THE AUSTRALIAN INSTITUTE OF
REFRIGERATION, AIR CONDITIONING AND HEATING

GUIDELINES

Management guideline for the phase-out of refrigerant R22

Impacts and strategies for building owners, operators and maintainers

INDUSTRY GUIDE 2015

AIRAH

Management guideline for the phase-out of refrigerant R22

Impacts and strategies for building owners, operators and maintainers

Preface

If there is one key message for owners and operators of R22 equipment it is this: **phase-out is a reality**. It is happening now and needs to be managed. Experience in Europe has shown that when organisations address R22 phase-out early and proactively, they benefit in the long term. A plan should be developed to look at alternatives to R22 and assess the priorities in terms of costs, benefits and service continuity.

For existing air conditioning and refrigeration systems using refrigerant R22 there are really only four options, a hierarchy of proactive responses, that can be considered:

- Retain and maintain your aging R22 system and hope that you won't have a major breakdown or leakage;
- Retrofit your system to use an alternative refrigerant, typically a high-GWP HFC;
- Replace your system with an exact match of new equipment; or
- Review, redesign and upgrade your system for superior high energy efficiency, and low-cost, low-emissions outcomes.

When assessing refrigerant alternatives and replacement systems the focus should be on low-GWP and system life-cycle costing. High-GWP refrigerants are likely to be the subject of increasing future controls. Switching to low-GWP refrigerants where possible may avoid the double-step of moving to a high-GWP HFC refrigerant and then having to switch again at a later date. Replacing old R22-based systems has the added benefit of the improved reliability and energy efficiency of next generation refrigerant systems.

This Guide helps building owners, facilities managers, system operators, and technical service providers to all be on the same page and talk the same language when it comes to planning for R22 phase-out. As well as providing comprehensive background material, the Guide also explains the audit and asset management process and the technical options available. All stakeholders need to work together to manage this change; the use of this Guide will make that task easier and more manageable.

Vince Aherne
Editor

Disclaimer

Executive summary

This guideline provides advice relating to the increased scarcity of refrigerant R22, a commonly used refrigerant found within air conditioning and refrigeration systems.

R22 is being phased out in accordance with Australia's obligation to the Montreal Protocol on Substances that Deplete the Ozone Layer.

The phase-out is being applied via a reduction in allowable imports of R22 into Australia. In 2014, Australia's import quota was reduced by 75 per cent compared to that of 2013, and this will be followed by a further reduction in 2016 when imports will remain at a stable minimum level until complete phase-out occurs in 2030.

The continued use of R22 presents a risk to owners or managers of building assets. The ongoing reduction in imports is resulting in reduced availability and an elevated cost for this refrigerant, where obtainable. Availability of the refrigerant is expected to be highly constrained from 2016 onwards, when the import quota reduces to its lowest level.

There are four management options available: retain and manage the R22 plant, retrofit the plant with an alternative refrigerant, replace the R22 equipment, or replace and upgrade the system.

While retrofitting equipment to use a different refrigerant is frequently possible, this option has limited application. The success of retrofitting will depend on a variety of considerations including the refrigerant used, system capacity, seals, valves and component changes, warranty requirements and ongoing parts availability. In many cases upgrading to new equipment may be the only acceptable solution when an R22 system can no longer be maintained or repaired.

There are numerous factors such as funding, procurement method, engineering design and equipment lead-time that can add considerable time and affect the chosen strategy for the management of R22-based assets. A management strategy needs to consider not only the technical solutions, but also the business priorities and needs of the owner, such as the intended future usage for affected buildings.

Building owners and managers are encouraged to carry out audits of their building assets and develop asset registers of R22-charged equipment. The management strategy adopted for individual R22-based systems can be prioritised based on some key characteristics. These include age of equipment, criticality of the site and other factors, in order to reduce risk and proactively future-proof the adversely affected mechanical services within your buildings.

Contributors

This Management Guideline for the Phase-out of Refrigerant R22 was prepared by the State of Queensland (Department of Housing and Public Works) 2015 and peer reviewed with AIRAH's assistance.

The following individuals contributed or reviewed and commented during the development of the guideline:

- Vince Aherne, M.AIRAH
- Reg Binding, M.AIRAH
- Michael Bennett
- Evan Blair, M.AIRAH, (primary author)
- Don Cleland, HM. AIRAH
- Neil Cox
- Graeme Dewerson, Affil.AIRAH
- Paul Eagling
- Kristy Harder
- David Harrison, Affil.AIRAH
- Julian Hudson, M.AIRAH
- John McCormack
- Louise McCann, Affil.AIRAH
- Bryon Price, F.AIRAH
- CSP Sarathy, M.AIRAH
- Stephen Smith, M.AIRAH
- Phil Wilkinson, F.AIRAH

About AIRAH

The Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) is an independent, specialist, not-for-profit technical organisation providing leadership in the HVAC&R sector through collaboration, engagement and professional development.

The Institute's mission is to lead, promote, represent and support the HVAC and related services industry, and membership. The Institute produces a variety of publications, communications and training programs aimed at championing the highest of industry standards. AIRAH encourages world's best practice within the industry, and has forged a reputation for developing the competency and skills of industry practitioners at all levels.

Contents

Purpose of this guideline

The aim of this guideline is to provide advice to building owners, operators and maintainers about the issues associated with the continued use of refrigerant R22 in air conditioning and refrigeration equipment, and to encourage the development of strategies for the planned management, recovery, reclamation or safe destruction of this ozone-depleting substance.

Who should use this guideline?

Owners, operators and facilities managers of buildings and facilities containing air conditioning or refrigeration equipment that operates using R22. Technical service providers conducting technical audits, system maintenance and new system installation activities.

Scope

This guideline provides background information and a series of recommendations to help building owners and facility managers develop audit procedures and management strategies to help them decide whether to:

1. Retain and manage R22 assets; or
2. Retrofit R22 assets with an alternative refrigerant; or
3. Replace R22 assets; or
4. Upgrade R22 assets.

This guideline applies to vapour-compression-cycle refrigeration and air conditioning systems — such as window-mounted room air conditioners, split-systems, package units and chilled-water production machines (chillers), as well as commercial and industrial refrigeration systems including storage cases and cool rooms — that operate with R22 refrigerant.

This guideline does not cover equipment operating on an absorption refrigeration cycle.

Glosssary

ARCtick

A licence scheme introduced by the Australian Government in response to Australian obligations under the Montreal Protocol. Under the scheme the Australian Refrigeration Council Ltd (ARC) administers refrigerant handling licences and refrigerant trading authorisations on behalf of the Australian Government, for professionals in the refrigeration and air conditioning industry.

Chlorofluorocarbon (CFC)

CFCs are fluorocarbon compounds in which all the hydrogen atoms of a hydrocarbon are replaced with atoms of chlorine and fluorine. Previously used as working fluids in vapour-compression-cycle air conditioning and refrigeration equipment until their phase-out under the Montreal Protocol in the early 1990s (e.g. R12).

Global warming potential (GWP)

A relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. It is calculated over a specific time interval (20, 100 or 500 years). GWP is expressed as a ratio to carbon dioxide (whose GWP is standardised to 1).

