Prepared for the Department of the Environment

April 2014

 

HFC Consumption in Australia in 2013 and an Assessment of the Capacity of Industry to Transition to Nil and Lower GWP alternatives

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This paper has been prepared for the Australian Government, Department of the Environment, (DoE) Environment Quality Division, Ozone Protection and Synthetic Greenhouse Policy Team.

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For bibliographic purposes this report may be cited as: A study into HFC consumption in Australia, Peter Brodribb and Michael McCann 2014, Canberra.

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# Acknowledgements

The authors would like to thank the following industry associations and the individuals in the companies who have provided invaluable information, expert advice, and participated in in-confidence surveys during the course of preparing this study and the industry consultation workshops.

|  |
| --- |
| **Industry associations** |
| Australian Institute of Refrigeration Air Conditioning and Heating |
| Air Conditioning & Refrigeration Equipment Manufacturers Association of Australia |
| Air Conditioning and Mechanical Contractors' Association of Australia |
| Australian Refrigeration Association |
| Australian Refrigeration Council |
| Refrigeration and Air Conditioning Contractors Association |
| Refrigerants Australia |
|  |
| **Companies** |
| A-Gas Australia |
| Ashdown-Ingram |
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| Highgate Car Air |
| Hychill Australia  JAS Oceania |
| Orica Chemicals; Orica Australia |
| Oz-Chill |
| Tyco Fire Australia |
| UTC Building & Industrial Systems |

# Glossary

|  |  |
| --- | --- |
| Ammonia Refrigerant | Anhydrous Ammonia (R717) has excellent thermodynamic properties, making it effective as a refrigerant, and is widely used in industrial and process refrigeration applications because of its high energy efficiency and relatively low cost. Ammonia is used less frequently in commercial refrigeration applications, such as in supermarket and food retail, freezer cases and refrigerated displays due to its toxicity, and the proximity of the general public. |
| Article 5 Countries | Article 5 countries are developing countries (e.g. African nations; China, India and Thailand; and South American and most Middle Eastern countries) and non-Article 5 countries are developed countries (e.g. Australia; European Union members such as Germany, Denmark and United Kingdom; Japan; Canada and the United States). |
| Azeotrope | See refrigerant glide. |
| Bottom-up model | A method of estimation whereby the individual appliances, equipment and product categories that make up the equipment bank are estimated separately. The individual results are then aggregated to produce an estimate of the refrigerant bank by refrigerant species. In the context of this study, consumption estimates (i.e. leakage plus local manufacture plus exports) is reconciled with the top down data (i.e. bulk imports), except in 2012 where stockpiling occurred and adjustments were made to account for changes in industry behavior. |
| Cascade refrigeration system | A cascade system is made up of two separate but connected refrigeration systems, each of which has a primary refrigerant. The separate refrigerant circuits work in concert to reach the desired temperature. Cascade systems in operation today in Australia are R404A/R744 (CO2); R134a/R744 and R717 (ammonia)/R744. A cascade refrigeration system is also sometimes referred to simply as an ‘advanced refrigeration system’. |
| CHF1 | Cold Hard Facts 1, the original refrigeration and air conditioning (RAC) study undertaken by the authors in 2007 based on 2006 data. |
| CHF2 | Cold Hard Facts 2, an updated study of the RAC industry in Australia with an expanded brief to encompass new application/equipment classes, new and emerging refrigerants, and report on the refrigerant bank. |
| Chlorofluorocarbons (CFCs) | Molecules containing carbon, fluorine, and chlorine. CFCs are the major ozone depleting substance phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer. Many CFCs are potent greenhouse gases. |
| Coefficient of performance (COP) | The ratio of the heat extraction rate divided by the power consumed by the refrigeration compressor(s) and necessary ancillaries. The COP is dimensionless and is used to express the system efficiency. |
| Compressor | A device in the air conditioning or refrigeration circuit which compresses refrigerant vapour, and circulates that refrigerant through to its phases of condensation and evaporation, in order to produce the refrigeration effect. The compressor is available in many forms such as piston, scroll, or screw. |
| Compressor rack | The machine assembly which accommodates the main high pressure components of a refrigeration circuit in a single structure, allowing off site connection to associated pipe work and vessels. |
| Condensing unit | Condensing units exhibit refrigerating capacities ranging typically from 1 kWr to 20 kWr, they are composed of one (or two) compressor(s), one condenser, and one receiver assembled into a ‘condensing unit’. |
| CO2 refrigerant | A widely used industrial refrigerant with high thermodynamic properties is suitable for process refrigeration applications, and automotive air conditioning use. In the past its high operating pressures have limited its use in small to medium commercial refrigeration applications. Technical innovation such as micro cascade systems and commercial availability of components such as compressors and other in line accessories is assisting its transition into smaller scale applications. |
| CO2-e | Carbon dioxide equivalent is a measure that quantifies different greenhouse gases in terms of the amount of carbon dioxide that would deliver the same global warming. |
| Cumulative distribution function | Cumulative distribution function of the normal distribution with mean (μ) and standard deviation (σ) evaluated at a point in time (year x). |
| Direct emissions | Global warming effect arising from emissions of refrigerant, or any other ‘greenhouse gas’, from the equipment over its lifetime. |
| Energy Efficiency Ratio (EER) | The ratio of the cooling output (kWr) divided by the total electric energy input. The EER is dimensionless and is used to express the air conditioning system cooling efficiency. |
| Energy consumption per year | Energy consumption of the appliance, equipment or system per annum in kWh per year, or GWh per year for an application or equipment sector. |
| End-of-Life (EOL) | Domestic, commercial or industrial device reaching the end of its useful lifespan. End- of-life (EOL) emissions are direct emissions from ozone depleting substance (ODS) and synthetic greenhouse gases (SGG) refrigerants not recovered for destruction or reclamation. |
| Equivalent Carbon Price (ECP) | Under the Australian Government's Clean Energy Future Plan, synthetic greenhouse gases listed under the Kyoto Protocol have an equivalent carbon price applied through the Ozone Protection and Synthetic Greenhouse Gas Management legislation. Gases covered will include hydrofluorocarbons, perfluorocarbons (excluding gases produced from aluminium smelting) and sulfur hexafluoride, whether in bulk form or contained in equipment. |
| E3 | Equipment Energy Efficiency Committee of the Council of Australian Governments (COAG) operating under the Ministerial Committee on Energy and administered by the Equipment and Appliance Energy Efficiency Team in the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education. |
| Gas | A general term used throughout this report, referring to ozone depleting substances, synthetic greenhouse gases and natural refrigerants. The term can refer to refrigerants when the substance is used as a working fluid in equipment or used in other applications. |
| Gas Species | A gas species is defined as a refrigerant category based on its chemical family. For example CFCs, HCFCs and HFCs are all synthetic gases and are defined as different gas species. Similarly Hydrocarbon refrigerant is another gas species, and HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290) refrigerants are all part of this family. Other gas species include anhydrous ammonia and Carbon Dioxide. |
| Global Warming Potential (GWP) | A relative index that enables comparison of the climate effect of various greenhouse gases (and other climate changing agents). Carbon dioxide, the greenhouse gas that causes the greatest radiative forcing because of its abundance is used as the reference gas. GWP is also defined as an index based on the radiative forcing of a pulsed injection of a unit mass of a given well mixed greenhouse gas in the present-day atmosphere, integrated over a chosen time horizon, relative to the radiative forcing of carbon dioxide over the same time horizon. The GWPs represent the combined effect of the differing atmospheric lifetimes (i.e. how long these gases remain in the atmosphere) and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame. |
| Greenhouse Gases (GHG) | The Kyoto Protocol covers emissions of the six main greenhouse gases, namely Carbon dioxide (CO2); Methane (CH4); Nitrous oxide (N2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulfur hexafluoride (SF6). The scope of this study covers the equivalent in carbon dioxide due to indirect emissions from electricity generation, and direct emissions from HFCs. |
| GWh | Gigawatt hours is a unit of measurement for electricity use (1 watt hour x 109). |
| Hydrocarbons (HCs) | The term hydrocarbon refers to the main types and blends in use in Australia including HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290). HC-600a is the preferred hydrocarbon refrigerant in domestic refrigeration applications as it is suited to both refrigerator and freezer applications. HC-290 is the preferred hydrocarbon option for non-domestic stationary applications as its performance characteristics are more suited to medium temperature applications (i.e. greater than zero degrees Celsius). HC-436 is a hydrocarbon blend that is commonly used in mobile air conditioning retrofit applications. |
| Hydrochlorofluorocarbons (HCFCs) | Chemicals that contains hydrogen, fluorine, chlorine, and carbon. They deplete the ozone layer, but have less potency compared to CFCs. Many HCFCs are potent greenhouse gases. HCFC-22 is the most common refrigerant in the Australian refrigerant bank. |
| Hydrofluorocarbons (HFCs) | Chemicals that contain hydrogen, fluorine, and carbon. They do not deplete the ozone layer and have been used as substitutes for CFCs and HCFCs. Many HFCs are potent greenhouse gases. |
| Hydrofluoro-olefins (HFOs), and HFO blends | Chemicals known as hydrofluoro-olefins that contain hydrogen, fluorine, and carbon, and are described as unsaturated HFCs. They do not deplete the ozone layer and have very low GWP values. For example HFO-1234yf, with a GWP of 4 and HFO-1234ze with a GWP of 6. Refer *Section 3.4* for further details. |
| HVAC&R | Heating, Ventilating, Air Conditioning and Refrigeration |
| Indirect emissions | Global warming effect of the CO2 emitted as the result of the generation of the electrical energy required to operate electrical equipment, sometimes also referred to as ‘energy related emissions.’ |
| Indirect emission factor | The indirect or CO2 emission factor is the mass of CO2 emitted by the power generator per kWh of electrical power supplied to the refrigeration installation taking in efficiency losses in generation and distribution. |
| kWr | Refers to kilowatts of refrigeration capacity where as kW relates to kilowatts of electrical power. |
| KWh | Kilowatt hour (1 watt hour x 103). |
| Kyoto Protocol | The Kyoto Protocol sets binding emissions limits for the six greenhouse gases listed in the Protocol. The Australian Government is committed to reducing emissions of the six main greenhouse gases, which includes the synthetic greenhouse gases (SGGs) listed under the Kyoto Protocol, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6). |
| Lifespan | Lifespan is the expected useful life of the equipment in years. |
| Low GWP substances or refrigerants | This term can and is used to refer to both the commonly referred ‘natural’ refrigerants, HFC substances with a GWP lower than those commonly used today and the near to commercial HFOs being scaled up by the major synthetic greenhouse gas manufacturers that are sometimes referred to as low GWP HFCs. |
| Low temperature refrigeration | Temperatures below 0oC that the general public would often think of as the point of ‘freezing’. |
| Minimum energy performance standards (MEPS) | Regulatory requirements for appliances or equipment manufactured or imported to Australia to ensure a set level of energy efficiency performance is met or exceeded. In the RAC industry MEPS typically cover appliances such as domestic refrigerators, some refrigerated display cases, and a wide range of air conditioners (excluding portable, chillers below 350kWr, etc.). |
| Montreal Protocol | The Montreal Protocol on Substances that Deplete the Ozone Layer sets binding progressive phase out obligations for developed and developing countries for all the major ozone depleting substances, including CFCs, halons and less damaging transitional chemicals such as HCFCs. |
| Natural refrigerants | Hydrocarbons (R600a, R290 and R436), ammonia (R717) and carbon dioxide (R744) are commonly referred to as natural refrigerants. The term ‘natural’ implies the origin of the fluids as they occur in nature as a result of geological and/or biological processes, unlike fluorinated substances that are synthesised chemicals. However it has to be noted that all ‘natural’ refrigerants are refined and compressed by bulk gas manufacturers via some process and transported like other commercial gases so also have an ‘energy investment’ in their creation, storage and transport. |
| Operating hours per year | The number of hours the appliance, equipment or system operates at full input load or maximum capacity. |
| Ozone depleting substances (ODS) | Chemicals that deplete the ozone layer (e.g. HCFCs). |
| PJ | Petajoule (1 Joule x 1015). |
| Pre-charged equipment (PCE) | Pre-charged equipment is defined as air conditioning equipment or refrigeration equipment (including equipment fitted to a motor vehicle) that is imported containing a hydrofluorocarbon (HFC) or hydrochlorofluorocarbon (HCFC) refrigerant charge. |
| RAC | Refrigeration and air conditioning. |
| Recovery efficiency | Proportion of refrigerant charge that is recovered from a system when it is decommissioned at the end of its useful working life. The Recovery/recycling factor has a value from 0 to 1. |
| Refrigerant | Working fluid in the vapour compression refrigeration cycle. |
| Refrigerant bank | The ‘bank’ of refrigerant gases is the aggregate of all compounds and substances employed as working fluids in the estimated 44 million mechanical devices using the vapour compression cycle in Australia. |
| Refrigerant charge | The original refrigerant charge of refrigerant used as the working fluid for heat transfer inside a piece of equipment. |
| Refrigerant glide | The difference between the saturated vapour temperature (or dew point is the temperature at which all of the refrigerant has been condensed to liquid) and the saturated liquid temperature (temperature at which a liquid refrigerant first begins to boil in the evaporator) is referred to as the temperature glide of the refrigerant.  At a given pressure, single component refrigerants such as HFC-134a have zero glide and are therefore azeotropes. Refrigerant mixtures (blends) behave somewhat differently and have measurable temperature glide when they evaporate (boil) and condense at a constant pressure. HFC-507A is an azeotropic blend whereas HFC-404A is a near azeotrope. |
| Refrigerant leak rate | The annual leak rate is defined as the sum of gradual leakage during normal operation, catastrophic losses amortised over the life of the equipment and losses during service and maintenance expressed as a percentage of the initial charge per annum. |
| Refrigerant recovery | Removal of refrigerant from a system and its storage in an external container. |
| Refrigerated cold food chain (RCFC) | The refrigerated cold food chain is part of the food value chain, which involves transport, storage, primary and secondary processors, distribution and retailing of chilled and frozen foods from farm gate to consumer. However, in this report domestic refrigeration and freezers are treated as a separate segment. |
| Remote condensing unit | Condensing unit located remotely from the evaporator, typically outdoors (see condensing unit). |
| Remote RDC | Refrigerated display cabinet (RDC) with its refrigerating machinery sited remote from the cabinet structure. |
| Self**‐**contained RDC | Refrigerated display cabinet with its refrigerating machinery sited remotely from the cabinet structure. |
| Second Assessment Report (AR2) | Second Assessment Report of the United Nations Framework Convention on Climate Change, released in 1996. Australia’s legally binding emission obligations under the Kyoto Protocol are calculated based on AR2 and therefore Australian legislation, including the *Ozone Protection and Synthetic Greenhouse Gas Management Act*, also cite GWPs from AR2. |
| Synthetic greenhouse gases (SGGs) | SGGs listed under the Kyoto Protocol, include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6). |
| Synthetic substances or synthetic refrigerants | HCFCs, HFCs and HFOs are commonly referred to as synthetic substances or synthetic refrigerants. |
| Technology segment | A term used by the authors to refer to a defined set of technologies within the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry sector. A segment of the broad family of technologies employed in the HVAC&R sector is defined by the application (i.e. mobile or stationary, commercial or residential) and then bounded by a range of size of the charge of working gas, although for the purpose of modeling, an average charge size for each segment has been calculated. |
| Truck refrigeration unit (TRU) | TRUs are refrigeration systems powered by dedicated diesel internal combustion engines designed to refrigerate fresh and frozen perishable products (mostly food but also pharmaceuticals and other materials) that are transported on semi-trailers, rigid trucks and rail cars. Fresh is typically classed as 2oC and frozen -20oC. |
| Walk**‐**in cool room | A walk**‐**in cool room is a structure formed by an insulated enclosure of walls and ceiling, having a door through which personnel can pass and close behind them. The floor space occupied by this structure may or may not be insulated, depending on the operating temperature level. |

# Abbreviations

|  |  |
| --- | --- |
| AC | Air conditioning |
| AR2 | Second Assessment Report, similarly A4 is Forth Assessment Report |
| ABS | Australian Bureau of Statistics |
| BCA | Building Code of Australia |
| CHF | Cold Hard Facts |
| CO2-e | Carbon dioxide equivalent |
| DCCEE | Department of Climate Change and Energy Efficiency, now Department of Industry, Appliance Energy Efficiency Team (DoI) |
| DEWHA | Department of Environment, Water, Heritage and the Arts |
| DSEWPaC | Department of Sustainability, Environment, Water, Population and Communities, now Department of the Environment |
| DoE | Department of the Environment |
| EOL | End-of-life |
| GHG | Greenhouse Gas |
| GWh | Gigawatt hour |
| HVAC&R | Heating, ventilation, air conditioning, and refrigeration |
| IEA | International Energy Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| kWh | Kilowatt hour |
| kt | Kilo tonnes, or thousand tonnes |
| LPG | Liquefied petroleum gas |
| L | Litre |
| MEPS | Minimum energy performance standards |
| MAC | Mobile air conditioning |
| MJ | Megajoule |
| Mt | Mega tonne, or million tonnes |
| OPSGGMA | Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, including amendments. |
| ODS | Ozone depleting substances |
| OEM | Original Equipment Manufacturer |
| PJ | Petajoule |
| RAC | Refrigeration and air conditioning |
| RCFC | Refrigerated cold food chain |
| SGG | Synthetic greenhouse gas |
| TAFE | Technical and Further Education |
| Tonne | Metric tonne |
| UNFCCC | United Nations Framework Convention on Climate Change |

# Executive summary

National governments, international bodies and the suppliers of hydrofluorocarbons (HFCs), alternative substances and related equipment are for various reasons, involved in negotiating and preparing for a fourth wave of evolutionary change in the essential technology of refrigeration – the refrigerant gases used as the thermal media for heat transfer, and in a range of other medical, industrial and manufacturing applications.

