs may be reduced significantly, largely as a result of increased energy efficiency.
  Theoretical applicable end-uses: commercial air-conditioning/chillers, industrial process refrigeration, residential air-conditioning.

- *Ice Slurry.* Currently, the only technology available using ice slurry in Australia is secondary loop systems (described below). However, other countries (e.g., New Zealand, the United States) have other ice slurry technologies available on the market. Ice slurry systems are a type of thermal energy storage system that can be used to cool products quickly by melting the ice created and stored within this same system. These systems have high cooling capacities that typically result in system designs with smaller pipes, improved energy efficiency, and lower costs. Additionally, the slurry, which can be pumped directly over the product, may also be stored and used during

hours when energy costs are lower. One disadvantage associated with these systems is that, as the slurry is pumped through the system, ice can clog valves.
Theoretical applicable end-uses: cold storage, industrial process refrigeration.

- *Secondary Loop Systems***.** Secondary loop systems circulate a secondary coolant or brine from the central refrigeration system to the display cases, isolating customers from the refrigerant (UNEP, 1999; Alliance, 1999). Secondary loop technologies can use a wide variety of fluids in the primary loops (e.g., ammonia, ice slurry, HFCs, hydrocarbons, carbon dioxide, and others) and secondary loops (e.g., water, organic and non-organic salts, alcohols, slurries, and others). Several types of secondary loop technologies currently available on the market are described in more detail below:

  - *HFC Secondary Loop Systems.* Secondary loop systems using HFCs as the primary refrigerant have lower leak rates and operate at reduced charges, thereby reducing HFC leaks. Other positive features of this technology may include enhanced reliability, more efficient defrost, longer shelf life, and less required maintenance than conventional direct expansion systems (U.S. EPA, 2001). According to industry, the primary disadvantages of these systems include higher costs and energy efficiency penalties.
  Theoretical applicable end-uses: cold storage, retail food.

  - *Ammonia Secondary Loop Systems.* Ammonia can be used in place of HFCs as the primary refrigerant in secondary loop systems. Secondary loop systems have lower leak rates and operate at reduced charges. In these types of systems, ammonia is kept out of public contact (e.g., outside of buildings), and non-toxic fluids are used as secondary coolants. The use of ammonia is very common in certain countries and strongly restricted in others (ECOFYS, 2000). For example, for many decades ammonia has been used in almost all dairies, breweries, slaughterhouses, and large freezing plants nearly all over Europe, while its use is heavily regulated in North America (ACHR News, 2000). The use of ammonia refrigerant is beginning to expand into retail food and smaller-sized chillers in some countries, particularly those in the European Union (U.S. EPA, 2001). Ammonia must be used carefully because it is toxic and slightly flammable. Ammonia is an explosion hazard at 16 to 25 percent in air, which creates a problem in confined spaces. However, because ammonia has a strong odour, refrigerant leaks are easily detectable. Additionally, because ammonia is lighter than air, dispersion is facilitated in the event of a release (UNEP, 1999). To ensure safety, modern ammonia systems are fully-contained hermetic systems with fully integrated controls that regulate pressure throughout the system. Modern systems are also equipped with emergency diffusion systems and a series of safety relief valves to protect the equipment and its pressure vessels from over-pressurisation and possible failure (ASHRAE, 1993).
  Theoretical applicable end-uses: cold storage, retail food.

  - *Ice Slurry Secondary Loop Systems.* Ice slurry can be used as the secondary refrigerant in secondary loop systems. Ice slurry is a mixture of water, ice, and salt; when used for thermal cooling (i.e., to cool large buildings), ice slurry consists of water, ice, and ethanol. Ice slurry offers great potential for flow reduction and thermal storage; its cooling capacity can be up to seven times greater than the average secondary loop system using a cold brine solution. In addition, secondary loops offer great potential for refrigerant charge reduction in refrigeration systems. Associated benefits include lower refrigerant costs, increased energy efficiency, and improved performance. Market barriers include high capital costs and market unavailability (i.e., lack of equipment or slurry suppliers in Australia).
  Theoretical applicable end-uses: commercial air-conditioning/chillers, cold storage, industrial process refrigeration, retail food, transport refrigeration.

- *Propylene/Distilled Water Secondary Loop Systems.* A secondary loop technology using a mixture of propylene and distilled water as the secondary refrigerant has been available since November 2002, and is currently in use in several supermarkets in Australia and in more than 100 supermarkets across Europe. This technology has reportedly reduced HFC charge sizes by 78 percent while decreasing the total length of HFC piping from an average of 1,050 meters to only 30 meters (Austral Refrigeration, 2003).
  Theoretical applicable end-uses: retail food, industrial refrigeration (e.g., ice rinks).

- *Distributed Systems*. Replacing HFC direct expansion systems with HFC distributed systems offers the potential to reduce HFC emissions. A distributed system consists of multiple compressors that are distributed throughout the store, near the display cases they serve, connected by a water loop to a single cooling unit that is located on the roof or outside of the building. Distributed systems significantly reduce the refrigerant inventory and minimise the length of refrigerant tubing and the number of fittings that are installed in direct expansion systems, thereby reducing leaks of HFCs (Alliance, 1999). These systems can also be more energy efficient than direct expansion systems, leading to further reductions in global warming impacts (Sand *et al*., 1997). Industry reports the associated disadvantages to include costly and disruptive maintenance.
  Theoretical applicable end-uses: cold storage, retail food.

- *Desiccant Systems***.** Desiccant cooling systems are energy efficient and environmentally safe. They are used as stand-alone systems or with conventional air-conditioning to improve the indoor air quality of all types of buildings. In these systems, a desiccant removes moisture from the air, which releases heat and increases the air temperature. The dry air is cooled using either evaporative cooling or the cooling coils of a conventional air conditioner. The adsorbed moisture in the desiccant is then removed (the desiccant is regenerated to its original dry state) using thermal energy supplied by natural gas, electricity, waste heat, or the sun. Commercially-available desiccants include silica gel, activated alumina, natural and synthetic zeolites, titanium silicate, lithium chloride, and synthetic polymers (National Renewable Energy Laboratory website).
  Theoretical applicable end-uses: commercial air-conditioning/chillers, MVACs, residential air-conditioning.