Note: the GWP data provided in this guide is for information only and is based on the fifth IPCC assessment report. Other guides and standards may cite different GWP data sourced from earlier IPCC assessments.

Hydrochlorofluorocarbon (HCFC)

HCFCs are CFCs with hydrogen reintroduced to reduce the molecular stability of the compound (which means it is more liable to break down before reaching the ozone layer). Used as working fluids in vapour-compression-cycle air conditioning and refrigeration equipment (common HCFCs include HCFC-22 (R22), HCFC-123, HCFC-144, HCFC-141b and HCFC-142b).

Hydrofluorocarbon (HFC)

A class of fluorocarbon compounds that contain the carbon-fluorine bond. These substances do not deplete the ozone layer as they do not contain chlorine or bromine. Used as working fluids in vapour-compression cycle air conditioning and refrigeration equipment. High-GWP HFC refrigerants may be the subject of future usage controls.

ODP tonne

An ODP tonne is the quantity of the HCFC that results from multiplying its mass in tonnes by its ozone-depleting potential. Note that this amount, when referring to HCFC import quotas, includes all HCFC refrigerants, not just R22.

Ozone

Ozone (or trioxygen O_3) is a triatomic molecule, consisting of three oxygen atoms.

Ozone depleting potential (ODP)

The ODP of a chemical compound is the relative amount of degradation to the ozone layer it can cause, with trichlorofluoromethane (R-11 or CFC-11) the reference, being standardised to an ODP of 1.0.

Ozone depleting substances (ODS)

Substances that deplete the ozone layer and are widely used in refrigeration, air conditioning, fire extinguishers, as solvents for cleaning, electronic equipment and as agricultural fumigants. The most potent ODS are controlled by the Montreal Protocol.

Ozone layer

A portion of the stratosphere with a higher concentration of ozone (from 2 to ~8ppm) and prevents damaging ultraviolet light from reaching the Earth's surface.

Recovered refrigerant

Used refrigerant that has been withdrawn from a system.

Reclaimed refrigerant

Recovered refrigerant that has been reprocessed to an "as new" standard.

Recycled refrigerant

Reclaimed refrigerant that has been re-used in another (or the same) system.

Refrigerant classification

The ISO 817 system of classifying refrigerants into safety groups according to health and safety risks assessed on the basis of flammability and toxicity. Classifications include A and B for toxicity and 1, 2, 2L and 3 for flammability. The safety classification system is used when designing equipment, determining maximum refrigerant charge sizes, and defining the applications and locations in which they can be used.

Refrigerant R22

Chlorodifluoromethane or difluoromonochloromethane. This colourless gas is a hydrochlorofluorocarbon (HCFC). It was commonly used as a propellant and refrigerant. ODP = 0.055, GWP = 1810.

Temperature glide

Temperature glide occurs in near-azeotropic and zeotropic mixtures. It is the temperature difference that occurs between the vapour state and liquid state during evaporation or condensation at constant pressure, i.e. the temperature in the evaporator and condenser is not constant, as it is for a pure refrigerant or azeotropic mixture of refrigerants.

Vapour-compression refrigeration cycle

A thermodynamic refrigeration cycle where a circulating refrigerant is used as the medium that absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere (usually to the ambient environment).

Working fluid

The working fluid is the pressurised gas or liquid that is used as a medium in a thermodynamic cycle. In an air conditioning, refrigeration or heat pump system, the working fluid is a liquid or gas refrigerant that absorbs or transmits energy as it evaporates (heats) and condenses (cools).

1. Background

1.1 What is R22?

R22 is a manufactured fluorocarbon compound designed for use as the working fluid in refrigerative systems. R22 is a commonly used refrigerant gas contained within many air conditioning and refrigeration systems manufactured prior to 2005.

The R22 gas is contained inside the sealed refrigeration system. The R22 "charge" makes the cooling process possible for air conditioning (in summer), and can also enable heating (in winter) for some air conditioners. It is also used in commercial and industrial refrigeration.

R22 is a hydrochlorofluorocarbon (HCFC). It is one of a number of ozone-depleting substances (ODS) identified by the international community as harmful to the environment. R22 is also known as HCFC-22.

1.2 Phase-out of R22

The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol) is a protocol to the Vienna Convention for the Protection of the Ozone Layer. It is an international treaty designed to protect the ozone layer by progressively phasing out the production and use of numerous substances responsible for ozone depletion.

R22 and other HCFCs such as R123 are being phased out from use under the Montreal Protocol. Australia is a signatory to the Montreal Protocol, as is essentially every other developed country in the world (197 signatories in total), and therefore is required to abide by the Protocol's requirements.

1.3 Legislative requirements

Australia has adopted an advanced phase-out schedule for ozone depleting substances (ODS) including HCFCs. The phase-out schedule is specified in the Commonwealth Government's Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 (The Act).

The Act is the legislative mechanism under which Australia meets its obligations to phase-out ODS under the Montreal Protocol, and limits greenhouse gas emissions by controlling the use of synthetic greenhouse gases under the Kyoto Protocol to the United Nations Framework Convention on Climate Change. The Act controls the import, export, manufacture, acquisition, use, storage, handling and disposal of these substances. The Act specifies the limit of HCFC imports allowable for each calendar year.

In 2012 and 2013 the phase-out schedule reduced imports to only 16 per cent of pre-phase-out importation levels. In 2014 and 2015 the quota was cut a further 75 per cent – down to 4 per cent of pre-phase-out imports by 2016 (2.5 ODP tonnes). The import quota from 2016 to 2030 will be stable at 2.5 ODP tonnes until final phase-out in 2030. From 2030 there will be no allowable imports of the refrigerant. Refer to Appendix A for full phase-out details and what these percentages mean in terms of future low quantities of R22 available to the market.

Preventable emissions of R22 are prohibited. The Australian Refrigeration Council Ltd (ARC) administers refrigerant handling licences and refrigerant trading authorisations under the ARCtick licensing scheme. Any person handling R22 must hold the correct and current ARCtick licence.

2. Technical options

2.1 Potential risks for building owners, operators and maintainers

R22 is the working fluid for an estimated 30 per cent of all air conditioning and refrigeration equipment in Australia, so the import quota reduction occurring now creates certain risks for building owners, operators and maintainers.

Due to the quota reduction many suppliers have advised that the sale of R22 to new customers has substantially reduced from January 2014 and essentially will cease in January 2016. As a consequence, it will progressively become more difficult to maintain R22-charged equipment due to the scarcity and cost of the refrigerant.

The purchase price of R22 has substantially increased in the last few years and is likely to continue to rise. Current market prices depend on commercial arrangements with suppliers and the quantity purchased. It is important to note that R22 prices will continue increasing as import quotas are reduced and the market supply is further restricted.

Air conditioning and refrigeration equipment can require maintenance for various reasons, however "breakdown maintenance" (i.e. unplanned repairs) involving a leak of some or all of the refrigerant charge is the major concern.

It is estimated that up to 8 per cent of all R22 in use across facilities in Australia is lost to the atmosphere each year through equipment failure, thus requiring repair and recharge with new refrigerant. This could be a system developing a small leak and requiring repair and top-up of R22, or a system could suffer a catastrophic fracture of a component thus requiring repair and full restoration of the refrigerant charge. Older equipment is more prone to fatigue failure and loss of charge.