Due to their high global warming potential proposals for a phase down of HFCs, the third generation of inert and non-toxic synthetic refrigerants, have been put to the Parties to the Montreal Protocol. One recent and comprehensively drafted proposal, the North American Amendment (NAA), has been used as a model by the Australian Government’s Department of the Environment (DoE) to test the Australian industry’s capacity to adapt to a phase down of HFCs.

This report provides projections of Australian demand for HFCs across all the major applications to 2025, and compares that with the hypothetical HFC consumption cap that the NAA proposal would impose on Australia. The model from which the projections are derived is built on a stock model of all refrigeration and air conditioning equipment in the economy that has been updated annually since 2007. For a number of reasons Australian data in this industry is particularly good.

The NAA, as it applies to Australia, proposes a HFC consumption baseline, calculated in terms of CO2-e using the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) GWP values, against which future reductions in HFC use would be measured based on average consumption in the years 2008, 2009 and 2010. Using the NAA scheme Australia’s baseline would start at almost 10 MT CO2-e per annum.

Due to a mix of commercial and policy influences, it is estimated that if the NAA proposal had commenced in 2013, actual Australian consumption would have been lower than the baseline value at around 8.8 MT CO2-e per annum.

A number of significant technological trends already underway, as a result of international developments, such as the EU requirements for all new vehicle air conditioning to employ a refrigerant gas with a GWP <150 by 2017, mean that a number of lower GWP alternatives are already being introduced to the market that should steadily reduce the CO2 equivalent value of Australia’s annual HFC consumption over time. The uptake of new technology can be encouraged or accelerated with a mix of incentives.

However in the face of an agreement to phase down reliance on high GWP HFCs, it is apparent that for the majority of present day uses of high GWP HFCs, viable lower and zero GWP natural and synthetic refrigerants, are either available now, or being readied for commercial release on the near horizon, within one to three years.

This is the case for the majority of refrigeration and air conditioning applications in the market and for smaller consumers of the chemicals, such as fire suppression systems, foam blowing, aerosols and other medical and industrial uses.

There are a very few demanding applications, such as in small fishing vessels that are typical of the Australian fishing fleet, where no obvious and immediate options are available, and technical work is needed to be able to deliver the services required with lower GWP gases.

Despite the assessed technical capacity to meet the requirements of a HFC phase down, there are industry standards, human resource and economic issues that also need attending to if Australia is to achieve a smooth transition of its refrigerating and air conditioning industry through this next historical phase of change.

Possibly the most important consideration for the industry in planning for transition is the impact of the diversification, and the multiplication of refrigerant gases that is expected. This diversification includes, importantly, the introduction of mildly-flammable, and flammable gas charges across a wide range of applications, and potentially the introduction of many novel blends of a new generation of lower GWP HFCs. More than 50 new blends are reportedly being tested now.

This significant investment in new refrigerants, and the recent commercial release of lower GWP options for a number of applications, provides many pathways for migration of services and demand to lower GWP gases. Sector by sector analysis is provided in the body of the report identifying what are thought to be the most likely outcomes for the main application areas by 2025.

However, overall, the conclusions of this study are that there are no insurmountable obstacles for the Australian industry should it have to meet the requirements of an international HFC phase down, based on the NAA proposal and should appropriate national incentives to take up new technologies be provided.

# Introduction

It appears likely that a global agreement will be achieved at some time in the next few years to phase down the use of hydrofluorocarbons (HFCs). It is also likely that the Montreal Protocol will be the international mechanism employed for this task.

HFCs are a group of synthetic greenhouse gases (SGGs). The global warming potential (GWP) of HFC gases varies from very low (GWP of 1 to 6 in the case of the newer generation of unsaturated HFCs, referred to in this report as HFOs) to very high (GWP of 14,760). HFCs are used primarily as refrigerant gases in refrigeration and air conditioning equipment (RAC), replacing chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). HFCs can also replace CFCs and HCFCs in the production of foams and can be used in aerosols, as fire extinguishing agents, solvents and medical aerosol applications. CFCs and HCFCs have been phased out, or are subject to phase out timetables under the Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol).

Australia is party to the Montreal Protocol and implements its obligations through the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* (the Act). The Act not only regulates the management of ozone depleting substances (ODS) in Australia, but also regulates the import, export, manufacture, use and disposal of SGGs in Australia, which were developed as replacements for ODS.

Internationally, annual SGGs emissions are reported to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. The Government has committed to reduce Australia’s emissions to 5% below 2000 levels by 2020.

Under the Act a licence is required to manufacture and import bulk HFCs and to import HFCs contained in equipment. This facilitates collection of import data to calculate Australian emissions. End use controls are in place for HFCs in the refrigeration and air conditioning and fire protection sectors to reduce emissions. Australia currently has no import limits for HFCs.

For the last five years, proposals have been made by North America (USA, Canada and Mexico) and the Federated States of Micronesia to regulate a phase down of HFCs under the Montreal Protocol. A phase down under the Montreal Protocol would avoid the widespread adoption of HFCs by developing countries, and thereby avoid the risk of emissions of more than 90 Giga tonnes CO2-e by 2050 – equivalent to two years of total global greenhouse gas emissions (US EPA 2013).

This report examines the capacity of the Australian industry to meet the requirements of one proposal that is being actively considered for such a phase down, the North American Amendment (NAA) proposal. The latest version of the NAA proposal was considered by the 25th Meeting of the Parties of the Montreal Protocol in October 2013. This provides a good test case against which to assess Australia’s ability to meet any future HFC phase down program.

Key details of both the NAA proposal, and the Federated States of Micronesia proposal are provided in *Appendix A*.

**Notes on Global Warming Potential (GWP) of Refrigerant Gases**

This report often refers to the global warming potential (GWP) value of the various gases that are the subject of this study.

Australia’s legally binding emission obligations under the Kyoto Protocol are calculated based on the GWP values published in the Second Assessment Report (AR2) of the International Panel on Climate Change (IPCC) released in 1996. Therefore Australian legislation, including the Ozone Protection and Synthetic Greenhouse Gas Management Act (OPSGGMA), also cites GWPs from AR2.

However revised GWP values were reported in the Fourth Assessment Report (AR4) in 2007. The 2nd Kyoto Protocol commitment period is based on AR4 values and Australia will take on these values from 2015. As the NAA proposal is based on AR4 values, to reduce any confusion that using unfamiliar GWP values may cause, this analysis reports both AR2 and AR4 GWP values in the following or similar manner: HFC-134a (GWP of 1300/1430 - AR2/AR4).

Where gases that were not included in the AR2 assessment are referred to, the AR4 value is used, and that is noted in a superscript after GWP (e.g. GWPAR4 of HFC-245fa is 1030). A new class of substances that feature prominently in this report are the very low GWP unsaturated HFCs known as hydrofluoro-olefins (HFOs) that were not available at the time of publication of AR4. As such the GWPs attributed to HFOs and HFO blends that are discussed herein are based on industry data. The fifth assessment report is still in draft, and has not been used in this report.

## Development of HFCs

Following ratification of the Montreal Protocol in 1989, and the commencement of the phase out of HCFCs, several different types of HFCs were developed, and HFC blends were created to supply gases with different properties, ensuring that there was a HFC suitable for the majority of refrigeration and air conditioning (RAC) applications.

As a result, since the early 1990s HFCs have taken over many, but not all, of the largest air conditioning and refrigeration applications, and technology segments of the market.

HFCs have no effect on the ozone layer, however like HCFCs, they are potent greenhouse gases with the most common, HFC-134a, having a global warming potential of 1300/1430 (AR2/AR4). With the increased international focus on achieving greenhouse gas emission reduction targets, the international community is now actively discussing action on HFCs as well.

The global industry that manufactures and supplies HFCs have been developing lower GWP options for many applications. For instance several options to replace one of the main higher GWP HFCs are being offered. Substitutes for HFC-404A (GWP of 3260/3922) include HFC-407F (GWP of 1824/2107) and HFC-407A. These are interim solutions (still third generation HFCs but in novel blends) with different characteristics and lower GWP values.

HFC-32 (GWP of 650/675) is another refrigerant that is now being used in new air conditioning equipment that would have otherwise most likely employed the much higher GWP HFC-410A (GWP of 1725/2088).

In recent years a new generation of unsaturated HFCs, known as HFOs, have been developed and tested with very low GWPs. The first such substance to be introduced to the market, HFO1234yf, has a GWP of just 4 and is likely to be widely adopted for use in vehicle air conditioning systems.

*Figure 1* illustrates the evolution of refrigerant species and how they are presently managed under international environmental protocols.

|  |  |  |  |
| --- | --- | --- | --- |
| **Refrigerant types and progression of synthetic refrigerants** | | | |
| **Natural refrigerants** | | | |
|  | | | |
| **Synthetic refrigerants** | | | |
| **Montreal Protocol (in response to ODP)** | | **Kyoto Protocol (in response to GWP)** | |
|  | | | |
| **1st Generation**  CFC-12  GWPAR2/AR4 = 8100/10900  ODP = 1 | **2nd Generation**  HCFC-22  GWPAR2/AR4 = 1500/1810  ODP = 0.055 | **3rd Generation**  HFC-134a  HFC-410A  HFC-404A  ODP = 0  GWPAR2 ≥ 1300 to 3260  GWPAR4 ≥ 1430 to 3922  HFC-32  GWPAR2/AR4 = 650/675 | **4th Generation**  HFO-1234yf  HFO-1234ze  ODP = 0  GWP ≤ 10 |
| **3.5 Generation**  Retrofit HFC blends  HFC-407F (GWPAR2/AR4 of 1824/2107)  HFO-Blends under examination (Refer *Table 3*) | |
| *Figure 1: Refrigerant types and international industrial gas management regimes.* | | | |

While the natural refrigerants are not subject to controls under the framework of international treaties referred to in Figure 1 above, in Australia there are a range of regulations, codes and standards that apply to the handling of these gases because they present some degree of risk to human health either due to toxicity or flammability, at both the State and Federal level. The term ‘natural’ refrigerant may imply that the fluids occur in nature as a result of geological and/or biological processes, unlike fluorinated refrigerants that are synthesized chemicals. However it has to be noted that all ‘natural’ refrigerants, while being found in nature in various forms and from various sources, as refrigerants, are refined and compressed by bulk gas manufacturers, and transported like other commercial gases. As such natural refrigerants also have an ‘energy investment’ in their creation, storage and transport.

These natural refrigerants were first employed prior to the development of any synthetic refrigerants and it was those same properties of toxicity and flammability that drove the search for refrigerants that did not pose any of those risks. In the first and second generations of synthetic refrigerants the primary focus was simply on finding a refrigerant that would provide effective cooling while being non-flammable and non-toxic. In the 1970s however scientists discovered that CFCs, and to a lesser extent HCFCs were causing depletion of the ozone layer, which lead to the Montreal Protocol and to a phase out of CFCs and HCFCs, and commercialisation of HFCs. While HFCs are now the subject of scrutiny due to their global warming effect, a lot more is demanded of refrigerants today, and a lot more options are available. Today, the range of considerations when selecting the right refrigerant for an application is far more complex. They include:

* **Safety risks** and probabilities due to flammability and toxicity of substances (classifications defined by technical standards and regulations) and the circumstances of the refrigerating application;
* **Thermodynamic properties** of the refrigerant (i.e. co-efficient of performance, capacity, glide, pressure and temperature operating envelopes, etc.); and,
* **Life cycle carbon emissions** (i.e. direct, indirect and end of life), which encompasses refrigerant GWP, equipment efficiencies or co-efficient of performance and total system energy consumption.

## The NAA Proposal

While the Parties to the Montreal Protocol are likely to see new versions of the NAA proposal submitted to it for consideration in 2014, the essential framework that has already been articulated in existing versions of the NAA are likely to comprise the central features of future proposals.

The intent of the NAA proposal has been lent some considerable international momentum with the recent announcement of a bilateral agreement, reached between President Barrack Obama of the USA and President Xi Jinping of the Peoples Republic of China. In June 2013, following a meeting of the two Presidents, it was announced that the two countries would *“work together and with other countries to use the expertise and institutions of the Montreal Protocol to phase down the consumption and production of HFCs, among other forms of multilateral cooperation.”* In addition, in September 2013, the G20 Leaders statement supported a phase-down of HFCs using the mechanisms of the Montreal Protocol.

New plans to reduce the use of HFCs in the European Union have also been proposed. There are already requirements for European auto manufacturers to move to lower or zero GWP alternatives gases in mobile air conditioning systems, however new regulations have been proposed reducing HFC use across all applications by 79% in Europe by 2030.

These developments on their own have the potential to drive significant change in the Australian market, irrespective of the outcomes of the NAA proposal.

These policy developments are driven in part by new scientific findings on the potential future role of HFCs in atmospheric forcing. HFCs currently comprise less than 2% of global anthropogenic greenhouse gas emissions. However, as the standard of living and disposable incomes in many developing countries improves, and as they prepare to eliminate HCFCs under their Montreal Protocol obligations, the demand for HFCs is growing in line with increasing demand for refrigeration, air conditioning, and vehicles equipped with air conditioning This global trend has the potential to drive HFC use and emissions to much higher levels. According to an article in the US Proceedings of the National Academy of Science in 2009, HFC emissions could grow to between 28 to 45% of anthropogenic CO2-e emissions by 2050 if current rates of consumption are maintained (PNAS 2009).

All of these developments point to growing international momentum to phase down high GWP HFCs as part of the global effort to limit climate change.

The cumulative global benefits of the NAA proposal as estimated by the US Government are substantial. The US Government has estimated that the phase down of HFCs on the timeline proposed by the 2013 NAA proposal would avoid emissions equivalent to 1,900 Mega tonnes of CO2 (Mt CO2-e) to the end of 2020, and would avoid cumulative emissions of some 84,100 Mt CO2-e by the end of 2050.

Cumulative benefits achieved by controlling HFC-23 emissions as a by-product of the production of HCFC-22 is estimated by the US Government to avoid an additional 11,300 Mt CO2-e by the end of 2050.