Some of the key risks that owners, operators and maintainers face moving forward are:

- Aging R22-charged equipment experiencing more frequent maintenance issues and/or failures;
- Scarcity of R22 resulting in exorbitant maintenance costs when refrigerant purchase is required;
- Scarcity of parts for R22 systems increasing, making maintenance more difficult;
- Possible unavailability of R22 (especially in remote areas) leading to an inability to repair equipment; and
- Business disruptions due to downtime of failed equipment that is not able to be repaired and/or re-charged.

2.2 Technical options for managing R22 equipment

The options available for managing equipment using R22 depend on the type, size, and condition of equipment. R22 can be found in smaller systems such as "window-mounted" room air conditioners (RACs), up to larger air conditioning systems using water chillers providing hundreds of kilowatts of cooling (e.g. in office buildings). The refrigerant is also common in refrigeration and cool rooms.

The age, size and complexity of the system dictates which technical options are available for managing the risks associated with continuing to operate R22-charged equipment. There are four options available:

1. Retain and manage the R22 plant; or
2. Retrofit R22 equipment with an alternative refrigerant; or
3. Replace R22 equipment; or
4. Replace and upgrade R22 systems.

Table 1 provides a description of the four suggested management options which should be selected based on the type, age and condition of equipment, and the cost-effectiveness of the option.

Table 1: Technical options for addressing R22-charged equipment

Issues for consideration	Management options		Typical application
System type System complexity System age Plant condition Criticality of function Cost of options	**Option 1**	Retain and manage existing systems using enhanced maintenance procedures and updated leak-prevention practices, until failure occurs.	Systems that are not critical, are in good condition and have significant remaining economic life.
	Option 2	Retrofit existing system with an alternate, non-ozone-depleting, non-flammable refrigerant (e.g. blended HFC refrigerants).	Systems that are in good condition, have significant remaining economic life, and are cost-effective to retrofit.
	Option 3	Replace with new equipment which uses non-ozone-depleting refrigerant (i.e. like-for-like in capacity replacement, future-proof refrigerant where available).	Small or simple systems that are old, in poor condition, and whose function has not changed since the original design and installation.
	Option 4	Upgrade to new equipment which uses non-ozone-depleting refrigerant, taking into account additional considerations (i.e. an engineered upgrade, future-proof refrigerant where available).	Larger or complex systems that are old, in poor condition, and whose function has changed since the original design and installation.

2.3 Applying the technical options

2.3.1 Retain and manage existing R22 systems

One option, and the most passive management approach, is to continue to run and maintain the R22-based system until eventual failure occurs, and then replace it. This is not a long-term solution but can be used as an interim solution to provide time to plan and/or fund a more proactive management solution.

The retain and manage approach means reviewing the existing maintenance regime to ensure it includes maintenance for energy-efficiency tasks and regular leak checks, with a maintenance leak-prevention focus on high-risk components where leaks might occur.

This is the highest risk strategy in terms of the exposure of system owners and operators to high ongoing operating costs, maintenance costs, refrigerant leakage costs, potential environmental harm, and provision of service or risk of business disruption. As systems continue to age the risk of catastrophic failure increases. When this strategy is adopted, the true cost of system failure should be carefully considered. For example, this strategy is generally not recommended for refrigeration applications where loss of service or a disruption to the continuity of service results in loss of product (frozen food, blood storage, etc.).

Adopting this management approach may reduce the need to retrofit to a high-GWP HFC refrigerant or invest in new or upgraded systems. Large commercial and industrial systems can have economic lives far longer than the 7–12 years common for small systems, and keeping them operating on R22 is a valid and important potential management strategy in the short-to-medium term. This strategy is best applied as a precursor/risk reduction strategy before the planned retrofit or replacement of the R22-based system.

Stockpiling

Where the decision to retain and manage R22-based systems is made, owners and operators may need to consider some strategies to help secure or guarantee a future supply of R22 to meet their service and maintenance needs. Stockpiling recovered reclaimed refrigerant or stockpiling virgin refrigerant may be worth considering or requesting a service company to secure an on-going supply on your behalf. Legislative requirements must be met when stockpiling refrigerant.

Environmental considerations

From an environmental perspective, the stockpiling of R22 from decommissioned units for subsequent reuse in existing, still operating equipment is not a preferred option. Re-use of R22 is contrary to the intent of Australia's commitment to the Montreal Protocol, specifically that R22 is internationally recognised as an environmentally harmful substance that should not be permitted for widespread use. Systems using R22 are typically older and more prone to failure and leakage, recycling R22 back into equipment in such systems increases the risk of environmental harm due to eventual atmospheric release.

2.3.2 Retrofit with non-ozone depleting refrigerant

Where the existing R22-based system is in good condition, a short-to-medium term potential solution is to retrofit the existing equipment to operate on a HFC-based refrigerant specifically designed as a replacement for R22. These retrofits can be very cost-effective for systems where the replacement cost of the unit is far higher than the cost to retrofit. Retrofitting enables the owner to get the full working life out of the installed equipment.

The cost of the retrofit, and the extent of modifications required for the process, will depend on the condition and age of the system and the retrofit refrigerant chosen for the application. Plant condition, refrigerant glide limitations, material compatibility, oil, cooling capacity, power, leakage, system pressure and system downtime are just a few of the issues to look into when assessing whether to change refrigerant. Retrofitted plant will not normally be provided with an equipment warranty although there may be some limited warranty for the retrofit works. Retrofitted old plant will still be subject to potential parts availability and support issues, as it continues to age.

Some of the tasks required to undertake a retrofit include: recovering R22 and the charge of mineral oil from the system; renewing the filter-dryer; adjusting or replacing the refrigerant metering device (thermostatic valve if present); adding a suction filter; leak testing; recharging; and verifying correct operation. Any worn or damaged components also need to be replaced.

It is important to note that system capacity may be reduced with some retrofit refrigerants. This may mean the building cooling load demand is not able to be met on hot days and equipment may need to run for longer periods of time. Where the system coefficient of performance is less that that achieved with R22 this may cause increased system energy use.

Generally the older the system the higher the probability that leaks will be observed after a retrofit. Leaking of HFC blends can lead to the requirement for a full recharge of refrigerant gas in some circumstances. Refer to Appendix B for more technical detail on the retrofit option and a summary of common retrofit refrigerants.

Converting to a different refrigerant classification

When converting an existing HCFC-based system – which is an A1 refrigerant – to operate using an alternative refrigerant with an A2, A2L or A3 classification, a significant conversion process is required. In most cases this is not a recommended or cost-effective strategy. Refer to AIRAH's *Flammable Refrigerant Safety Guide* for a comprehensive list of the standards, regulations, and procedures that need to be considered when converting systems to use flammable refrigerants.

2.3.3 Replace or upgrade to new equipment

A long-term strategy is to replace R22-based systems and upgrade to a new energy-efficient low-GWP plant and equipment. Systems that are old, that are in poor condition, that are uneconomical to retrofit, and that serve critical functions should be upgraded.

Upgrading the equipment is a proactive management approach, with the two choices being:

1. A like-for-like replacement i.e. with no assessment of the actual cooling demand, or
2. An engineered upgrade i.e. which includes a design assessment of actual and future cooling demand.

One of the major and immediate benefits of the new equipment option is the built-in energy-efficiency uplift that can be as high as 40 per cent, depending on the system being replaced and the level of engineering applied in the replacement process. Refer to section 3.3 for further information on the benefits of upgrading to an engineered solution with a future-proof refrigerant.

2.4 Key management considerations

2.4.1 Management impacts

There are many factors to be taken into account when developing a strategy to address the risks presented by the R22 phase-out. Although this subject is largely a technical one, management decisions for the implementation of such a strategy will be required, taking into consideration factors such as:

- Impact of business interruptions. For example, a retain and manage (to failure) strategy for an air conditioning system may carry the risk of an occupied space being without air conditioning for the time it takes to repair or obtain new air conditioning – which may mean the space is temporarily unsuitable for occupancy, or a critical function cannot be served.
- Allowing enough time for professional engineering design and documentation to be prepared (particularly for complex sites with chillers). This may include assessment for potential energy savings due to upgraded equipment being more efficient (note: energy savings can offset the cost of installation in the longer term, allowing funding to be directed to further R22 upgrade works).
- Allowing sufficient time for tendering and procurement processes.
- Allowing for equipment delivery lead time. For example, new chillers can sometimes have a lead time of four months.
- Management of asbestos and other workplace hazards. For example, if penetrations through walls are required to install new equipment, professional asbestos removal may need to take place first.
- Technical assessment of brand and product selection. For example, the capital cost of equipment, its reliability, spare parts availability, after-sales service, energy efficiency and network compatibility should all be considered when selecting new equipment.
- Logistical efficiencies. For example, it may be more cost-effective to group works occurring in similar geographical areas together, especially in more remote locations.
- Additional requirements for new equipment installations. For example, requirements in the National Construction Code and some current Australian Standards will need to be complied with.

Importantly, consideration needs to be given to funding proposed equipment upgrades and/or retrofit projects. Where costs are prohibitive or available funding is constrained, it may be useful to develop costed work programs and include them into annual financial budgetary cycles over a number of years. Such works should form part of, or be co-ordinated in with, capital works, minor works or maintenance works programs.

All plant is eventually replaced or becomes redundant. A good organisational strategy is to have a managed asset approach that recognises life cycles, duty/application and asset condition, and applies a staged replacement plan. R22 phase-out replacement is often an accelerated component of such a plan, i.e. bringing forward the inevitable ¬– but with benefits. The potential benefits of an accelerated replacement program can include bulk-buy savings on plant, engineering and installation, streamlined logistics, plus a guaranteed ongoing energy and cost saving from the replaced plant.

2.4.2 New systems

The long-term alternative is to replace the existing R22-based system with new equipment. While this does represent a higher and immediate capital investment, overall costs should be offset to some extent by the new equipment being more energy efficient. Replacing systems in a planned and managed manner before a major equipment failure occurs:

- Minimises system down-time;
- Reduces unplanned capital expenditure;
- Reduces maintenance cost exposure; and
- Better controls the risks to business operations.

In general for new systems, the more efficient the unit, the more it will cost initially. However, more efficient equipment will actually save money over time as it requires less energy to operate. One thing that is required to ensure a long lifespan, and an energy-efficient system, is good regular maintenance.

2.4.3 Refrigerant type

Refrigerant selection is an important issue to consider when upgrading systems and equipment. All refrigerants have benefits and costs, advantages and disadvantages, and there is no single simple answer to the question, "Which is the best refrigerant to use?". The current global trend is towards the use of lower GWP refrigerants. There is, therefore, a strong case for owners of R22 systems to move to a new low-GWP solution rather than retrofitting or moving to a new high-GWP system that may be affected by new controls in future. There is a real danger that system owners who do a retrofit or buy new equipment may, in the not-too-distant future, be in a position where they need to retrofit again due to GWP rather than ODP issues. Existing and emerging low-GWP solutions are discussed in Appendix C.

2.4.4 Staged implementation

Often organisations don't manage the move away from R22 in one step. An intermediate option for building owners is where they retrofit and/or upgrade priority systems and then leverage legitimate recycling options to clean the reclaimed R22 and use it to run their less-critical lower priority systems, while they stage their transition and upgrade program.

2.4.5 Trial retrofit implementation

Where building owners have several similar systems, and make the decision to retrofit, a good strategy is to retrofit one system as a test case, analyse the performance and any complications or implementation issues, and then retrofit the rest of the equipment, applying any lessons learned.

3. Auditing, prioritisation and risk management

3.1 Audit of assets

Risk management of R22-charged equipment is centred on knowing the extent of such equipment (i.e. having an accurate R22 register/asset list) and prioritising response strategies, including those technical options involving the recovery and reclamation of R22 from that equipment. A flowchart is provided in Figure 1 outlining a recommended process to assist building owners and managers to develop and implement their risk-management response strategies.

3.1.1 Desktop audit

Initially a desktop audit should be carried out to identify those sites and/or buildings suspected or known to be using air conditioning and refrigeration equipment containing R22. Contributing information can be obtained from sources such as:

- Building asset registers;
- Plant and equipment registers;
- Operation and maintenance (O&M) manuals;
- Servicing and maintenance contract agreements;
- Servicing and maintenance records or log books;
- Manufacturers' literature;
- Project specifications or commissioning documentation; and
- Tender, workshop or as-installed drawings and other technical documentation.

Valuable information can also be gained from operational personnel such as on-site managers, facilities managers, or maintenance staff.

3.1.2 Detailed audit

The desktop audit can assist to conditionally prioritise sites for further evaluations. There will be many unknowns however, and ultimately a detailed audit may be required to clarify and confirm the presence of R22 in each item of equipment. In many cases this will include a site visit or contact with someone at the site to visually confirm the type of refrigerant in use.

Air conditioning and refrigeration equipment is generally required to clearly state and display the type of refrigerant it uses. It can often be found marked on the compressor or on the name plate. Some manufacturers design and rate compressors for a range of HFC and HCFC refrigerants in which case the compressor manufacture will not state the specific refrigerant on the nameplate.

Where the identity of the refrigerant in use in a system is unclear, a refrigerant analysis can be carried out. A refrigerant sample can be taken and analysed and the gas type/composition scientifically identified.

Key items of additional information that should be collected during the detailed audit are:

- Details of the equipment – make and model, cooling capacity;
- Function served – description of the area and function served by the system (e.g. office, workshop, refrigeration store or cold room) and an assessment of its importance (i.e. a critical function or not?);
- Type of equipment – air conditioning or refrigeration, air or water-cooled, chiller, package, split package, split-system, room air conditioner or other;
- Age of the equipment and date of installation;
- Kilograms of refrigerant charge inside the system;
- Safety issues – these may have changed since the original installation;
- Location of equipment and ease of access – e.g. rooftop-mounted, wall-mounted;
- Any requirement for access equipment to facilitate an upgrade or ongoing maintenance (such as cranes, ladders, safety harness attachment points);
- Performance of the equipment (e.g. reliability, capacity problems, energy consumption).