These estimated emissions avoided, of more than 90 Giga tonnes of CO2-e by 2050, are the equivalent of two full years of total global greenhouse emissions now. As such the potential contribution of this industry to achieving the aspirations of the global community are substantial.

The key elements of the NAA proposal include:

* The listing of 19 HFCs as a new Annex F to the Montreal Protocol (excluding HFOs);
* Recognition that there may not be alternatives for all HFC applications today, and therefore proposes a gradual phase down with a plateau of 15%, as opposed to a phase out;
* Consumption and production reduction steps for both Article 5 and non-Article 5 countries based on GWP weighted basis;
* A proposal that the baseline for Article 5 countries is calculated based on 90% of the average HCFC consumption and production over the period 2008, 2009 and 2010, which recognises current HFC data limitations in these countries;
* A proposal that the baseline for non-Article 5 countries is calculated from a combination of HFC consumption and production, plus 85% of HCFC consumption and production, averaged over the years 2008 to 2010.
* A requirement for licensing of HFC imports and exports and bans imports and exports to non-Parties.
* A requirement for reporting on HFC production, consumption, and by-product emissions from HFC manufacture; and,
* It makes the phase down of HFC production and consumption as well as the reduction of HFC-23 by-product emissions in developing countries eligible for funding under the Montreal Protocol’s Multilateral Fund.

More information on the operation, roles and functions of the various elements of the Montreal Protocol can be found at <http://www.environment.gov.au/topics/environment-protection/ozone/montreal-protocol>.

The NAA proposal recognizes that HFCs are alternatives in some existing HCFC applications, so baseline levels are set to accommodate some level of continuing transition from HCFCs to HFCs.

Because there is no production of HFCs in Australia, the NAA Proposal only applies to consumption of bulk gases imported into Australia. Gas imported into Australia in pre-charged equipment does not need to be accounted for under the proposal as that gas will be accounted for in the manufacturing country’s inventory.

A simple schematic illustrating the NAA proposed phase down metrics and timeline is included below at *Figures 2* and *3*.

|  |
| --- |
| **North American Amendment Proposal** |
|  |
| *Figure 2: HFC reduction steps for Non-Article 5 Countries (incl. Australia).* |
|  |
| *Figure 3: Cumulative emission reduction in % cut for Non-Article 5 Countries (incl. Australia).* |

## Australia and the NAA Proposal

**Calculating the Baseline** - The 2013 NAA proposal requires establishment of country baselines for each member country, and then proposes a consistent percentage reduction for all countries relative to their individual baseline.

The country baselines are calculated on average production and consumption of HFCs in the period 2008 to 2010, plus 85% of the average production and consumption of HCFCs in those same years in each country. As there is no production of HCFCs or HFCs in Australia, the Australian baseline will be calculated on consumption only. Consumption is defined in the NAA as bulk gas imports only.

Country baselines, and subsequent targets for reduction against the baseline, are expressed in terms of CO2-e, creating a common denominator for aggregation of both HCFCs and HFCs.

Because of the reporting protocols adhered to by Australian importers of HCFCs and HFCs, the data required to calculate an NAA baseline for Australia is very reliable.

Based on the NAA proposal the Australian baseline was calculated to be about 9,950 kilo tonnes CO2-e (AR4). Refer to *Appendix A1* for a summary of the calculations.

**Australia’s 2013 Consumption** - For a number of reasons, both commercial and to do with the government policy settings, since the end of the baseline period, Australian consumption of bulk gas imports are estimated to have been significantly lower than the baseline in CO2-e terms. In 2013 it is estimated that Australia’s bulk HCFC and HFC consumption was equivalent to approximately 8.8 Mt CO2. This is calculated on the basis of an estimated 3,990 tonnes of virgin bulk gases of all sorts being consumed in Australia in that year, as set out in *Table 1* below.

*Table 1: Estimates of 2013 gas consumption in Australia.*

|  |  |
| --- | --- |
| Gas type | 2013 consumption  Market estimate  (tonnes) |
| HCFC-22 | 565 |
| HCFC-22 re-use | 200 |
| HCFC-123 | 20 |
| HFC-134a | 1,700 |
| HFC-404A | 640 |
| HFC-407F | 40 |
| HFC-407C | 150 |
| HFC-410A | 575 |
| HFC-Mix | 300 |
| TOTAL (incl. re-use) | 4,190 |

Total estimated consumption for 2013 includes 200 tonnes of HCFC re-use for a total of 4,190 tonnes consumed in the period. This is comparable to an estimate by the same authors in January 2013 of a total consumption of 4,250 tonnes in the 2012 calendar year, and the historical average up to 2011 of around 4,500 tonnes per annum.

Thus the present 2013 prediction of 4,190 tonnes is around 310 tonnes or 7% below the pre-2012 long term average.

Actual imports during calendar year 2013 were only a fraction of this quantity at some 315 tonnes of bulk HFCs and 766 tonnes of HCFCs, largely as a result of a 2012 spike in imports as trading enterprises sought to delay, for as long as possible, the impacts of the ECP on imports introduced from July 1, 2012. As a result most of the HFCs consumed during 2013 were drawn from stock piles already on shore.

The ECP is expected to be removed after July 1 2014, and some industry members have expressed a view that bulk gas imports will revert back to the long term average once onshore stockpiles have been depleted. Various changes in market behaviour, such as reducing gas charges in equipment, or simply delaying equipment servicing have been pointed to as evidence that soft demand and market changes are temporary, and some of this may be true. This scenario has been explored and a transition scenario is illustrated by a dotted line in *Figures 3* and *4* if the transition was to commence at the long term average of 4,500 tonnes per annum.

Nonetheless, setting aside for the moment the possibility of temporary demand softening as a result of the import levy that may rebound when the levy is removed, the authors are confident in the estimate of consumption for the 2013 calendar year which was based on a range of bottom up and top down analysis and primary research in the market. Significant and permanent impacts on demand that account for the approximately 510 tonnes excised from the previous long term average bulk imports include;

* Strong growth off a low base of HFC or HCFC displacement by natural refrigerants in several applications in the course of the last three years, equivalent to more than 100 tonnes of bulk synthetic gas consumption per annum;
* Decline in demand from Australian manufacturers of more than 100 tonnes of bulk synthetic gas consumption per annum in the last three years, as manufacturing output has either declined, or capacity been permanently shut down (a trend that is going to continue for the next two to three years);
* A notable focus by larger enterprises in both the refrigerated cold food chain and in commercial chiller applications on leak prevention, detection and repair. This important trend, which anecdotal evidence suggests is becoming common practice in the industry, was instigated by various Federal and State Government greenhouse accounting, reporting and energy efficiency schemes starting in the early 2000s, was reinforced by the National Greenhouse Energy Reporting System (NGERS) from 2008 and became a central focus in the lead up to the introduction of the Equivalent Carbon Price (ECP). While it is hard to exactly quantify the resulting demand reduction, indications of the level of leak reduction in some major consumers lead the authors to estimate that effective leak reduction may have permanently removed demand for as much as 100 tonnes of bulk synthetic refrigerants per annum in the last three to five years.
* A substantial increase in enterprises openly engaging in re-use, particularly of HCFCs, estimated to be at least equivalent to 200 tonnes of bulk synthetic gas consumption per annum. Because of the inevitable phase out of HCFCs this will not permanently reduce overall demand however as some re-use of higher GWP HFCs has also been reported in the last year and that is expected to continue as a more common industry practice even if at relatively small volumes.

Thus, based on the best available data and primary market research, if the NAA proposal were to have commenced in 2013, Australia would have started with estimated consumption nearly 15% under the proposed baseline.

While that is a fortunate position to be in, it would be wise to assume that there is no certainty that this relatively advantageous position will be automatically maintained into the future, particularly as proposed NAA reduction milestones are reached and consumption caps fall.

Certainly there are some recent changes to market behaviour that have delivered one-off demand reductions that will not result in any permanent demand reduction. For instance recovery and re-use of HCFC-22, an activity that has grown quite quickly in the last three years to an estimated 200 to 250 tonnes per annum, is expected to peak and eventually decline in the two decades ahead as HCFC charged equipment is finally retired from the economy, and is replaced with new equipment charged with other gases. Given equipment pre-charged with HCFCs was imported as recently as 2010, a tail of this activity could easily persist until as late as 2025. Eventually all HCFC charged equipment will be replaced with new equipment, likely operating on the most common refrigerant of the day which, in some subsectors, could still involve a high GWP gas.

There has also been some shuffling of stocks in the value chain whereby technicians from some larger service companies no longer carry all of the commonly used refrigerants with them, but rather call on supplies as required from a central store. This has had the effect of reducing, to an unknown extent at this time, the total stock of gas in that part of the value chain. It is quite possible that having introduced this more efficient management of inventory in response to higher feedstock prices, that this may become a permanent feature of the supply chain, but on its own, while reducing volumes of gas held in the supply chain, does not reduce final demand from the stock of equipment.

However if, as one would expect, some buying decisions have been delayed for a period, waiting for the expected price reduction that should flow through to higher GWP HFCs following the announced removal of the ECP in the near future, there is likely to be some increased buying for a period. If that demand rebound is permanent, then some of the present comfortable differential between consumption and an NAA cap could be quickly eroded.

At the same time the authors believe that most of the demand reduction trends underlying their 2013 estimate of consumption are permanent and to some extent irrespective to changes in pricing. In the longer term the increase in synthetic refrigerant prices has been stronger than inflation in the economy, and increased market awareness of the economic returns of minimising leaks and loses, opportunities for re-use, reducing charge sizes overall, and growing appreciation of the value of moving to the most energy efficient and often lower GWP refrigerant options, point to these trends continuing.

**The Transition Model of future consumption** - For the purposes of assessing Australia’s capacity to meet a phase down timetable based on the NAA proposal, a projection of the stock of equipment, and thus the make up of the refrigerant bank in Australia has been constructed. Demand for bulk imports has been calculated based on forward estimates of gas required to service that bank, and to meet demands for charging of new equipment either manufactured in Australia, or imported without a gas charge.

This involved making assessments about the rate of adoption of existing lower or zero GWP gases and technologies, and the rate of adoption of some lower GWP gases that are on the verge of commercial production. While many species of refrigerant gas under development were examined to ascertain their state of readiness for the market, only technologies that have been demonstrated in the field as viable, have been assessed.

The model that was built is referred to as the Transition Model and the results of the model are illustrated in *Figures 4* and *5*. These illustrations show the predicted CO2-e value of bulk imports of synthetic gases into Australia out to 2025 by end use application of the gas, and then by species of gas imported. The blue dotted line on these charts illustrates an alternative scenario if the transition was to commence at the long term average of 4,500 tonnes per annum.

*Figures 6* and *7* illustrate the Transition Models projection of the bank of working gases in Australia out to 2025. Whereas Figure 8 shows the projected refrigerant consumption from 2013 to 2025 by gas species, which is mostly derived from the bank plus OEM manufacturer, charging new equipment, and other applications such as foams, fire protection and aerosols.

|  |
| --- |
| **Australia and the NAA Proposal by sub-sector application (above) and by gas species (below)** |
|  |
| *Figure 4: Australia and the NAA Proposal by sub-sector application in Mt CO2-e based on AR4.* |
|  |
| *Figure 5: Australia and the NAA Proposal by gas species in Mt CO2-e based on AR4.* |

|  |
| --- |
| **Refrigerant bank transition by gas species based on assumptions in tonnes (above) and Mt CO2-e (below)** |
|  |
| *Figure 6: Refrigerant bank transition from 2013 to 2025 by gas species in tonnes based on model assumptions.* |
|  |
| *Figure 7: Refrigerant bank transition from 2013 to 2025 by gas species in Mt CO2-e (AR4) based on model assumptions.* |

The Expert Group stock model of RAC equipment in the Australian economy provides a starting point for the projections of changes in the size and make-up of the bank of refrigerant gases in the economy.

As illustrated above in *Figure 5* the starting point in 2013 is a bank of all working gas (excluding ammonia in industrial refrigeration) of approximately 46,500 tonnes. This bank continues to grow, although with significant changes to the composition of the bank over the projection period, as nil and lower GWP refrigerants continue to improve market share, and with the commercial release of additional 4th generation low GWP HFO refrigerants over the next 1 to 5 years.

|  |
| --- |
| **Projected refrigerant consumption by species based on assumptions (tonnes)** |
|  |
| Note includes projected consumption from Foams, Fire protection, aerosols and other applications. |
| *Figure 8: Projected refrigerant consumption from 2013 to 2025 by gas species in tonnes based on model assumptions.* |

Efforts to project the rate and success of commercialisation of alternative technologies that are currently ‘under development’ will always carry greater uncertainties than projections of those for which commercial supply is already established. These uncertainties can be both in terms of available quantities and timing or market release. The eventual price of a product under development is always a considerable source of uncertainty which will be affected by a range of issues such as the scale of investment in initial production, the rate of adoption, and the development of supply lines against incumbent competition and technologies, all of which go towards changing the dynamics of the supply/demand relationship.

A level of confidence for projections of the rate of change and transition path in each sector and sub-sector has been provided in the later sections of this report. These are necessarily somewhat qualitative, but in general terms, where a technology is commercially established and any technical complexities have been dealt with by industry, thus becoming routine in day-to-day practice, a high level of confidence in the projected outcome is likely. At the same time, technology that is more competitive in its market niche can overtake even technology well established in the early stages of commercial deployment.

Where a technology has been tested and demonstrated as effective, but is not yet established as a commercial option, and does not appear to have any significant technical complexities, confidence in the projections of its uptake are likely to be medium. Where a technology is at demonstrated but pre-commercial state has some apparent technical challenges or possible regulatory limitations and complexities to overcome, confidence in the projections of uptake is likely to be lower.

Working through the many options that go into a projection of a sector or sub-sector technology mix, and then ascribing a level of confidence to the outcomes in that sector, is a judgement made by the authors.

Nonetheless, while the mix of final technology employed will almost certainly diverge from the projections due to influences and circumstances that could not be considered throughout the period of the study, at this stage the Transition Model demonstrates that there are alternatives either in the market now, or on the near commercial horizon, that will be able to provide the majority of RAC services required across the economy using lower or zero GWP refrigerants.

The impact of the changing composition of the bank is illustrated in *Figures 6 and 7* where changing bank is projected out to 2025 in tonnes and CO2-e value based on AR4.

It is immediately obvious that the growing wedge of gas with a GWP <10, visible in the top part of the illustration of the refrigerant bank in *Figure 6*, which is expressed in metric tonnes, effectively becomes invisible when the CO2-e value of the bank is calculated as illustrated in the second chart.

While the bank overall, and the RAC equipment and services demanded in the economy, continues to increase, the CO2-e value of the working bank rises until 2017 then decreases steadily as the second and third generation refrigerants retire and are replaced by nil and lower GWP working gases.

The projection of the declining CO2-e value of the bank in *Figure 7* above does not reflect overall growth in the total size of the bank. With some exceptions, it is expected that the market for RAC services and technology in Australia will continue to grow at a rate slightly faster than the overall rate of economic growth, even while the aggregate GWP of the bank of working gases falls as new, lower GWP gases are introduced and existing low GWP options take greater market shares.

There are a number of factors that have been considered, and no doubt there are factors as yet unforeseen, that could change the actual make up of the working bank in 2025. However there is one important feature of this projection that is obvious and unlikely to change. The RAC industry is going to see a rapid increase in the number of refrigerant gases, and a rapid diversification in the types of refrigerant gases employed in the economy. It is true that there are dozens of chemicals and gases supplied to the market now for all sorts of specialised applications and tasks. However the vast majority of refrigeration technicians, and many other players in the supply chain, only have to deal with between 3 and 5 of the most common refrigerants on a daily basis, all of which are non-flammable.

Within five years that number is expected to at least double, in terms of the day to day activities of most people employed in the field, and many of the future refrigerants expected to be commonly encountered will be at least mildly flammable, or flammable. This fact has some significant implications for the industry along the length of the supply chain, a subject that is discussed further in the next sections.