Ideally, this process will produce an R22 inventory that can assist future management, irrespective of the management strategy, or mix of strategies, applied. Often organisations don't move away from R22 in one step; management of R22 phase-out generally takes time and the R22 inventory is a useful management tool to assist this process.

3.2 Prioritisation of equipment for upgrade

The detailed audit can assist with firm prioritisation of upgrade work that may need to occur sooner rather than later. Some equipment may need to be given a priority over other equipment, depending on factors such as:

- The age of the equipment – older equipment is more likely to fail, has a limited supply of spare parts, and may be at the end of its economic life.
- Amount of refrigerant charge (kilograms) in the system – larger refrigerant charges carry more risk regarding damaging the ozone layer, while also exposing building owners to high refrigerant replacement costs.
- Critical sites – sites that require constant provision and precise control of space conditions (e.g. archives, laboratories) usually need to maintain spare cooling capacity at all times. This may elevate the need to proactively manage the R22 equipment at these sites.
- Location – remote areas may have more difficulty in obtaining R22 and, therefore, it may be more important to contend with these sites first.

3.3 Additional considerations for new plant and equipment

3.3.1 Meeting current standards

Installation of new equipment should adhere to the current technical and performance requirements as outlined in the National Construction Code and various applicable Australian Standards.

As an example, equipment that is currently roof-mounted and needs full replacement may now require roof walkways, handrails, safe access ladders and harness attachment points, which could potentially add substantial cost to the upgrade of a roof-mounted system. In such situations, a redesign of the system to accommodate ground or plantroom-mounted equipment may be beneficial.

The potential benefits or opportunities arising from any replacement and upgrade works required to manage the phase-out of R22 include:

- Significant energy-efficiency improvements for new plant;
- New five-year warranty for replaced equipment;
- Lower operation and maintenance costs for the system;
- Improved reliability; and
- Improved performance for engineered systems.

3.3.2 Engineered upgrades

An "engineered" upgrade (as opposed to a like-for-like replacement) takes into consideration the variables of the conditioned space that determine the calculated cooling capacity of the new equipment. For example, in an air conditioned space some factors may have changed since the air conditioning equipment was originally installed. Changes that can be accommodated in an engineered design and selection process include:

- Greater use of computers and servers may mean the heat load has increased (existing air conditioning might not be coping in summer, therefore a like-for-like replacement will not cope either).
- Passive design changes or building modifications such as window shades and extra roof insulation may in fact result in a reduced heat load, thus enabling installation of a smaller (i.e. lower capacity) air conditioning system.
- The building may have been modified – e.g. rooms added, areas demolished, layout altered, functional usage changes, walls added or removed, etc.
- The occupancy volume may have changed – more or less people in the same space means different loads on the air conditioning due to a change in outdoor air requirements under Australian Standard 1668.2-2012.
- Technological changes in the types of equipment available – some equipment selections and system configurations may change due to advances in equipment designs and capabilities. This may have impacts on the need (or not) for plantroom space, access, services etc. Some older system designs may no longer be suitable and may require substantial re-engineering.

3.4 Reclamation or destruction of R22

As a guiding rule, recovered R22 should not remain with the mechanic or contractor for re-use in subsequent R22 system repairs. Recovered R22 must be either destroyed, or reclaimed (to the 'as new' standard) and recycled. Recovered refrigerant should always be reclaimed or destroyed by an approved processor.

3.4.1 Destruction

The destruction (rather than re-use) of recovered R22 ensures the removal of this ozone depleting substance from the environment entirely. Persons involved with project works (i.e. engineers, designers, project managers, contractors, and refrigeration mechanics) should be made aware of any preference for R22 destruction during R22 upgrade or retrofit works. This requirement should be noted in contract documentation and specifications relating to the project.

R22 should be recovered and destroyed by withdrawing it from the system, transferring it into recovered gas cylinders and depositing it at one of more than 250 collection points across Australia. A rebate is paid (currently $3 per kilogram) for the deposit of the refrigerant (based on weight) by Refrigeration Reclaim Australia (RRA).

RRA is a not-for-profit organisation that recovers and destroys surplus and unwanted ozone depleting and synthetic greenhouse gas refrigerants. The refrigerant is processed, tested and destroyed, using technologies that transform the refrigerants to harmless salts.

3.4.2 Reclamation and recycling

Alternatively, recovered R22 can be reclaimed and recycled.

The destruction of recovered R22 is an energy-intensive process that produces CO_2 both at the power station and as a by-product of the refrigerant degradation (the recovery and destruction process has a GWP< 10, compared to GWP for emitted R22 of 1810). Manufacture of new synthetic refrigerants is also energy intensive and relies on the mining of fluorspar (the natural ore containing fluorine).

The recovery, reclamation, and recycling of R22, although it could cause some ozone depletion through reuse and subsequent emission, should be balanced against the environmental downsides of destruction. (R22 emission results in ozone depletion and a global warming impact around 180 times greater than R22 destruction). The use of reclaimed R22, cleaned to a recognised standard was embraced in Europe as part of their phase-out strategy. The use of legitimate refrigerant recycling can allow building owners to make the best use of their R22 resource and insulate them against the impact of shortages due to the phase-out.

However, it should be noted that this practice increases the possibility of atmospheric release at some point in the future, and is at odds with the intent of the Montreal Protocol. Also, it cannot be guaranteed that the refrigerant that is recovered from the system does not contain contaminants, e.g. high levels of moisture could cause corrosion in the new system.

Recovered refrigerant must be reclaimed prior to re-use or recycling.

Refrigerant recycling

Legitimate recycling means R22 that is reclaimed (cleaned) to a recognised standard such as AHRI 700 *Standard for Specifications for Fluorocarbon Refrigerants*. Where refrigerant is recovered it should either be destroyed or reclaimed. The re-use of recovered refrigerant that has not been reclaimed (cleaned) can be detrimental to a refrigerant system. Recovered refrigerant can contain moisture, oils, acidity, particulates and non-condensable gasses. Re-using this refrigerant may cause corrosion to copper and aluminium components, shortening the life of heat transfer coils and compressors.

Recovered refrigerant must be reclaimed prior to re-use. Reclaimed refrigerant should be treated and processed so that it conforms to the AHRI 700 standard. Using recovered refrigerant that has not been reclaimed may void equipment warranty and seriously damage the system.

3.5 Recommended risk management strategy

1. Undertake initial "desktop" audit to identify impacted facilities or buildings that have or may have R22-based equipment, and begin to create an equipment register or database.

   Use information sources like:
   - Asset registers
   - Service/maintenance records or logs
   - Technical specifications.

2. Analyse desktop audit findings to determine preliminary prioritisation and identify essential data required.

3. Analyse detailed audit findings and prioritise equipment for attention.

   Need to consider factors such as:
   - Risk of failure – critical sites
   - Estimated upgrade or retrofit costs
   - Logistics and remote locations
   - Potential energy savings from upgrade
   - Management of asbestos on site.