# Technical summary

The table in *Section 3.1* provides a snapshot view of the potential for available low GWP refrigerants, and for those low GWP refrigerants deemed to be close to commercial availability, to be employed in mainstream RAC services. In brief, upon examining the options that are either currently available in new equipment, or have been shown to be viable or, as is the case with HFO blends, are being rapidly developed for commercial release, it is apparent that there are viable options for the majority of mainstream RAC applications to operate on nil or lower GWP refrigerants.

Following on from that assessment *Section 3.2* provides a summary of the nil and lower GWP refrigerants that are available including notes on their availability, and any immediate limiting factors or obstacles to their adoption.

A technical summary is provided at the end of the technical summary in *Section 3.6, Transition map to nil or lower GWP options for main equipment classes and technologies*, which summarises the options currently available (High, lower and nil GWP), the future range of lower and nil GWP options as well as key comments on each technology path.

## Current and future potential for nil and lower GWP options

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Application | Currently available in new equipment | | | | Viable and under development | | | |
| HC | R717 | R744 | HFO | HC | R717 | R744 | HFO blends |
| **Stationary air conditioning** |  | | | | | | | |
| Wall hung split systems | Y | N | N | N | Y | N | Y | Y and DI |
| Split ducted systems | Y | N | N | N | Y | N | N | Y and DI |
| Roof top packaged | Y | N | N | N | Y | N | N | Y and DI |
| Chillers < 530 kW | Y | Y | Y | N | Y | Y | Y | Y |
| Chillers > 1055 kW | Y | Y | N | Y | N | Y | Y | Y |
| Precision control AC | N | N | N | N | N | N | N | Y and DI |
| Other stationary (hot water heat pumps) | YY | Y | YY | N | Y | Y | Y | Y and DI |
| **Stationary refrigeration** |  | | | | | | | |
| Supermarket systems: large | Y† | Y | YY†† | N | Y | Y | Y††† | Y†††† |
| Supermarket systems: medium | Y† | Y | YY†† | N | Y | Y | Y | Y†††† |
| Supermarket systems: small | Y | N | Y | N | Y | Y | Y | Y†††† |
| Medium commercial refrigeration | Y | Y | Y | N | Y | Y | Y | Y and DI |
| Process refrigeration and cold storage | Y | YY | YY | N | Y | Y | Y | Y |
| Milk Vat (dairy industry) | N | NMV | N | N | N | Y | N | Y and DI |
| Self-contained equipment | YY | N | Y | N | Y | Y | Y | Y and DI |
| Domestic refrigerators and freezers | YY | YDR | N | N | Y | Y | Y | Y and DI |
| **Mobile AC** |  | | | | | | | |
| Passenger and light commercial vehicles | YMAC | N | Y | Y | Y | N | Y | Y and DI |
| Commuter vehicles | N | N | N | Y | N | N | Y | Y and DI |
| Buses (>7m in length) | N | N | Y | N | N | N | Y | Y and DI |
| Passenger rail | N | N | N | N | N | N | Y | Y and DI |
|  | | | | | | | | |

Refer notes on following page.

**Current and future potential for nil and lower GWP options (continued)**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Application | Currently available in new equipment | | | | Viable and under development | | | |
| HC | R717 | R744 | HFO | HC | R717 | R744 | HFO blends |
| **Transport Refrigeration** |  | | | | | | | |
| Truck | N | N | Y | N | Y | N | Y | Y and DI |
| Fishing vessels | N | NFV | NFV | N | N | Y | Y | Y and DI |
| **Other applications** |  | | | | | | | |
| Foam applications | Y (Most applications - variety of solutions) | | | | Remaining applications (HFOs) | | | |
| Fire protection | Y (Most applications - inert gas systems) | | | | Remaining applications (HFOs) | | | |
| Aerosols | Y (Excluding medical and hazardous area uses) | | | | Remaining applications (HFOs) | | | |
|  | | | | | | | | |

Notes:

Y = Generally yes and requires either equipment change or is available off-the-shelf in new equipment if new equipment is being purchased.

YY = Immediate opportunity to transition (requires equipment change or is available off-the-shelf in new equipment).

Y and DI = Generally yes and has potential to be used as a drop-in replacement for existing equipment with non flammable blends.

N = Generally no.

† Not used in large systems due to charge restrictions - opportunity for self-contained and small or isolated charge systems to be used.

†† Majority of applications are cascade systems that employ a smaller charge of high GWP HFC plus CO2 (R744).

††† Warm climate trans-critical CO2 systems are under development.

†††† Potential drop-in replacement for advanced systems designed for this technology path.

MV Australian milk vat technology do not currently have ammonia (R717) options available – this option may emerge with the development of commercially available smaller scale ammonia compressors to suit the capacity range.

DR Applicable to ammonia-water absorption systems that have been available for many years.

MAC OKA, a former minor manufacturer of specialised four-wheel drives used hydrocarbon refrigerant in new vehicles. HFO-1234yf and CO2 (R744) have been selected as the global platform for new vehicles.

FV Highly efficient ammonia-CO2 cascade systems used on large (>80 meters in length) fishing vessels in the EU are not suited to the smaller Australian fleet.

The concept of this table was adapted from UNEP 2011c.

*ISO/ANSI/ASHRAE 34-2013, Designation and Safety Classification of Refrigerants*, the latest edition of *Standard 34* (ASHRAE 2013) provides number designations for refrigerants. The authors have adapted these numbers to assist readers understand which family a refrigerant comes from by placing a HC, CFC, HCFC, HFC or HFO in front of the ASHRAE number instead of ‘R’, except for ammonia and carbon dioxide refrigerants. For example R600a is HC-600a and R134a is HFC-134a.

## Summary of commercially available nil and lower GWP options, and associated challenges

|  |  |  |
| --- | --- | --- |
| Gas type | Challenges to market entry | Potential solutions |
| Hydrocarbons  HC-290 (propane)  HC-600a (isobutane)  HC-436 | Skills gap  Highly flammable  Challenges for equipment with refrigerant charge >1kg  Challenges for equipment with remote condensers  Risk and liability concerns for industry and regulators  Incorrect labelling | Charge limits, safety devices (leak testing) and pump down circuits  Engineering design to isolate charge and manage risk  Training and education  Standards and service procedures  Research and development  Retrofit only undertaken by skilled practioners and strictly in accordance with manufacturer’s guidelines and technical standards  Target applications:   * Domestic refrigeration; * Self-contained refrigeration (i.e. refrigerated vending machines/chest; freezers/small display cases, bottle water coolers, hot water heat pumps); * Retrofit of mobile air conditioning with charge <1 kg; and, * Packaged air conditioning with charge <1.5 kg (i.e. portable and window/wall). |
| CO2 (R744) | Skills gap  Acute toxicity and associated safety risks  High operating pressure  System reliability and leak reduction  Economies of scale and associated higher equipment costs  Low critical temperature, can lead to low efficiency  Needs new servicing infrastructure for mobile air conditioning  Not as effective in high ambient regions (>35oC) | Engineering design  Research to overcome safety and efficiency barriers  Training and education  Financial incentives  Target applications:   * Refrigerated vending machines; * Hot water heat pumps; * Reefers – refrigerated containers; * Advanced refrigeration systems; and, * Large process refrigeration applications with heating requirement; * Applications in low ambient regions (<35oC). |
| Ammonia (R717) | Skills gap  Toxicity risks and slightly flammable  Safety code restrictions  Many applications not commercially viable <50 kWr | Engineering design  Standards and safety regulations  Codes of practice  Commercialisation of smaller capacity ammonia compressors  Financial incentives  Target applications:   * Large and some medium commercial refrigeration; * Cold storage and process refrigeration; and, * Chillers for air conditioning. |

(Sources EPA 2010a and EPA 2010b)

**Summary of commercially available nil and lower GWP options, and associated challenges (continued)**

|  |  |  |
| --- | --- | --- |
| Gas type | Challenges to market entry | Potential solutions |
| HFO-1234yf | Mild flammability  Market availability  International regulatory approvals for new species  Limited production capacity - high refrigerant price  There are concerns regarding the decomposition products in the event of a release into the environment | Engineering designs and applications matched to level of flammability  Increase production capacity  Research and development  Note: HFO blends with characteristics (i.e. pressures, efficiency and flammability) that more closely match widely used refrigerants HCFC-22, HFC-410A and HFC-404A are not consider commercially available at the time of writing this report and are reviewed in *Section 3.4*. |
| HFO-1234ze(E) | As above. | As above. |
| HFO-1233zd(E) | Market availability  International regulatory approvals for new species  Limited production capacity  There are concerns regarding the decomposition products in the event of a release into the environment | Being non-flammable and having a moderate cost, this refrigerant is on a fast track for adoption. R-number designation application is expected for 2014 (UNEP 2013c, p41). |
| HFC-32 | Mild flammability  Skills gap  Not a drop-in replacement for HCFC-22 equipment  Market acceptance (local and overseas)  Service supply chain issues:   * Lack of compliant service cylinders; and * Australian Dangerous Goods Code for transport and storage classifies HFC-32 as a dangerous good under Division 2.1 Flammable gases. | Research and development  Transformation of supply chain to handle large volumes of class 2AL refrigerants  Training and education  Target applications:   * Split air conditioning units; * Most small to medium stationary AC applications; * Risk assessment of larger charge applications such as VRV systems is currently under evaluation; and * High ambient regions (i.e. better high ambient performance than HFC-410A). |
| HFC-152a | High flammability risks  Limited support from multinational vehicle OEMs  Limited production capacity | Engineering designs and applications matched to level of flammability  Increase production capacity |
| HFC-407F  HFC-407A | Transitional option for HFC-404A  Cost of refrigerant versus change in GWP AR4 (3922 to 2107)  Poor market perception of drop-in replacements - leakage, resulting in efficiency and performance issues | Carbon levy for high GWP refrigerants has encouraged the use of HFC-407F versus HFC-404A, removal of levy has potential to remove financial incentive.  Market as retrofit rather than drop-in replacement |

**Summary of commercially available nil and lower GWP options, and associated challenges (continued)**

|  |  |  |
| --- | --- | --- |
| Gas type | Challenges to market entry | Potential solutions |
| Cascade system with HFC and CO2 | More expensive  Energy efficiency concerns with earlier designs  Technician and operator experience  Technology path is on fast track for widespread adoption in supermarket and similar applications | Training and education  Standards, codes of practice and design guidelines  Case studies (share latest innovations) |
| Fire Suppression  Novac 1230  IG-01 (Argon)  IG-100 (Nitrogen)  IG-541  IG-55 | Commercial barrier – more expensive  Existing infrastructure – filling stations  Cannot be piped long distances - requires multiple pockets for large spaces  Technical barrier - space and speed of discharge, particularly in the marine and aerospace industries | Financial penalty or tax for high GWP products |
| Note: IG-541 is a blend of nitrogen/argon/CO2, and IG-55 comprises nitrogen/argon. The mass composition of these blends can vary slightly depending on the supplier. | | |
| Refer end of *Section 3.6* for summary of foam, aerosols and solvents. | | |

## Rapidly emerging nil or lower GWP alternatives

Some of the commercially available nil and lower GWP refrigerant gases listed in the preceding table are assessed as having real potential for rapid growth. Quite dramatic changes in the make up of the refrigerant bank have occurred previously, driven by international treaties, government regulation, and industry demand. The adoption of HFC-410A in the first decade of this century, for instance, is an example of a successful deployment of new technology, even though technical standards had to be revised, and new job skills had to be learned. First introduced in Australia in 2003, by 2010 HFC-410A had effectively replaced HCFC-22 in 90% of applications where previously HCFC-22 had been the refrigerant of choice.

It is possible that existing nil and low GWP or new refrigerants presently in the early stages of deployment could deliver similar rates of growth, while replacing gases that have been targeted for removal from the economy. Natural refrigerants, while presently providing only a very small part of the total refrigerant demand in Australia, are well placed to grow strongly in applications to which they are best suited, and where proven technology is competitively priced and understood by the market.

A survey of natural refrigerant suppliers, conducted for the purposes of this study, indicates that more than 100 tonnes of hydrocarbons were supplied in total last year to charge equipment, or service equipment across most sectors. *Table 2* below records the results of the survey which also revealed that at least 80 tonnes of CO2 was supplied to supermarket installations in 2013, and nearly 540 tonnes of ammonia was supplied, almost exclusively to large cold store and industrial sites.

This demonstrates the viability of these nil and low GWP refrigerant options. It is quite possible that only relatively small changes in market conditions could see any, or all of these established technologies become dominant in their optimal applications in a relatively short space of time.

*Table 2: Supplies of natural refrigerants in 2013 in tonnes and dissection by application.*

|  |  |  |  |
| --- | --- | --- | --- |
|  | Hydrocarbons | Ammonia (R744) | CO2 (R774) |
| Volumes supplied in 2013 (tonnes) | 106 | 538 | 84 |
| Dissection by application segment | % | % | % |
| Stationary AC: domestic and light commercial | 9% | 0% | 0% |
| Stationary AC: commercial (chillers and close control) | 12% | 0% | 0.2% |
| Stationary AC: domestic hot water heat pumps | 0% | 0% | 0% |
| Mobile AC: registered vehicles | 49% | 0% | 0% |
| Mobile AC: un-registered vehicles | 1% | 0% | 0% |
| Domestic refrigeration | 15% | 0% | 0% |
| Refrig. Cold Food Chain: self contained units | 4% | 0% | 0% |
| Refrig. Cold Food Chain: remote condensing units | 1% | 0% | 0% |
| Refrig. Cold Food Chain: process and cold storage facilities | 7% | 88% | 0% |
| Refrig. Cold Food Chain: transport refrigeration | 2% | 0% | 0% |
| Refrig. Cold Food Chain: supermarkets (excl. cold storage) | 0% | 6% | 99% |
| Other - Heavy engineering and mining | 0% | 5% | 0% |
| Total | 100% | 100% | 100% |

The potential for natural refrigerants to grow market share is discussed in more detail on a sector by sector basis later in the report, but in general, along with the zero or low GWP properties of these gases, natural refrigerants options can be attractive when employed in applications where energy efficiency is important. If for instance all RAC technologies were assessed in terms of full life cycle carbon emissions, both direct and indirect, in a very wide range of applications natural refrigerants would provide sound economic benefits to end users and consumers (e.g. Ammonia in large scale systems and hydrocarbon in sealed systems). However there are other technical and commercial barriers relating to both the toxicity, the flammability and global economies of scale of some of the natural refrigerants that need to be overcome.

Ammonia (R717) for instance is the refrigerant of choice due to its higher energy efficiency in a relatively small number of large water chilling applications for industrial space cooling, refrigeration at large distribution centres and cold stores, and in some mine operations, all in situations where the plant is designed to a specification and run under closer engineering supervision and control. This is unlike the vast majority (>98%) of all large chillers sold and installed which are charged by synthetic gases that are non-toxic and inert, and that are largely left to automated operation managed (and more frequently also monitored) by generalist build services manager or remote contract service engineering firms.

Hydrocarbons are also more efficient and require a smaller charge than synthetic alternatives in many small applications, however due to flammability of the gas and safety code restrictions, hydrocarbon charged applications are more likely to find wider acceptance in applications with very small charges (<1 kg).

CO2 on the other hand is not flammable, and is highly efficient up to about 35oC ambient, after which there is an energy penalty incurred when ambient temperatures stay high for any period. CO2, like HCs is growing market share in a number of smaller hermetically sealed applications (e.g. vending machines, refrigeration display cases, hot water heat pumps, etc.) but also in larger, closely managed cascade systems in supermarkets.

Together these refrigerants have potentially a lot of market share to gain under almost any HFC phase down scenario. The extent of their adoption in areas where technical issues are sufficiently resolved will, to a large extent, depend on commercial issues, competition and regulatory settings.