4. Investigate and determine a technical solution based on type of equipment.

   Produce an R22 inventory

   Technical options:
   - Retain and manage, retrofit refrigerant, like-for-like upgrade, engineered solution

   Type of equipment:
   - Refrigeration or air conditioning, water-chiller, package unit, split-system, wall or window-mounted unit.

5. Develop a program schedule.

   Combine the technical solution with the prioritised detailed audit to determine which projects to proceed with first, how to achieve them and in what time frame.

6. Prepare cost estimates.

   Need to consider:
   - Life-cycle costs – including capital and maintenance costs, energy cost savings
   - Allow for adherence with current Australian Standards and National Construction Code.

7. Develop budgetary requirements and funding arrangements.

8. Develop project delivery strategy.

   Need to consider:
   - Grouping works occurring in similar regional areas, especially remote communities
   - Allowing time for professional engineering (documents, drawings, specifications) to be prepared as well as tender and procurement periods (required for complex sites and larger installations)
   - Coordination with other projects/works at the same site
   - Economies of scale, purchase/install.

9. Procure and complete projects.

10. Maintain and update R22 equipment database.

Figure 1

3.6 Further information on the topic

- The Commonwealth Government Department of the Environment monitors the history of imports of ODS into Australia, manages the import and use of refrigerants and is responsible for the implementation of and compliance with the Montreal Protocol in Australia: http://www.environment.gov.au/protection/ozone/montreal-protocol
- Refrigerant Reclaim Australia (RRA) is the product stewardship organisation for the Australian refrigerants industry. RRA is a not-for-profit organisation created to work nationally with industry to share the responsibility for, and costs of, recovering, reclaiming and destroying surplus and unwanted refrigerants.

  RRA's aim is to improve the industry's environmental performance by reducing the level of emissions of refrigerants through its take-back program. Since being established in 1993, RRA has become integral in the management of used and unwanted refrigerant, and the reduction in emissions of ozone depleting and synthetic greenhouse gas refrigerants. https://refrigerantreclaim.com.au/
- The Montreal Protocol on Substances that Deplete the Ozone Layer: http://ozone.unep.org/new_site/en/montreal_protocol.php
- Ozone Protection and Synthetic Greenhouse Gas Management Act 1989: http://www.comlaw.gov.au/Details/C2013C00235
- Cold Hard Facts II http://www.environment.gov.au/system/files/resources/fa48d00d-1fb9-4797-90f4-47a6eed2c9c7/files/cold-hard-facts2.pdf
- A study into HFC consumption in Australia, Peter Brodribb and Michael McCann 2014, Canberra. http://www.environment.gov.au/system/files/resources/5c47433d-fd84-495f-adce-3484e0bc208e/files/hfc-consumption-australia-2013_0.pdf
- UNEP's Report of The Technology And Economic Assessment Panel (TEAP) May 2013 Volume 2 – Task Force Report - Additional Information to Alternatives on ODS
- The fifth IPCC assessment report
- AIRAH has produced a range of information relevant to R22 phase-out:
- *AIRAH Flammable Refrigerant Safety Guide* – contains a comprehensive list of the standards, regulations, and procedures that need to be considered when using flammable refrigerants. The guide is supplemented by three fact sheets and a video. http://www.airah.org.au/FRSG
- AIRAH Methods of Calculating Total Environmental Warming Impact (TEWI) Best Practice Guideline: http://www.airah.org.au/TEWI_Guide
- Five HFC refrigerant levy fact sheets – These fact sheets also address replacement of R22 equipment, alternative and natural refrigerants, leak prevention strategies and energy efficiency: http://www.airah.org.au/HFCrefrigerantlevy
- Industry publication by AIRAH regarding R22 phase-out, April 2014: http://www.airah.org.au/imis15_prod/Content_Files/HVACRNation/2014/04-14-HVAC&R-001.pdf

Appendix A HCFC phase-out

HCFCs and the Montreal Protocol

The Montreal Protocol addresses HCFCs in Annex C Group I and II for production and consumption control measures. The production and consumption base level tonnages and reduction schedules are different (allowable production levels are higher) because a signatory to the Montreal Protocol may be manufacturing and exporting HCFCs to other countries to allow them to use their consumption quotas.

The Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, Part IV — HCFC quotas, Section 24 outlines the HCFC industry limits in Australia as shown in the following Table:

Calendar year	HCFC import limit
Quantity of HCFCs in ODP tonnes per year:	
1996–1999	250 (pre phase-out usage)
2000–2011	(continued reduction, not shown/relevant)
2012–2013	40
2014–2015	10 (current year)
2016–2029	2.5
2030	0

ODP tonnage and refrigerant tonnage

The majority of HCFC imports into Australia are R22 and R123 (every kilogram of R123 imported means less R22 can be imported).

Using the ODP of R22 at 0.055 — The maximum actual tonnage (as opposed to ODP tonnage) amount that can be imported during these periods could be considered to be approximately:

2013: 727 tonnes per annum

2014–2015: 181 tonnes per annum

2016–2029: 45 tonnes per annum

2030: 0 tonnes

As a comparison, and to put these import quantities into perspective, the working bank of HCFC refrigerants contained in operational equipment was estimated in 2013 to be in excess of 11,428 metric tonnes of refrigerant.

Appendix B Retrofit refrigerants

The retrofit option

Retrofitting existing R22-based systems with alternative refrigerants specifically designed for the purpose can be very cost-effective where the replacement cost of the unit is higher than the cost to retrofit. Retrofitting enables owners to get the full working life out of the installed equipment.

R22 can be removed from a vapour-compression system and an alternative retrofit refrigerant used in its place, however, these refrigerants are not simple "drop-in" replacements. A drop-in replacement implies no system changes, whereas using R22 "retrofit refrigerants" usually requires system changes such as adjusting the superheat setting, changing the filter-dryer, resetting or renewing the thermal expansion valve, and recovering and renewing the oil. In some cases it may be necessary to add a suction filter to trap the dirt due to cleaning ability of the replacement refrigerant and oil combination. In addition, new oils may need to be used, elastomeric seals replaced, system components and fittings assessed for possible leakage, and the capacity of the equipment operating on the new refrigerant checked for suitability.

Retrofitting may not be worthwhile for smaller equipment that is likely to be more than six years old and may have an economic life of only seven to 12 years (depending on location and servicing). As a consequence, options for managing this type of equipment can be limited and these should also be considered for replacement or upgrade.

Note: Retrofitting smaller systems could be cost-effective in the circumstances where the system has already lost its charge, and (after the system is repaired) charging with a retrofit refrigerant and implementing the associated system modifications, is less expensive than recharging with R22 or replacing the system.

Technical considerations

Mineral oils and alkylbenzene lubricants, which have traditionally been used with R22, are immiscible with the retrofit refrigerants, and in almost all cases must be renewed with miscible lubricants such as polyol esters. Some retrofit refrigerants contain hydrocarbons in the blend – such as isobutane – which will assist with the compatibility with mineral oil, however, polyol ester oils are generally recommended.