Another gas with potential for very strong growth of market share in some applications is HFC-32. While still having a GWP of 650/675, HFC-32 is likely to establish itself as a leader in the stationary air conditioning market, replacing HFC-410A (GWP of 1725/2088) while being able to deliver the same cooling services with a charge as much as 30% smaller than was required with HFC-410A.

HFC-32 has been commercially available for only two years, yet in 2013 a significant quantity of pre-charged equipment containing HFC-32 was imported into Australia (DoE 2014). HFC-32 provides a very good example of how fast this industry can move, when conditions are right.

In June 2011, two of the largest Japanese manufacturers of air conditioning equipment, Daikin Industries Ltd., and Panasonic Corporation reached an agreement to introduce high-efficiency air-conditioners using HFC-32 in the Indonesian market for a United Nations Development Programme project. The project is targeted at developing countries and is intended to both replace ozone-depleting substances such as HCFC-22, and to leapfrog higher GWP gas charged technologies. Other leading Japanese companies Fujitsu General, Hitachi and Toshiba are now part of this agreement.

Both Daikin and Panasonic expected that introducing this technology in Indonesia could start a global trend for other high ambient temperature developing countries. Subsequently Daikin launched the world’s first air conditioners to use HFC-32 into the Japanese market in November 2012. Daikin has also launched products in Europe and India (Daikin Industries 2014).

Other suppliers that launched HFC-32 products in the Japanese market in 2013 include Mitsubishi, Hitachi, Panasonic, Fujitsu General and Sharp. As a result Japan presently has a total estimated installed base of around 100,000 pieces and growing. Both Daikin Industries and Fujitsu General launched HFC-32 products in Australia late 2013, with several other companies expected to follow. In a recent development Daikin Industries has shared the IP for production of HFC-32 with the other leading members of the industry. As a result there is an emerging consensus among the industry leaders that this refrigerant could provide a common design path for new product in the medium sized class of air conditioners.

If, as seems likely, significant product lines from most leading manufacturers are converted to HFC-32, Australia may have reduced supply options and may in the future have little choice other than to adapt to the new technical standards and requirements of dealing with this mildly flammable refrigerant.

At the same time the even more flammable hydrocarbon refrigerants are also expanding market share in Australia, a fact that does not seem to have created any tremendous difficulty for the industry and its supply lines to date.

## Fourth generation synthetic substances and blends under development

There is a new class of very low or substantially reduced GWP synthetic substances, known as hydrofluoro-olefins (HFOs, also described as unsaturated HFCs), and HFO blends that are relatively close to full commercial release. Whilst convention is to only discuss refrigerants with *ISO/ANSI/ASHRAE 34, Designation and Safety Classification of Refrigerants,* R-number designation, it is considered necessary to discuss HFO blends as many are close to commercialisation and receiving R-number designations.

The first low GWP substance is HFO-1234yf, with a GWP of around 4. This gas was originally developed as a replacement for HFC-134a in mobile air conditioners and could potentially be employed in many other refrigeration and air conditioning applications. Another low GWP product is HFO-1234ze(E), with a GWP of around 6 that has potential for use in foam blowing, aerosol and specific vapour compression applications.[[1]](#footnote-1)

Another emerging class of lower GWP options are HFO blends that comprise HFO-1234yf and HFO-1234ze(E), and other stable refrigerants, including HFC-32, HFC-125, HFC-134a, HFC-152a, CO2 and hydrocarbons. These blends are designed to achieve operating characteristics for a diverse range of air conditioning and refrigeration applications.

The main public source of information on performance characteristics of these new refrigerants is available via the AHRI (Air Conditioning, Heating, and Refrigeration Institute) Low-GWP Alternative Refrigerants Evaluation Program. *Table 3* provides a list of lower GWP refrigerants that are being reviewed and evaluated by the program.

The timing of the release of these emerging refrigerants in Australia is dependent on several factors including:

* Testing of refrigerant by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and allocation of ‘R’ numbers and refrigerant classifications in accordance with *ISO/ANSI/ASHRAE 34, Designation and Safety Classification of Refrigerants*.
* NICNAS (National Industrial Chemicals Notification and Assessment Scheme) registration and accreditation.
* Sufficient scaling of production of HFOs to make them available for blending into emerging refrigerants.[[2]](#footnote-2)

The latest local market intelligence suggests the first blends will be available for sale in bulk in 2014 although there is no indication of price. At this stage there is a lack of detailed information about such things as thermodynamic properties of the refrigerant (i.e. co-efficient of performance, capacity, glide, pressure and temperature operating envelopes, etc.) and refrigerant classifications defined by technical standards and regulations (i.e. flammability and toxicity of substances) or vapour compression applications intended for each blend.

*Section 3.5* provides a summary of a recent evaluation prepared by the Technology and Economic Assessment Panel (UNEP 2013c, p40 to 46) on emerging HFO blends that are near to commercialisation.

*Table 3: Refrigerants under examination by AHRI Low GWP Alternative Refrigerants Evaluation Program.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Temporary designation | Supplier | Mass composition | | AR4 GWP-100 |
| Substances | Mass (%) |
| R-1234yf | Honeywell, Arkema, Daikin | R-1234yf | (100) | 4 |
| R-1234ze | Honeywell | R-1234ze | (100) | 6 |
| AC5 | Mexichem | R-32/R-152a/R-1234ze | (12/5/83) | 92 |
| ARM-42a | Arkema | R-134a/R-152a/R-1234yf | (7/11/82) | 117 |
| ARM-30a | Arkema | R-32/R-1234yf | (29/71) | 199 |
| LTR6A | Mexichem | R-32/R-744/R-1234ze | (30/7/63) | 206 |
| D2Y-65 | Daikin | R-32/R-1234yf | (35/65) | 239 |
| DR-7 | DuPont | R-32/R-1234yf | (36/64) | 246 |
| D2Y-60 | Daikin | R-32/R-1234yf | (40/60) | 272 |
| L-40 | Honeywell | R-32/R-152a/R-1234yf/R-1234ze | (40/10/20/30) | 285 |
| L-20 | Honeywell | R-32/R-152a/R-1234ze | (45/20/35) | 331 |
| HPR1D | Mexichem | R-32/R-744/R-1234ze | (60/6/34) | 414 |
| ARM-70a | Arkema | R-32/R-134a/R-1234yf | (50/10/40) | 482 |
| DR-5 | DuPont | R-32/R-1234yf | (72.5/27.5) | 490 |
| ARM-31a | Arkema | R-32/R-134a/R-1234yf | (28/21/51) | 491 |
| L-41a | Honeywell | R-32/R-1234yf/R-1234ze | (73/15/12) | 494 |
| L-41b | Honeywell | R-32/R-1234ze | (73/27) | 494 |
| N-13a | Honeywell | R-134a/R-1234yf/R-1234ze | (42/18/40) | 604 |
| N-13b | Honeywell | R-134a/R-1234ze | (42/58) | 604 |
| AC5X | Mexichem | R-32/R-134a/R-1234ze | (7/40/53) | 622 |
| XP-10 | DuPont | R-134a/R-1234yf | (44/56) | 631 |
| R-32/R-152a | National Refrigerants | R-32/R-152a | (95/5) | 647 |
| R-32 | Daikin, National Refrigerants | R-32 | (100) | 675 |
| R-32/R-134a | National Refrigerants | R-32/R-134a | (95/5) | 713 |
| D4Y | Daikin | R-134a/R-1234yf | (60/40) | 860 |
| ARM-41a | Arkema | R-32/R-134a/R-1234yf | (6/63/31) | 943 |
| N-20 | Honeywell | R-32/R-125/R-134a/R-1234yf/R-1234ze | (12.5/12.5/31.5/13.5/30) | 975 |
| D52Y | Daikin | R-32/R-125/R-1234yf | (15/25/60) | 979 |

*Table 3 (cont.): Refrigerants under examination by AHRI Low GWP AREP.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Temporary designation | Supplier | Mass composition | | AR4 GWP-100 |
| Substances | Mass (%) |
| R-32/R-134a | National Refrigerants | R-32/R-134a | (50/50) | 1053 |
| LTR4X | Mexichem | R-32/R-125/R-134a/R-1234ze | (28/25/16/31) | 1295 |
| N-40b | Honeywell | R-32/R-125/R-134a/R-1234yf | (25/25/20/30) | 1331 |
| N-40a | Honeywell | R-32/R-125/R-134a/R-1234yf/R-1234ze | (25/25/21/9/20) | 1346 |
| DR-33 | DuPont | R-32/R-125/R-134a/R-1234yf | (24/25/26/25) | 1410 |
| ARM-32a | Arkema | R-32/R-125/R-134a/R-1234yf | (25/30/25/20) | 1577 |
| Note: The exact blend compositions are still under development and evolving, and therefore GWPs and characteristics cited in various technical publications may be slightly different. | | | | |

## Summary of emerging HFO blends on the near horizon

|  |  |  |  |
| --- | --- | --- | --- |
| Developmental blends and intended application | Energy efficiency, efficacy | Extent of commercialisation and cost indication | Barriers and restrictions |
| L-40 (GWP of 285)  Replace HFC-404A  Low and medium temp non-domestic refrigeration | When used in the current HFC-404A systems, L-40 apparently exceeds the capacity of HFC-404A with an efficiency improvement of around 10%. | Equipment components are already produced on a commercial scale. It is anticipated that this refrigerant will be available during the next 1 to 2 years.(1)  Production of ingredient HFO-1234yf may be an initial barrier to be overcome (priority to mobile air conditioning).  The direct cost of this refrigerant is likely to be higher than HFC-404A.(2)  It probably works with existing POE lubricants. | The main barriers are related to the safe use of the mildly flammable refrigerants (class 2L under *ISO 817*). Current standards such as *ISO 5149* are being updated to accommodate this new class. In practical terms this means that systems located indoors with large charge sizes are often restricted. Similarly, due to uncertainties over future adoption there are currently gaps in availability of certain types of components including compressors. In addition, technicians must be well trained and competent in handling flammable refrigerants if the flammability is to be dealt with safely. Some building safety codes may ban use of flammable refrigerants in certain types of buildings. The moderate temperature glide of this refrigerant may be an issue for certain applications. There are also concerns regarding the decomposition products of some of the components in the event of a release into the environment. |
| L-20 (GWP of 331)  Replace HCFC-22  Stationary AC | When used in the current HCFC-22 technologies, L-20 matches the capacity of HCFC-22 with an efficiency ranging from 95% to 97%. Further improvements can produce better efficiencies, especially for cooling only operation in warm climates. | As above, except contains HFO-1234ze(E) which has a moderate cost and greater availability than HFO-1234yf.  The direct cost of this refrigerant is similar to current HFCs such as HFC-407C. It works well with existing POE lubricants. Due to its good efficiency at high ambient temperatures, power consumption would be lower relative to other options. | As above. |
| (1) The timing of the release in the Australian market is expected to be within 1 to 3 years depending on global priorities of chemical suppliers.  (2) This cost comment relates to a general base cost scenario without a carbon levy. | | | |

(Source: UNEP 2013c, p40 to 46)

**Summary of emerging HFO blends on the near horizon (continued)**

|  |  |  |  |
| --- | --- | --- | --- |
| Developmental blends and intended application | Energy efficiency, efficacy | Extent of commercialisation and cost indication | Barriers and restrictions |
| L-41 (GWP of 460)  Replace HFC-410  Stationary AC | The efficiency of L-41 systems is at the same level of R-410A. The capacity is approximately 6% to 10% lower than HFC-410A still this capacity is easily recovered in new systems. Discharge temperatures are slightly higher than HFC-410A, still below the limit of existing compressors technologies. Due to its relative higher critical point compared to other refrigerants, L-41 performs well at high ambient temperatures (warm climates). | Equipment components are already produced on a commercial scale. It is anticipated that this refrigerant will be available during the next 1 to 2 years. (1)  Contains HFO-1234ze(E) which has a moderate cost and greater availability than HFO-1234yf.  The direct cost of this refrigerant is similar to HFC-410A.(2) It works well with existing POE lubricants. Power consumption increases its effectiveness at high ambient temperatures relative to HFC-410A. | As above. |
| DR-5 (GWP of 490)  Replace HFC-410  Stationary AC | The efficiency of DR-5 is at the same level of HFC-410A. The capacity is approximately 6% to 10% lower than HFC-410A still this capacity is easily recovered in new systems. Discharge temperatures are slightly higher than HFC-410A, still below the limit of existing compressors technologies. Due to its relative higher critical point compared to other refrigerants, DR-5 performs well at high ambient temperatures (warm climates). | Equipment components are already produced on a commercial scale. It is anticipated that this refrigerant will be available during the next 1 to 2 years. (1)  The direct cost of this refrigerant would be slightly high as it contains HFO-1234yf which has an expensive manufacturing cost. (2)  It works well with existing POE lubricants. Due to its good efficiency at high ambient temperatures, power consumption would be lower relative to HFC-410A. | As above. |
| (1) The timing of the release in the Australian market is expected to be within 1 to 3 years depending on global priorities of chemical suppliers.  (2) This cost comment relates to a general base cost scenario without a carbon levy. | | | |

(Source: UNEP 2013c, p40 to 46)

**Summary of emerging HFO blends on the near horizon (continued)**

|  |  |  |  |
| --- | --- | --- | --- |
| Developmental blends and intended application | Energy efficiency, efficacy | Extent of commercialisation and cost indication | Barriers and restrictions |
| N-13 (GWP of 590)  Replace HFC-134a  Medium temp non-domestic refrigeration and stationary AC where HFC-134a is currently used. | When used in reciprocating or scroll compressors, this refrigerant produces efficiency levels comparable to HFC-134a.  When used in scroll and reciprocating compressors, the same POE lubricant oil can be used. | These chemicals are already produced at a commercial scale. It is anticipated that this refrigerant will be available during the next 1 to 2 years. (1)  Being a blend of HFO-1234ze(E) and existing ones (HFC-134a), its cost is moderate and not significantly different from existing blends available in the market.(2) | This refrigerant would be classified by ISO 817 as A1 (low toxicity, non-flammability).  Being non-flammable and having a moderate cost, this refrigerant is on a fast track for adoption. |
| XP-10 (GWP of 630)  As above. | As above.  Due to its high critical temperature, it will perform very well in warm climates. | Equipment components are already produced on a commercial scale. It is anticipated that this refrigerant will be available during the next 1 to 2 years. (1)  Being a blend of a high manufacturing cost molecule (HFO-1234yf) and HFC-134a, its cost is expected to be high. (2) | This refrigerant would be classified by ISO 817 as A1 (low toxicity, non-flammability).  Its high cost would be the main barrier for widespread adoption by the market. There are also concerns regarding the decomposition products of some of the components in the event of a release into the environment. |
| (1) The timing of the release in the Australian market is expected to be within 1 to 3 years depending on global priorities of chemical suppliers.  (2) This cost comment relates to a general base cost scenario without a carbon levy. | | | |

(Source: UNEP 2013c, p40 to 46)

**Summary of emerging HFO blends on the near horizon (continued)**

|  |  |  |  |
| --- | --- | --- | --- |
| Developmental blends and intended application | Energy efficiency, efficacy | Extent of commercialisation and cost indication | Barriers and restrictions |
| N-40 (GWP of 1390)  Replace HFC-404A  Medium and temp non-domestic refrigeration. | This refrigerant has a capacity marginally higher than HFC-404A and a greater efficiency. The same POE lubricant oil can be used as with HFC-404A. | The component chemicals are already produced at a commercial scale. It is anticipated that this refrigerant will be available during the next 1-2 years.(1)  Being a blend which includes HFO-1234yf and HFO-1234ze, its cost is likely to be higher than conventional HFC mixtures.(2) | This refrigerant would be classified by ISO 817 as A1 (low toxicity, non-flammability).  Being non-flammable and having a moderate cost, this refrigerant is on a fast track for adoption.  No significant barriers are anticipated with this refrigerant for safety. The moderate temperature glide of this refrigerant may be an issue for certain applications that may influence the design of equipment. |
| DR-33 (GWP of 1410)  As above. | As above. | As above, except being a blend which includes HFO-1234yf, its cost is likely to be higher than conventional HFC mixtures. | As above. |
| (1) The timing of the release in the Australian market is expected to be within 1 to 3 years depending on global priorities of chemical suppliers.  (2) This cost comment relates to a general base cost scenario without a carbon levy. | | | |

(Source: UNEP 2013c, p40 to 46)

## Transition map to nil or lower GWP options for main equipment classes and technologies

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Domestic refrigeration** | | | | | | |
| HFC-134a | 1430 |  | HC-600a | 3 | Yes | Technology path for new equipment - opportunity to transition immediately (most probable alternative) |
| HC-600a | 3 |  | HFO blends | ~600 | No | Potential technology path for existing bank and new equipment in 1 to 3 years |
|  |  |  | HFO-1234yf | 4 | Yes | Technology path for new equipment in 2 to 5 years |
| **Non-domestic refrigeration (self-contained)** | | | | | | |
| HFC-134a | 1430 |  | HC-600a | 3 | Yes | Technology path for new equipment - opportunity to transition immediately |
| HC-600a | 3 |  | CO2 (R744) | 1 | Yes | Technology path for new equipment - technical and commercial barriers |
|  |  |  | HFO-Blend | ~600 | No | Technology path for existing bank and new equipment in 1 to 3 years |
| CO2 (R744) | 1 |  | HFO-1234yf | 4 | Yes | Technology path for new equipment in 2 to 5 years |
| **Non-domestic refrigeration with remote condensers** | | | | | | |
| HFC-134a | 1430 |  | CO2 (R744) | 1 | Yes | Technology path for new equipment - technical and commercial barriers |
| (Medium temp) |  |  | Ammonia (R717) | 0 | Yes | Technology path for new equipment - commercial barriers |
|  |  |  | Hydrocarbons | 3 | Yes | Safety, engineering, training and regulatory issues to overcome |
| HFC-404A  (Low and med temp) | 3922 |  | HFO blends | ~600 | No | Technology path for existing bank and new equipment in 3 to 5 years  (Class 1, HFC-134a replacement) |
| Hydrocarbons | 3 |  | HFO blends | ~1400 | No | Technology path for existing bank and new equipment in less than 3 years  (Class 1, HFC-404A replacement) |
|  |  |  | HFO-1234yf | 4 | Yes | Technology path for existing bank and new equipment in 2 to 5 years |
| **Non-domestic refrigeration: supermarket and centralised rack systems** | | | | | | |
| HFC-134a  (Medium temp) | 1430 |  | Cascade systems HFO/CO2 | <10 | Yes | Technology path for new equipment 2 to 5 years – possible charge limit restrictions on class A2L refrigerants |
| HFC-404A  (Low and med temp) | 3922 |  | CO2 only systems  (Trans-critical) | 1 | Yes | Technology path for new equipment - technical (limited to low ambient regions) and commercial barriers. High ambient trans critical systems currently under development |
| Cascade systems | See |  | HFO blends | ~600 | No | Technology path for existing bank and new equipment in less than 3 years  (Class 1, HFC-134a replacement) († Reduced charge and GWP) |
| HFC/Ammonia/CO2 | note † |  | HFO blends | ~1400 | No | Technology path for existing bank and new equipment in less than 3 years  (Class 1, HFC-404A replacement) |
| CO2 only system  (Low temp) | 1 |  | HFO-1234yf  (Medium temp) | 4 | Yes | Technology path for new equipment in 2 to 5 years – possible charge limit restrictions on class A2L mildly flammable refrigerants |
| HFC-407F and other retrofit replacements are possible interim options as they have a GWP around half of HFC-404A | | | | | | |

**Transition map to nil or lower GWP options for main equipment classes and technologies (continued)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Non-domestic refrigeration: cold storage and process refrigeration** | | | | | | |
| CO2 only systems | 1 |  | Ammonia (R717) | 0 | Yes | Technology path for new equipment – opportunity to transition immediately |
| HFC-134a | 1430 |  | CO2 only systems | 1 | Yes | Technology path for new equipment - technical and commercial barriers |
| (Medium temp) |  |  | Cascade systems HFO/CO2 | See note † | Yes | Technology path for new equipment – opportunity to transition immediately († Reduced charge and GWP) |
| HFC-404A  (Low temp) | 3922 |  | Hydrocarbons | 3 | Yes | Technology path for new equipment - charge limit restrictions on A3 flammable refrigerants |
|  |  |  | HFO blends | ~600 | No | Potential technology path for existing bank and new equipment in less than 3 years (Class 1, HFC-134a replacement) |
|  |  |  | HFO blends | ~1400 | No | Potential technology path for existing bank and new equipment in less than 3 years (Class 1, HFC-404A replacement) |
|  |  |  | HFO-1234yf  (Medium temp) | 4 | Yes | Technology path for new equipment in 2 to 5 years – possible charge limit restrictions on class A2L mildly flammable refrigerants |
| **Non-domestic refrigeration: chillers** | | | | | | |
| HFC-134a | 1430 |  | Ammonia (R717) | 0 | Yes | Technology path for new equipment (safety and training issues) opportunity to transition immediately |
| HFC-410A | 2088 |  | Hydrocarbons | 3 | Yes | Technology path for new equipment - charge limit restrictions on A3 flammable refrigerants |
| HFC-407C | 1774 |  | HFO blends | ~600 | No | Potential technology path for existing bank and new equipment in less than 3 years (Class 1, HFC-134a replacement) |
| HFC-404A | 3922 |  | HFO blends | ~1400 | No | Potential technology path for existing bank and new equipment in less than 3 years (Class 1, HFC-404A replacement) |
| Ammonia (R717) | 0 |  | HFO-1234yf  (Medium temp) | 4 | Yes | Technology path for new equipment in 2 to 5 years – possible charge limit restrictions on class A2L mildly flammable refrigerants |
| Absorption chillers | 0 |  | Absorption chillers | 0 | Yes | Technology path for new equipment – particularly in tri-generation systems |
| **Non-domestic refrigeration: road transport** | | | | | | |
| HFC-134a  (Off-engine) | 1430 |  | Limited immediate commercially viable technology path for existing equipment/sub-sector | | | |
| HFC-404A  (All types) | 3922 |  | CO2 (Open loop system) | 1 | Yes | Technology path for new equipment - technical, commercial and economies of scale barriers |
| Hydrocarbon (Off-engine aftermarket) | 3 |  | CO2 (closed loop system) | 1 | Yes | Technology path for new equipment in <5 years - under development |
| CO2 (Open loop systems) | 1 |  | HFO blends | <300 | Yes | Technology path for new equipment in 2 to 5 years - class A2L mildly flammable refrigerants design considerations |
| Advanced HFC system design is considered the next step, hermetically sealed, smaller refrigerant charge and economised engine | | | | | | |

**Transition map to nil or lower GWP options for main equipment classes and technologies (continued)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Small AC: Stationary air conditioning: self-contained with charge < 1.5 kg** | | | | | | |
| HFC-410A | 2088 |  | HC-290 | 3 | Yes | Technology path for new equipment - opportunity to transition immediately - training in handling flammable refrigerants required |
| HFC-407C | 1774 |  | HFC-32 | 675 | Yes | Technology path for new equipment - training in handling mildly flammable refrigerants required |
| HFC-32  HC-290 | 675  3 |  | HFO blends | >300 | Yes | As above, except in 1 to 3 years. Efficiency performance, mild flammability, and other characteristics are under examination versus GWP |
| **Medium AC: Stationary air conditioning: self contained with charge >1.5 kg** | | | | | | |
| HFC-410A | 2088 |  | HFC-32 | 675 | Yes | Technology path for new equipment, training in handling mildly flammable refrigerants required and application restrictions based on charges size |
| HFC-407C | 1774 |  | HFO blends | >300 | Yes | As above, except in 1 to 3 years. Efficiency performance, mild flammability, and other characteristics are under examination versus GWP |
|  |  |  | HFO blends | >1000 | No | Potential technology path for existing bank and new equipment (commercialisation timeline unknown) |
| **Medium AC: Stationary air conditioning: split systems** | | | | | | |
| HFC-410A | 2088 |  | HFC-32 | 675 | Yes | Technology path for new equipment, training in handling mildly flammable refrigerants required and application restrictions based on charges size |
| HFC-407C | 1774 |  | HFO blends | >300 | Yes | As above, except in 1 to 3 years. Efficiency performance, mild flammability, and other characteristics are under examination versus GWP and risk |
| HFC-32  HC-290 | 675  3 |  | HC-290 | 3 | Yes | Technology path for new equipment, training in handling highly flammable refrigerants required and application restrictions based on charges size (typically <1 kg) |
|  |  |  | HFO blends | >1000 | No | Potential technology path for existing bank and new equipment (commercialisation timeline unknown) |
|  |  |  | Solar absorption chiller | 0 | Yes | Technology path for new equipment - technical and commercial barriers (application limitations) |
|  |  |  | CO2 (R744) | 1 | Yes | Technology in this application is in its infancy - not currently considered a viable technology path |
| Not-in kind technology such as evaporative coolers (proven technology path for select applications/low humidity geographical regions) and indirect evaporative cooling (rapidly evolving technology that can be used in conjunction with refrigerative cooling) can displace AC capacity. | | | | | | |

**Transition map to nil or lower GWP options for main equipment classes and technologies (continued)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Large AC: Stationary air conditioning: chillers** | | | | | | |
| HFC-134a  HFC-410A | 1430  2088 |  | HFO-1234 | 6 | Yes | Technology path for new equipment in 1 to 3 years. Training in handling mildly flammable refrigerants required and increased costs arising from safety compliance, and additional ventilation and leak detection in plant rooms |
| HFC-407C | 1774 |  | HFO-1233zd | >7 | Yes | Technology path for new equipment in 1 to 3 years. Being non-flammable and having a moderate cost, this refrigerant is on a fast track for adoption |
| HCFC-123 | 77 |  | HFO blends | ~600 | No | Potential technology path for existing bank and new equipment in less than 3 years (Class 1, HFC-134a replacement) |
| Ammonia (R717)  Absorption chillers | 0  0 |  | HFO blends | >300 | Yes | Technology path for new equipment based on HFC-410A designs. Training in handling mildly flammable refrigerants required and application restrictions based on charges size. Efficiency performance, mild flammability, and other characteristics are under examination versus GWP and risk |
|  |  |  | HFC-32 | 675 | Yes | Technology path for new equipment based on HFC-410A designs. Training in handling mildly flammable refrigerants required and application restrictions based on charges size. Risk assessment currently being undertaken |
|  |  |  | Hydrocarbon | 3 | Yes | Technology path for new equipment, training in handling highly flammable refrigerants required and limited applications (charge size restrictions, isolated charge requirements, refer technical standards) |
|  |  |  | Ammonia (R717) | 0 | Yes | Technology path for new equipment (safety and training issues) opportunity to transition immediately in niche applications |
|  |  |  | Absorption chillers | 0 | Yes | Technology path for new equipment – particularly in tri-generation systems |
| **Hot water heat pumps: domestic** | | | | | | |
| HFC-134a | 1430 |  | CO2 | 1 | Yes | EcoCute technology widely available in Europe and Japan - commercial barriers |
| Hydrocarbons | 3 |  | Hydrocarbons | 3 | Yes | Technology path for new equipment – domestic and hybrid hot water and air conditioning system already available in Australia |
| CO2 (R744) | 1 |  | HFO blends | ~600 | No | Potential technology path for existing bank and new equipment in less than 3 years (Class 1, HFC-134a replacement) |
|  |  |  | HFO-1234yf | 4 | Yes | Technology path for new equipment in 1 to 3 years |
|  | | | | | | |

**Transition map to nil or lower GWP options for main equipment classes and technologies (continued)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Mobile air conditioning: passenger and light commercial vehicles, commuter buses and trucks** | | | | | | |
| HFC-134a | 1430 |  | HFO-1234yf | 4 | Yes | Technology path for new equipment bank in 1 to 3 years |
| Hydrocarbon | 3 |  | HFO blends | ~600 | No | Technology path for existing bank of equipment in less than 3 years (Class 1, HFC-134a replacement) |
| (Aftermarket) |  |  | R744 (CO2) | 1 | Yes | Technology path for new equipment - supported by some major vehicle manufacturers |
|  |  |  | HFC-152a | 140 | Yes | Technology path for new equipment - not supported by major vehicle manufacturers |
|  |  |  | Hydrocarbons | 3 | - | Possible technology path (flammability issues) - not supported by major vehicle manufacturers |
| **Mobile air conditioning: buses (> 7 meters in length) and trains** | | | | | | |
| HFC-134a | 1430 |  | HFO-1234yf | <10 | Yes | Technology path for new equipment in 1 to 3 years (performance under examination) |
| HFC-407C | 1774 |  | HFO blends | <150 | Yes | Technology path for existing bank equipment in less than 3 years (replacement for equipment based on HFC-134a design) |
|  |  |  | HFO blends | - | Yes | Possible technology path for new equipment in less than 3 years (replacement for equipment based on HFC-407C design) |
|  |  |  | R744 (CO2) | 1 | Yes | Technology path for new equipment – in buses use in EU (high ambient limitations), limited publically disclosed information available on trains |
|  |  |  | HFO blends | ~600 | No | Potential technology path for existing bank of equipment in less than 3 years (Class 1, HFC-134a replacement) |
|  |  |  | HFC-152a | 140 | Yes | Technology path for new equipment - no plans |
|  |  |  | Hydrocarbons | 3 | - | Flammability, technology (leak containment) and liability issues |
|  | | | | | | |

**Transition map to nil or lower GWP options for main equipment classes and technologies (continued)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Foams** | | | | | | |
| HFC-365mfc/  HFC-227ea blend | 1109 |  | HFO-1234ze(E)  HFO-1233zd | <10 | See footnote[[3]](#footnote-3) | Technology path in 1 to 3 years - low capital cost, product cost uncertain  HFO-1233zd is non-flammable |
| HFC-245fa | 1030 |  | Hydrocarbons | ~3 | Yes | Current technology path - high capital costs due to flammability, requires economies of scale |
| Hydrocarbons  (Mostly n-Pentane) | 3 |  | HFO blends | <1000 | - | Technology path in 1 to 3 years - low capital cost, product cost uncertain |
| CO2 and water | 1 |  | CO2 and water | 1 | Yes | Current technology path - technical limitations with some foam applications |
| **Fire protection** | | | | | | |
| FM 200 | 3220 |  | Fluoroketone and a range of inert gases: | | | Immediate technology path for the vast majority of applications where |
| (HFC-227ea) |  |  | Novec 1230 | 1 | Yes | HFCs are currently used |
| FE 25 (HFC-125) | 3500 |  | IG-01 (argon) | 1 | Yes | Main barrier is commercial |
| FE 36 (HFC-236fa) | 9810 |  | IG-100 (nitrogen) | 1 | Yes |  |
| Fluoroketone and a | 1 |  | IG-55 | 1 | Yes |  |
| range of inert gases |  |  | IG-541 | 1 | Yes |  |
| Note: IG-541 is a blend of nitrogen/argon/CO2, and IG-55 comprises nitrogen/argon. | | | | | | |
| **Aerosols** | | | | | | |
| HFC-134a | 1430 |  | HFO-1234ze | <6 | Yes | Currently being sold into applications to replace HFC-134a. May not be suitable for all applications. If HFO-1234ze were found to be a suitable substitute in medicinal applications (inhalers, sports medicine, etc.), it would take many years before it was thoroughly tested and approved for use. |
| HFC-152a | 124 |  | HFC-152a | 124 | Yes | Not suited to mildly flammable applications, and commercial barriers |
| Hydrocarbon | 3 |  | Hydrocarbon | 3 | Yes | Not suited to use in hazardous areas (incl. paint marking applications for underground mining, blast bags for setting explosives, etc.) |
| Hydrocarbon propellants are already used in the majority of non-flammable applications | | | | | | |
|  | | | | | | |

**Transition map to nil or lower GWP options for main equipment classes and technologies (continued)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Current options | GWP  (AR4) |  | Lower GWP options | GWP | Equipment replacement | Comments |
| **Solvents[[4]](#footnote-4)** | | | | | | |
| HFC-43-10mee | 1,300 |  | HFE-449/569 | <300 | - | Commercial barriers and limited solvency capability relative to HCFCs |
| HFE-449sl (HFE-7100) | 297 |  | HFE-347pcf2 | 580 | - | New HFEs such as HFE-347pcf2 have lower GWPs than current HFCs with suitable solvency – commercial barriers due to economies of scale |
| HFE-569sf2 (HFE-7200) | 59 |  | HFO-1233zd | <7 | - | Claimed to be a highly effective cleaning solution that is non-flammable, with favourable toxicity properties. Suitable for electronics, metal, medical and precision cleaning. It can be used in vapour degreasing equipment, cold cleaning and may be dispensed from an aerosol can.[[5]](#footnote-5) |
| No single option is well suited to replace all HCFC and HFC applications, consequently there is a wide range of alternatives including aqueous or semi- aqueous cleaning agents (limitations in application that cannot tolerate water); hydrocarbons including alcohol (flammability limitations in hazardous uses); and chlorinated and brominated carbon (toxicity and possible carcinogen concerns) | | | | | | |
|  | | | | | | |

# Refrigerant bank and consumption

## Dissection by major sector

In 2013 Australia employed a bank[[6]](#footnote-6) of synthetic refrigerant gas, HCFCs and CFCs in all applications of approximately 46,500 tonnes.