Most common R22 retrofit refrigerants are hydrofluorocarbon (HFC) blends. Blended refrigerants are made by mixing several refrigerants together in specific proportions in order to create the desired operating characteristics. As a consequence, they behave differently to single-component refrigerants like R22. Some blends can fractionate when leaking from evaporators and condensers, which will alter the refrigerant's overall composition. This happens where a change of state is occurring and the blend has naturally separated; they will leak proportionally while in a superheated or subcooled condition. Where a leak of fractionated refrigerant has occurred, the entire refrigerant charge may need to be recovered and replaced with virgin blend refrigerant to ensure the correct blend ratio (and hence system performance) is maintained. This can be an expensive maintenance practice, especially for some larger air conditioning chillers, which can contain more than 100kg of refrigerant. The fractionation effect is dependent on temperature glide.

Every chiller or item of equipment that is to be considered for refrigerant retrofit needs to be assessed individually – different types of evaporators have different needs. Single-pass evaporators (refrigerant or water), counter-flow, DX, tube-in-tube, tube-in-shell and plate types may require a different refrigerant blend than multi-pass (refrigerant or water) and flooded evaporators. Also, some heat exchanger configurations can suffer a significant drop in performance with refrigerants that exhibit "temperature glide". For example, retrofitting a chiller with a refrigerant that exhibits temperature glide can result in significant loss of performance, unless the chiller can be reconfigured so that the refrigerant flow is counter to the water flow, so that the temperature glide matches the water temperature change.

R22 interacts strongly with many elastomers, causing significant swelling and often, over time, a measurable increase in hardness in the system elastomeric seals. HFC blends do not have as strong an effect on the elastomers commonly used as seals in refrigeration systems. As a result, when retrofitting an R22 system with an alternative HFC blend, it is possible for leaks to occur at elastomeric seals that have been previously exposed to R22 refrigerant.

Replacing elastomeric seals should be addressed as part of the retrofit process. Components commonly affected are Schrader core seals, liquid-level receiver gaskets, solenoid valves, ball valves, flange seals, and some shaft seals on open-drive compressors. It is recommended to actually replace the valves in question with new valves rather than using seal kits, as this will help remove a potential leak path from ageing equipment.

Retrofit guidelines

There are a number of refrigerants that are suitable for R22 retrofitting purposes, the most common are listed below. Retrofit refrigerants are not a "drop-in" replacement for R22 and in all cases system modifications need to be included. The refrigerant manufacturer/supplier published guidelines for retrofit practices and processes must be followed and the equipment OEM should be consulted. Manufacturer retrofit guidelines are typically available from their respective websites.

Market forces and concerns regarding HFC refrigerant GWP may see the range of products available for this type of retrofit contract, so it is important to consider the current (and future) availability and cost of the selected refrigerant (refer to Appendix C).

Typical retrofit refrigerants

R407C ODP = 0, GWP = 1610.

This is a ternary blend of hydrofluorocarbon (HFC) compounds (23% R32, 25% R125, and 52% R134a). It has no chlorine content, no ozone-depletion potential, and only a modest direct global-warming potential. In addition to slight capacity losses, R407C requires a greater cooling surface area compared to R22, but the mass flow rate of the gas is much the same.

R407F ODP = 0, GWP = 1824.

This refrigerant blend (30% HFC-32, 30% HFC-125, 40% HFC-134a) serves as a non-ozone depleting replacement for R22 in low- and medium-temperature commercial refrigeration applications such as supermarket freezer cases, display cases, reach-in coolers, transport refrigeration, and ice machines.

Requires polyol ester compressor lubricant. This blend has a lower mass flow and this may cause a problem with oil return, especially if the suction pipe work has already got a lower flow rate. Check flow rates to ensure that oil is returned.

R427A ODP = 0, GWP = 1828.

This refrigerant blend (15% R-32, 25% R-125, 10% R-143a, and 50% R-134a) offers comparable capacity to R22 and nearly identical operating pressures and can be used with minimal need for modification to the existing R22 installation. It can be used to retrofit low-temperature refrigeration equipment and air conditioning installations. It requires polyolester (POE) lubricants but is tolerant of high levels of alkylbenzene or mineral oils of up to 10 per cent.

R428A ODP = 0, GWP = 3607.

This is a HFC blend retrofit solution used for low-temperature applications and flooded evaporator systems where temperature glide makes other options unfeasible. It has a glide of 0.8°C and needs a significant mass flow increase when compared to R22. A change of thermostatic expansion valve is recommended.

R434A ODP = 0, GWP = 3245.

This is a retrofit solution used for medium-temperature applications and flooded evaporator systems where temperature glide makes other options unfeasible. It has a glide of 1.5°C and needs a significant mass flow increase when compared to R22. A change of thermostatic expansion valve is recommended.

R438A ODP = 0, GWP = 1890.

This refrigerant blend (44.2% HFC-134a, 8.5% HFC-32, 45% HFC-125, 0.6% isopentane, 1.7% N butane) has an A1 safety classification (non-flammable and low toxicity) and is suitable for residential and commercial air conditioning, and medium and low-temperature refrigeration systems. It is not recommended for use in centrifugal compressor systems or for chillers with flooded evaporators. For use in semi-flooded systems with low-pressure receivers, refer to manufacturer guidelines.

It can be suitable with mineral oils, AB, and POE. This blend has a lower mass flow and this may cause a problem with oil return, especially if the suction pipe work has already got a lower flow rate. Check flow rates to ensure that oil is returned.

Low-GWP options

Most of the retrofit refrigerants listed in this appendix have a high-GWP and are likely to be the subject of future controls. There is a real danger that system owners who do a retrofit may need to retrofit again due to GWP rather than ODP issues. This should therefore be a consideration for those who own HVAC&R equipment containing R22. The industry is now transitioning to low-GWP refrigerants and more information on these alternatives is provided in Appendix C.

Change of refrigerant classification

All of the above retrofit refrigerants are classified as A1 – low-toxic and non-flammable refrigerants – the same classification as R22. Where a different classification of refrigerant is being considered (e.g. A2, A2L, or A3), a system conversion process is required. Refer to the AIRAH *Flammable Refrigerant Safety Guide* for more details.

Appendix C Long-term refrigerant options

Refrigerant selection

There is no single refrigerant solution that can be specified for refrigeration or air conditioning applications; specific applications, technical characteristics, industry selection criteria, market forces and individual design preferences will typically determine final refrigerant selections and system configurations.

Energy efficiency should always be a major factor informing refrigerant selection and equipment design choices. Capital cost (purchase and install) is an important consideration but operating costs, such as electricity consumption, typically dominate the system life-cycle cost. True environmental performance (using TEWI or LCCP analysis) should be considered when making refrigerant/system design choices. System and refrigerant comparisons within these assessments should be scientific and use proper assessment protocols.

The four main selection criteria are safety, environmental impact, performance and cost.

Safety criteria:

- Safety in use, and also during storage and transport;
- Acceptable toxicology;
- Acceptable flammability;
- Acceptable pressure characteristics.

Environmental criteria:

- Zero ozone-depletion potential (ODP);
- Low or no global-warming potential (GWP);
- Good life-cycle performance in intended climate;
- Recycling and/or reclamation infrastructure in place.

Performance criteria:

- High energy efficiency over the complete operating range;
- Long-term durability;
- Long-term availability/acceptability.