Import data and market intelligence indicates around 3,990 tonnes of bulk gas, both HFCs and HCFCs, was consumed in 2013, of which it is estimated that around 70% was required to maintain the existing bank of equipment, equivalent to about 6% of the installed bank of gas.

The bank of working gases is largely comprised of commonly used synthetic refrigerants with GWP values that range from 1300/1430 for HFC-134a to 3260/3922 for HFC-404A, and a relatively small quantity of refrigerants with GWP <10, such as hydrocarbons, CO2 and ammonia.

Excluding only gases with a GWP <10, in aggregate the GWP of the bank is calculated to be equivalent to approximately 88,200 kilo tonnes of CO2-eAR4 and the 2013 consumption of bulk imports was equivalent to 8,800 kilo tonnes of CO2-eAR4.

The refrigerated cold food chain accounts for around 11% of the total refrigerant bank, with domestic refrigerators and freezers containing a further 5%. Thus all refrigeration equipment, essential in the maintenance of food supplies and food quality, employs around 16% of the total bank.

By far the larger proportion of the working bank is to provide air conditioning for human comfort in homes, workplaces and motor vehicles. Both the bank and the bulk imports are dominated by use in stationary air conditioning systems which accounted for 63% of the bank and consumed approximately 39% of the annual bulk imports. Stationary air conditioning applications continues to be the fastest growing bulk gas consuming segment and also dominate imports of pre-charged equipment.[[7]](#footnote-7)

More than a million new air conditioning units have been installed each year in Australia, a level of demand which is fed by the expectations of householders, the workforce and consumers for air conditioning services to be ubiquitous in urban and city buildings.

The second largest portion of the bank is mobile air conditioning comprising approximately 20% of the total in 2013. This gas is predominantly contained in a rolling stock of more than 15 million registered vehicles containing HFC-134a. An estimated 31% of bulk imports were consumed in mobile air conditioning applications with local manufacturing of mobile air conditioning systems estimated to consume 135 tonnes of gas, a level of demand which has declined by around 80 to 100 tonnes per annum since the closure of the Mitsubishi factory in Adelaide in 2008. The larger use of gas in this sector (~80 %) was consumed servicing air-conditioning systems in existing vehicles, which have an estimated leak rate of 10% per annum, plus in replacement of gas lost from vehicles that had some form of collision or compressor failure.

Around 6% of bulk imports are consumed in applications that do not form part of the working bank such as foam blowing, fire protection and aerosols. Additionally it is estimated around 110 tonnes of gas is exported, mostly in shipping vessels and pre-charged equipment (i.e. 55 tonnes in 90,939 motor vehicles in 2013). Each major application sector is discussed in detail in other sections of the report including an outline of the equipment types, characteristics of equipment employed, a dissection of annual consumption and the bank of working gas in each sub-sector and in some of the main equipment types. *Figures 9* and *10* illustrate the dissection of service consumption and the refrigerant bank for 2013 by major application based on tonnes, and *Table 4* provides summary data.

|  |
| --- |
| **2013 service consumption by major sector (% by tonnes)** |
|  |
| *Figure 9: 2013 service consumption by major sector based on bottom-up analysis of equipment, % share by tonnes.* |
| **2013 bank by major sector (% by tonnes)** |
|  |
| *Figure 10: 2013 bank by major sector based on bottom-up analysis of equipment, % share by tonnes.* |

*Table 4: Estimates of 2013 gas consumption and refrigerant bank by major sector in tonnes.*

|  |  |  |
| --- | --- | --- |
| Sector/applications | 2013 total consumption  (tonnes) | 2013 bank  (tonnes) |
| Domestic refrigeration | 25 | 2,270 |
| Refrigerated Cold Food Chain | 1,000 | 5,070 |
| Stationary air conditioning | 1,535 (incl. 200 re-use) | 28,680 |
| Mobile air conditioning | 1,250 | 9,515 |
| Foams | 200 | - |
| Fire protection | 50 | - |
| Aerosols | 40 | - |
| Export and other | ~90 | - |
| Total | 4,190 | 45,535 |

## Dissection by common gas types

The bank of working gas is dominated by three main gas types: HFC-134a (~14,600 tonnes or 32%), HCFC-22 (~9,600 tonnes or 21%) and HFC-410A (~16,700 tonnes or 37%).

HFC-134a is the predominant gas used in mobile air conditioning and self-contained refrigeration. An estimated 1,700 tonnes of bulk gas was consumed in 2013 with around 64% consumed servicing existing mobile air conditioning systems plus replacing gas lost from vehicles that had some form of collision or compressor failure. HFC-134a has become more widely used in other applications in recent years including medium temperature non-domestic refrigeration, and in liquid chilling for air conditioning and process refrigeration applications.

The Montreal Protocol sets out a mandatory timetable for the phase out of ozone depleting substances (ODS) and earlier analysis (ES 2008) indicates that Australia has, using Customs declarations and industry import quotas, managed the phase out of bulk imports of HCFCs in accordance with its agreed timetable (OPSGGMA 1989). From a peak of importing more than 3,800 tonnes in 1999, in 2006 there were approximately 2,100 tonnes of bulk HCFCs imported. This has since declined by nearly half to less than 1,200 tonnes in 2010, around 766 tonnes in 2013, and is on target to reach the agreed cap, equivalent to just 45.5 tonnes of HCFC-22 in 2016.

However HCFCs, with a GWPAR4 of around 1810, still make up a significant portion of the bank of working gas in stationary air conditioning equipment which can routinely achieve an effective working life of more than 15 years.

It is expected that this dominance of the working bank will begin to decrease quite quickly as newer equipment charged with alternative gases replaces older air conditioning equipment. With an estimated stock of some 10 million smaller air conditioning units (<20 kWr[[8]](#footnote-8)) in the economy, and annual imports of more than one million units, most equipment containing HCFCs is expected to be replaced within the next five to ten years.

The proportion of HCFCs in the working bank of gas is already significantly below its share of the bank in 2006, estimated at that time to be 40% including some CFCs. In the course of the last decade, new gas blends were introduced for use in applications that previously would have used HCFCs.

HFC-410A (a blend containing 50% HFC-32 and 50% HFC-125 with a GWP of 1725/2088) was first introduced to Australia in commercial quantities in the early to mid-2000s. HFC-410A is currently the fastest growing refrigerant in the bank with more than 1,700 tonnes of gas imported in pre-charged equipment in 2013 (totalling around 64% of all refrigerant imported in equipment that year).

Bulk gas consumption of HFC-410A in 2013 is estimated to be around 575 tonnes with around 180 tonnes consumed in local manufacturing, mostly stationary air conditioning equipment (i.e. split ducted systems, roof top packaged systems and chillers).

The main class of equipment containing HFC-410A is split air conditioning systems connected to one indoor evaporator unit. These units have an estimated leak rate of 3 to 4 % per annum, which is a significant improvement on older equipment which, mostly containing HCFC-22, has leak rates typically 8% or more per annum. The improved leak rate is mostly attributed to the dominance of mass produced split air conditioning systems with more reliable components, improved designs delivering better containment, and better installation practices achieved through improved skills, licensing and the increasing experience of the workforce with this equipment.

HFC-407C (a blend containing 23% HFC-32, 25% HFC-125 and 52% HFC-134a with a GWP of 1526/1774) was introduced in Australia around the same time as HFC-410A for similar applications. HFC-407C was viewed by some local and overseas equipment manufacturers as an opportunity for a simple transition from HCFC-22, as it has similar operating pressures that can use the same components with minimal re-design. The existing bank of HFC-407C is estimated to be around 1,250 tonnes with bulk imports in 2013 estimated to be 150 tonnes. Many stationary air conditioning equipment designs have migrated to HFC-410A or HFC-134a for larger chillers.

HFC-404A (a blend containing 44% HFC-125, 4% HFC-134a and 52% HFC-143a with a GWP of 3260/3922) and HFC-507A, a similar blend in terms of composition, characteristics and applications are both referred to as HFC-404A in this report. The first installation using HFC-404A was in a Coles supermarket in 1990 and was commonly used in refrigeration applications by 1995 when CFCs used in new equipment were banned by law. In 2013 the HFC-404A bank comprises around 3,300 tonnes or around 7% of the volume of the working bank, but closer to 15% in GWPAR4 terms because of its high GWP.

The consumption of HFC-404A is very high relative to the size of the bank (7% of the bank and 16% of imports). This occurs firstly because new equipment containing HFC-404A is mostly charged on site. HFC-404A pre-charged equipment represented only 1% of pre-charged imports on average over the last five years, and secondly its common applications exhibit considerably higher leak rates than most other applications. Notably supermarket refrigeration systems, walk in cool rooms, beer cooling systems, and mobile refrigeration systems with typical leak rates ranging from 10 % to 25 % or historically as high as 35% in some marine refrigeration applications.

*Figures 11* and *12* illustrate the dissection of HFC consumption and the refrigerant bank for 2013 by common gas types based on tonnes.

|  |
| --- |
| **2013 consumption by type (tonnes and %)** |
|  |
| *Figure 11: 2013 consumption by substance based on bottom-up analysis of applications in tonnes and %.* |
| **2013 bank by type (% by tonnes)** |
|  |
| *Figure 12: 2013 bank by refrigerant type based on bottom-up analysis of equipment, % share by tonnes.* |

# HFC Bulk imports

One of the two sources of growth in the bank is via the import of bulk refrigerant gases. Yet a surprising proportion of bulk imports do not add to the working bank, but are instead consumed replacing gas lost through leaks and during equipment service.

On average around 4,500 tonnes of both HCFCs and HFCs bulk gas were imported per annum from 2006 to 2011, of which it is estimated that around 70% (~3,150 tonnes) was consumed to maintain the existing stock of equipment. In other words more than two thirds of annual bulk imports are being used to replace gas that is lost to air from working equipment every year.

The rest of the annual bulk imports (around 30%) is used to charge new equipment manufactured in Australia, to charge equipment imported without a charge of working gas (i.e. pre-charged with nitrogen), or consumed in other applications such as foam blowing, fire protection and aerosols. A small proportion, (~30 to 50 tonnes) is re-exported for servicing shipping vessels and supplying wholesalers located in the Pacific Islands.

While it appears that the working bank of gas has stabilised in recent years, the announcements in mid-2011 of the introduction of the ECP resulted in a significant increase in bulk imports in early 2012, and strong growth in stocks held by businesses throughout the supply chain.

The Department of the Environment data indicates that total imports of all species of refrigerant gas in 2012 were equivalent to more than two and a half years of average supply of HFCs, or a total of more than 12,511 tonnes of bulk gas.

This was at a time when general activity in the sector was slower than previous years due to cool summers in 2010 and 2011, sluggish economic activity which led to reduced building and construction activity, and a slow-down in spending and investment during the 2011-12 financial year.

This stockpiling has greatly affected the volume and mix of HFC bulk imports in 2013. The total import of HFCs in 2013 was 315 tonnes with a significant portion (>50%) of imports being those that do not attract the ECP as they are not included in the Kyoto Protocol.

*Figure 13* illustrates the actual mix of HFC species imported in bulk (this chart does not include imports of HCFCs).

*Figure 14* provides a six-year trend of imports of HFCs in kilo tonnes of CO2-e. The bulk import reporting format changed mid way through 2011, and kt CO2-e calculated in this chart was based on AR2 GWP values. Bulk imports for 2012 and 2013 were not included as they are distorted due to the ECP.

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| **2013 HFC bulk imports by species** |
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| *Figure 13: Actual 2013 HFC bulk gas imports by type, % by tonnes.* |

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| **Trend of HFC bulk imports in kt CO2-e** |
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| *Figure 14: Six year trend of HFC bulk imports as reported in major SGG categories in kt CO2-e.* |
| Note: 2011 estimated based on 6 months data as bulk import reporting format changed mid way through 2011, and kt CO2-e calculated based on AR2 GWP values. |

(Source: DE 2014)

# Domestic refrigeration

**The bank and annual consumption**

Domestic refrigeration in Australia is estimated to contain approximately 2,200 tonnes of high GWP HFCs, approximately 5% of all high GWP HFCs in the stock of RAC equipment in Australia. Domestic refrigeration is estimated to consume less than 0.6% (~25 tonnes) of annual bulk imports of synthetic refrigerant consumption.

The main refrigerants used in domestic refrigeration are HFC-134a (GWP of 1300/1430), and hydrocarbon HC-600a (Isobutene, GWP of 3). The large majority of the existing stock of appliances contains HFC-134a (>90%). Some very old products manufactured prior to the early 1990s contain CFC-12.

In Australia about 8% of domestic refrigerators are estimated to contain HC-600a compared to around 2% globally.

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| **2013 bank and consumption (tonnes)** |
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| *Figure 15: Domestic refrigeration refrigerant bank and HFC consumption in 2013 in tonnes.* |

**The stock of equipment, annual sales, industry trends**

In 2013 there were an estimated 17.1 million domestic refrigerators and freezers in Australia, a figure that is growing at an estimated 2.7% per annum. New sales including portable refrigerators are estimated at around 1.4 million units in 2013, outstripping annual retirements of old and broken down equipment in that year by around 475,000 units. The average life of domestic refrigerators-freezers ranges from 9 to 20 years and the stock is modelled based on an average of 15 years for refrigerators and 17 years for freezers with a standard deviation of 2 years.

A typical product contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system with refrigerant charges ranging from less than 50 grams to more than 250 grams. Typical storage volumes can range from 20 litre portable refrigerators to large 850 litre units with ice and beverage dispensing features. The average size of the domestic fridge-freezer is increasing, however machines with beverage dispensing capability only represent a relatively small fraction of existing stock.

Portable systems and passenger vehicle refrigerators include 240VAC/12VDC chest style fridge-freezers through to freestanding upright products suitable for caravans, camper trailers, motor homes, boats, buses, four wheel drives, etc. More than 100,000 portable and passenger vehicle refrigerators are imported each year; major suppliers include Dometic Group (Waeco brand) and Engle Australia. Evercool, Norcoast and OzeFridge manufacture small quantities of portable 12V refrigerators in Australia. There is in the order of 550,000 of portable devices in the economy.

Consumption of bulk HFC-134a from the only remaining Australian refrigerator manufacturer, Electrolux Appliances based in Orange NSW, has declined from 50 to 60 tonnes per annum five years ago to virtual zero as the conversion to HC-600a of all major product lines was finalised in 2013.