Cost criteria:

- Low capital cost (refrigerant and system);
- Low operating cost (energy and leakage);
- Low system maintenance;
- Better overall life-cycle cost compared to alternatives.

Low global warming potential refrigerants

In order to future-proof refrigeration and air conditioning systems from impacts due to future controls placed on high-GWP refrigerants, it is recommended that low-GWP refrigerant options be investigated for replacement systems. There are several low-GWP or reduced-GWP options currently available or under development (refer to the report A study into HFC consumption in Australia).

Many of the retrofit options outlined in Appendix B are HFC refrigerants that have a high GWP. There is mounting concern regarding the climate impacts of high-GWP refrigerants when they are released into the environment, and it appears likely that these refrigerants will be controlled in the future. Controls may be imposed through international agreements such as the Montréal Protocol or individual national or regional agreement such as the European F-gas regulations.

It is likely that high-GWP HFC refrigerants will be subject to internationally agreed phase-downs, and corresponding usage restrictions will apply in Australia in the short-to-medium term.

In order to future-proof refrigeration and air conditioning systems from impacts due to future controls placed on high-GWP refrigerants it is recommended that low-GWP refrigerant options be investigated for replacement systems. There are several low-GWP or reduced-GWP options available or under development.

Natural refrigerants

Hydrocarbon refrigerants

Hydrocarbon (HC) refrigerants include three main pure refrigerants, R290 (propane), R1270 (propene) and R600a (isobutane) and a number of blends, some of which also comprise R170 (ethane). All have a safety classification of A3 (lower toxicity, higher flammability). They have zero ODP and GWP ranges from 1.8 to 5.5.

The pure refrigerants have been used commercially for many years. Despite their excellent thermo-physical and transport properties, usage is limited in occupied spaces due to maximum allowable charge rules that restrict their use in direct systems. Generally they have thermo-physical properties that lead to very good efficiency and low discharge temperatures.

Technicians must be well-trained and competent in handling HC refrigerants if the flammability risk is to be dealt with safely.

R717 ammonia (NH_3)

Ammonia (NH_3) has been used as a refrigerant for more than 100 years. It has a safety classification of B2 (higher toxicity, lower flammability), which restricts its use (in direct systems) in occupied spaces. It has a zero ODP and zero GWP and offers excellent efficiency. The vapour pressure and refrigerating capacity is similar to R22. However, its high discharge temperature means that for lower temperature applications two-stage compression is normally needed.

Ammonia is a low-cost refrigerant, but requires the use of steel piping and components, and so capital cost can be more than for competing HFC-based systems. Ammonia systems become cost-competitive as the capacity increases. Due to their good efficiency, their life-cycle costs tend to be very competitive. There is a lack of suitable components for small-capacity systems due to incompatibility of the refrigerant with copper and its alloys, and a lack of well-trained designers and technicians competent to work with the refrigerant.

Ammonia has traditionally been used in the commercial and industrial refrigeration sector, but can also be used in air conditioning applications.

R744 carbon dioxide (CO_2)

Carbon dioxide (CO_2) is a single-component substance with a safety classification of A1 (lower toxicity, non-flammable). It has a zero ODP and a GWP of 1. CO_2 has reasonably good efficiency for certain levels of operating temperatures. The vapour pressure is several times greater than other refrigerants and the volumetric refrigerating capacity is correspondingly higher.

With a low critical temperature, the cycle efficiency declines. At ambient temperatures of 35°C, the efficiency of a basic cycle is only about 50–60 per cent of R22 although technical modifications to a basic system can bring the efficiency to within 10 per cent of R22. However, CO_2 cascade systems using CO_2 as the primary refrigerant and another refrigerant as the secondary refrigerant can be very efficient, and provide a number of advantages including:

- Efficiency of the system is high even in the hot climates;
- Only a small amount of refrigerant is needed for the high-temperature stage;
- Temperature difference required for cascade heat exchanger is relatively low; and
- On the high side, various refrigerants can be used: HC, HFC or NH_3.

The cost of the CO_2 refrigerant is low but, due to its high pressure, system capital costs tend to be higher than for competing HFC-based systems.

Synthetic refrigerants

Hydrofluorocarbon (HFC) refrigerants

Hydrofluorocarbon refrigerants are organic compounds that contain fluorine and hydrogen atoms. HFC refrigerants were developed to replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) such as R22. HFCs have low or no ozone-depletion potential but some common HFC refrigerants do have a high-GWP. Their atmospheric concentrations and contribution to anthropogenic greenhouse gas emissions are increasing, causing international concern about the climate impacts caused by HFCs. It is likely that high-GWP HFC refrigerants will face usage controls in the future. Alternatives include medium-GWP HFCs, such as R32 and HFO refrigerants.

Hydrofluoro-Olefine (HFO) refrigerants

HFO (Hydrofluoro-Olefines) are "fourth generation" refrigerants comprising of unsaturated fluorocarbons such as HFO-1234yf and HFO-1234ze, that contain at least one carbon-carbon double bond. These molecules are highly reactive in the atmosphere, and consequently have a relatively short atmospheric lifespan. They have been developed by refrigerant manufacturers as a low-GWP alternative to traditional or "third generation" HFC refrigerants. Because HFOs are new molecules that require a complex production process, these refrigerants may have a higher purchase cost than other HFCs. As production rates increase the price premium may be reduced. Some examples include:

- HFO-1234yf – a single-component refrigerant with a GWP of about 4. It has been developed to replace R134a and the pressure/temperature characteristics are almost identical. It is classed as an A2L refrigerant (low toxicity, lower flammability).
- HFO-1234ze(E) – a single-component refrigerant with a GWP of 6. It can replace R134a in new equipment where its lower volumetric capacity can be addressed in the design of the equipment. It is classed as an A2L refrigerant (low toxicity, lower flammability).
- HCFO-1233zd(E) ¬– a single-component refrigerant with a GWP of 6, It is classed as an A1 refrigerant (low toxicity, non-flammable).

The main barriers are related to the safe use of lower flammability refrigerants. Technicians must be well-trained and competent in handling flammable refrigerants, if the flammability is to be dealt with safely. Concerns about the products of combustion when flammable HFOs are burnt have also been raised. Products of combustion include hydrogen fluoride (hydrofluoric acid), which is toxic and can be lethal in unventilated spaces

Blended refrigerants

Some of the low-GWP alternative refrigerants entering the market are mixtures of single-component HFCs and HFOs, blended in order to achieve lower GWP and higher vapour pressures. Some blends also include CO_2 and hydrocarbons in small proportions. The final composition of a blend is typically a compromise between GWP, flammability and refrigeration cycle performance efficiency.

Blends are being typically developed as replacement retrofit refrigerants for existing high-GWP HFC refrigerants.

Low-GWP refrigerants and flammability

Many low-GWP refrigerants (both natural and synthetic) are flammable and it is important, if they are to be applied safely, that design engineers and installation and service technicians are properly trained and competent in handling their flammability, as well as toxicity or high pressure characteristics.

Refer to the AIRAH *Flammable Refrigerant Safety Guide* for a comprehensive list of the standards, regulations, and procedures that need to be considered when using flammable refrigerants.