Electrolux has recently (January 2014) announced its intention to close down its manufacturing in 2016. As a result, given the fact that it is unlikely any new refrigeration manufacturer is likely to establish operations in Australia before that time, or in the foreseeable future, Australia is likely to be entirely dependent on imports of all domestic refrigeration systems from that time onwards.

**Lower and no GWP alternatives and barriers to transition**

There are presently no significant barriers to transition to low GWP working gases in this technology segment.

Widespread global adoption of HC-600a is the most likely outcome predicted at this time, as evidenced by the existence of more than 500 million domestic refrigerators containing HC-600a in the global market to date (UNEP 2013c, p57).

More than 50% of current new global production of domestic refrigeration systems employs HC-600a, the remainder uses HFC-134a. Worldwide over 50 million appliances each year are being produced with HC-600a (UNEP 2013c, p58).

HC-600a continues to be effectively the only commercial alternative to HFC-134a. Concerns with the high flammability of HC-600a no longer exist for appliances with very low charges, and no new alternative has matured to become energy-efficient and cost-competitive.

The transition in domestic refrigeration technology from HFC-134a to HC-600a began in Europe and Japan in the early 2000’s. As a result the technology using HC-600a is quite mature (UNEP 2011d). This transition commenced in earnest in Australia in the course of the last three to four years, and initially with premium models and chest freezers.

There are many obvious benefits in migrating from HFC-134a to HC-600a in domestic refrigeration equipment including:

* Improvements in the energy efficiency of appliances charged with HC-600a in the order of 7% (an attribute that could assist in the long term programs to improve household energy efficiency in Australia);[[9]](#footnote-9)
* Reduced refrigerant charge required for effective operation of the appliances (i.e. based on an equal molar basis, 100 grams of HFC-134a is required to do the equivalent work that just 57 grams of HC-600a can do);
* Reduction in the noise level of the appliance; and,
* Eliminating the need for end of life recovery of residual charge (or loss to air) of the HFCs.

According to a 2011 study for a review of the European Regulation on fluorinated greenhouse gases (EC 2011a), the investment cost for domestic refrigeration HC-600a equipment is 1.7% higher than for HFC-134a, which in real terms represents less than $20 additional cost to an Australian imported product. This increased cost is basically due to the larger size of compressors and higher production cost related to the requirements for safety systems. However annual running costs and lifetime cost of HC-600a equipment are lower, resulting in overall negative cost differential in the case of HC-600a (UNEP 2013c, p57, 9). With increasing economies of scale the additional production cost is likely to diminish.

It is feasible to use HFO-1234yf in domestic refrigerators and freezers as it has demonstrated the potential for comparable efficiency to HFC-134a. Initial developments to assess HFC-134a replacement with HFO-1234yf have begun, but are not being pursued as a high priority. CO2 (R744) is also being evaluated, but its application implies additional costs (UNEP 2013c, p1), and there is little environmental, commercial or technical reason for perusing this option.

**Scope for Australian industry to transition**

A quite rapid transition of domestic refrigeration equipment sold in Australia to HC-600a charged systems is already underway.

A small survey of 66 fridge-freezers on display of a large retail outlet was undertaken in 2010. At that time 51 products (76%) were found that contained HFC-134a (Fisher & Paykel, Samsung, LG, Kelvinator and Westinghouse). 15 products (23%) contained HC-600a (Electrolux, Westinghouse, Hisense and some larger LG models).

This survey was repeated again in 2013 when 76 products were inspected at which time only 35 products (46%) were charged with HFC-134a and 41 products (54%) were charged with HC-600a.

A January 2014 survey of 95 products has demonstrated how quickly the trend is progressing with only 28 products (30%) being charged with HFC-134a and the balance (67 products, 70%) being charged with HC-600a.

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 16: Domestic refrigeration - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
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| *Figure 17: Domestic refrigeration - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

The transition model predicts that by 2025 all domestic refrigerators will be charged with gases with a GWP <10. It is likely that the last new refrigerators charged with HFC-134a will be imported and sold by 2021 by which time there will be more than 20.6 million devices in total, with 48% of them carrying a charge of HFC-134a.

While the entire stock of appliances will take some 15 to 20 years to reach end of life the total demand from this stock for bulk imports is expected to only be in the vicinity of 16 tonnes per annum at the time the last devices are sold, and declining steadily from that point, as domestic refrigerators have a very limited service requirement.

The effect of this now apparently inevitable migration of the entire stock of domestic refrigeration would be to remove at least that amount (16 tonnes) from annual bulk import demand between now and 2025. Although any concerted HFC-134a recovery program of any part of the HFC-134a contained in end of life domestic appliances every year could conceivably reduce demand even further if the gas recovered is able to be recycled back into the market. The transition model predicts that more than 10 million domestic refrigerators charged with a total of more than 1,500 tonnes of HFC-134a, will reach end of life between 2013 and 2025.

**Assumptions of modelling and level of confidence**

* Sales growth rate of domestic refrigerators and freezers post 2010 through to 2025 is 1.5% per annum.
* Last OEM is scheduled to close operations in 2016.
* The average charge remains constant at 150 grams, which relates to the amount of high GWP refrigerant that will be displaced, not the actual charge of HC-600a which can be up to 50% less.
* The average leak rate remains constant at 1% per annum from 2013 to 2025.
* The transition will be complete by 2021, and possibly earlier, depending on the rate of the global transition or import restriction measures imposed by Australia.

*Table 5: Predicted transition scenario for domestic refrigeration sector.*

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| --- | --- | --- |
|  | Predicted proportion of refrigerant contained in new products by volume | |
| 2020 | 2025 |
| HFC-134a | 5% | 0% |
| GWP <10 | 95% | 100% |
| Predicted scenario has a high level of confidence, and a low level of complexity. | | |

**Potential actions to support a smooth transition**

Given the lead being taken by the global manufacturing industry in this segment it may be considered to be unnecessary to take any further action. However it is likely that the trend could be accelerated with some simple communication strategies. At present it would appear that there are no marketing efforts by any brands promoting the use of hydrocarbon charges in product to distinguish appliances from HFC-134a product. However it has long been known that consumers use energy ratings as part of the purchasing decision making process and as such it can be assumed that the improved efficiency of hydrocarbon charged product will be directly influencing sales volumes.

The Queensland Government, Department of Mines and Energy maintains a register of approved hydrocarbon refrigerant appliances, which lists an extensive number of domestic refrigerators and freezers, including models from Blessington, Bosch, Siemens, Changhong Electric, Electrolux, GAF, Hafele, Haier, Miele, Mitsubishi Electric, Panasonic, Samsung, Sharp, SMEG, Think Appliances, Unileaver, Vintech, Vintec and Whirlpool (QGDME 2014).

A low cost strategy for the Federal Government would be to liaise with the Queensland Government to ensure that the website is regularly updated and comprehensive, as well as considering some broader communication strategy for use of hydrocarbon appliances, for instance highlighting the general improvement in energy efficiency that hydrocarbon refrigerants can deliver. Once consumers are aware of the environmental benefits and are enquiring about these products when doing price comparisons, major retailers will soon pick up on the trend and start to promote the lower GWP gases, associated with improved energy efficiency, for a period at least.

A further step, if the Government was committed to accelerating this well established trend, would be to introduce a ban on imports of HFC-134a pre-charged domestic refrigeration equipment or a GWP limit of <150 GWP for this class of equipment. A number of established regulatory models and system could be used to bring such a ban about.

Given the generally small charge of refrigerant gas likely to be found in each appliance (as little as 50 grams in some cases and up to around 250 grams) and the very large number of appliances in operation, moving this broad class of domestic technology to such a low GWP working gas would eventually eliminate the present issue of end of life gas collection and simplify the process of other materials recovery and metals recycling from domestic refrigeration. The cost of abatement for appliances with small refrigerant charges is very high (>$100 per kg) so there is merit in reducing this legacy.

However such a move should not detract from efforts to capture and destroy or re-use the significant bank of high GWP HFCs that is already employed in domestic refrigeration systems, estimated to be approximately 2,200 tonnes of HFC-134a equivalent to more than 2.9/3.2 (AR2/AR4) Mt of CO2-e.

# Refrigerated cold food chain

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| **2013 bank and consumption (tonnes)** |
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| *Figure 18: Refrigerated cold food chain refrigerant bank and consumption in 2013 in tonnes.* |

**Introduction**

This diverse sector, including tens of thousands of major individual pieces of equipment, comprises what is often referred to as the cold food chain, the backbone of the fresh and processed foods distribution network.

Non-domestic refrigeration devices have to store and display food and beverages at different levels of temperature for chilled and frozen food. The refrigerating capacities of equipment vary from hundreds of Watts up (fractional horsepower rated units) to 1.5 MW.

There are three main categories of equipment found in the refrigerated cold food chain:

* Stand-alone equipment often referred to as ‘self-contained’ equipment;
* Remote condensing units; and,
* Supermarket systems sometimes referred to as centralised systems as they are found in plant rooms.

This sector also includes mobile refrigeration systems that provide the temperature controlled transport links between producers, suppliers, wholesalers and retailers. A further important sub-sector is the specialised area of industrial refrigeration commonly found in large cold storage and distribution centres, and food manufacturing processes.

Refrigerant choices with non-domestic refrigeration are often determined by the two main levels of temperatures necessary for the conservation of fresh food and beverages (referred to in industry as medium temperature where produce is refrigerated to temperatures above zero degrees Celsius), and frozen food (low temperature, refrigerated to zero degrees and below).

**The bank and annual consumption**

The refrigerated cold food chain is estimated to contain a bank of some 5,070 tonnes of refrigerants, of which around 3,300 tonnes is high HFC-404A with a GWPAR4 of 3922, or about 11% of all high GWP HFCs employed in Australia.

Notably, running third behind both mobile and stationary AC in terms of the total bank employed, this sector consumes approximately 1,000 tonnes per annum, or around 25% of all annual consumption, second only to mobile ACs.

Consumption of bulk HFCs, as compared to the split of the bank, across the three main categories of non-domestic refrigeration varies considerably as a result of the differing characteristics of the technology.

The numerous stand-alone systems with small refrigerant charges, that are typically hermetically sealed, contain a bank of approximately 900 tonnes (around 2% of the total bank), and have an annual leak rate of between 3% and 6%, requiring just under around 87 tonnes of bulk imported HFCs to replace lost gas in 2013 and small OEMs.

On the other hand refrigeration systems with remote condensing units, which are generally hard working systems, with often long exposed refrigeration lines operating in areas such as loading bays, distribution centres and the packing areas of farms, with a bank of about 3,040 tonnes of high GWP HFCs (around 7% of the bank), have an annual leak rate of about 15%, requiring more than 456 tonnes of bulk imported HFCs in 2013 (more than 11% of total consumption of bulk imported high GWP HFCs in 2013). A further 204 tonnes of bulk high GWP HFCs were imported to charge new equipment with remote condensing units.

The equally hard working but often better maintained supermarket systems are estimated to contain some 1,130 tonnes of high GWP HFCs (around 3% of the bank) and, with a leak rate of around 12%, required some 141 tonnes of bulk imported HFCs to replace losses (or approximately 4.4% of annual consumption). A further 112 tonnes of bulk high GWP HFCs was imported for charging new equipment in the supermarket sector.

**The stock of equipment, annual sales, industry trends**

Small RCFC:Self-contained equipment (charge <1.5kg)

Demand from stand-alone commercial refrigeration is estimated to result in the import of approximately 83 tonnes of high GWP HFCs or approximately 2.5% of total bulk imports in 2013.

Stand alone commercial refrigeration equipment typically contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system with relatively small refrigerant charges ranging from 40 grams in a bottle water cooler to up to 1.5 kg in a refrigerated display case.

Stand alone refrigeration is used in a diverse range of equipment and applications. It is estimated that there are approximately 810,000 pieces of stand-alone commercial refrigeration equipment operating in Australia of which more than 730,000 are charged with high GWP HFCs in such applications as:

* Refrigerated display cabinets covering plug-in-type food retail and supermarket cabinets; sandwich-pizza preparation and display counters; kitchen and foodservice storage and preparation equipment; glass door merchandisers and upright cabinets; chest cabinets commonly used for ice cream display; ice cream makers; blast chiller freezers; wine, drink and glass chilling cabinets for bars, restaurants and hotels, and various specialised cabinets for food catering and pharmaceutical applications;
* Bottle water coolers and water dispensers for offices, factories, gymnasiums, etc.;
* Refrigerated beverage vending machines often purchased by major food manufacturers such as Coca-Cola, Pepsi and Schweppes, and also independent vending suppliers located at airports, railway stations, offices, factories, warehouses, universities and schools, etc;
* Ice makers commonly used in cafes, hotels/bars and food courts. These are generally packaged freestanding, bench-top or under-bench units, and may have a small storage basket or bin with access door, or dispense ice and beverages automatically;
* Post-mix beverage cooling and dispensing equipment that transforms concentrated syrup, typically supplied in ‘bag-in-box’ casks, mixed with water that is circulated through an ice bank cooler to serve carbonated drinks in all sorts of hospitality venues including pubs, clubs, hotels, large restaurants with bars and entertainment venues;
* Drop-in and slide-in packaged refrigeration units used in small walk-in coolrooms extensively used throughout the food chain to refrigerate fresh, chilled and frozen produce; and,
* Small packaged liquid chillers used in a wide variety of applications in laboratories and industry.

Consumption of bulk import synthetic refrigerant is declining in this technology segment, mostly as more and more equipment is imported as pre-charged equipment containing synthetic refrigerants. The main local manufacturers include Williams Refrigeration, Hoshizaki Lancer, IMI Cornellius, Zip Industries, Aquacooler, Stoddart Manufacturing and others. The 2010 closure of Orford Refrigeration’s commercial refrigeration manufacturing operations in Toowoomba, Queensland and Frigrite Refrigeration in Victoria switched at least 15 mt of HFC-134a from bulk imports per annum to pre-charged imports in the future.

Medium RCFC: Remote condensing units

Remote condensing units employ a bank of approximately around 3,040 tonnes of high GWP HFCs, or about 7% of the bank. Demand for servicing and charging new remote condensing units is estimated to result in the import of approximately 660 tonnes of high GWP HFCs or approximately 16% of total bulk imports in 2013.

Remote condensing units typically range from 1 kWr to 20 kWr in refrigerating capacity, are composed of either one or two compressors, one condenser, and one receiver and are assembled into a ‘condensing unit’, which is typically located outdoors or ‘remote’ from the trading floor or refrigerated space.

Nearly 300,000 refrigeration systems with remote condensing units are used in a variety of applications including on refrigerated display cabinets, walk-in cool rooms, beverage cooling (beer), milk vat refrigeration on dairy farms and chilling and freezing applications in industry with less than 0.5% containing refrigerants with a GWP <10.

These medium sized and very hard working systems, often situated in high traffic areas of food processing, wholesaling and retailing operations, are estimated to have an average leak rates in the vicinity of 15% per annum, making them one of the largest consumers of bulk imports of HFCs. These systems are also an essential element of the cold food chain employed from farm to factory, in retail and hospitality.

The largest stocks of equipment in this diverse class can be found driving refrigeration cabinets, walk-in cool rooms, beverage cooling, and milk vats.

The term walk-in cool room is used to describe an enclosed storage space that is either refrigerated to temperatures above zero degrees Celsius (walk-in-cooler), or is refrigerated to zero degrees and below (walk-in freezer). Some older walk-in-coolers use HCFC-22, however HFC-404A has been the refrigerant of choice for both walk-in-coolers and freezers for more than a decade. Smaller walk-in-coolers typically with self-contained systems are inclined to use HFC-134a.

Walk in cool rooms are estimated to account for around 970 tonnes of the refrigerant bank and with a leak rate ranging between 15% and 20% consume approximately 160 to 180 tonnes of synthetic refrigerant per annum.

Beverage cooling applications generally employ a large gas charge, mostly due to the large refrigerant charge required for beer chilling applications where an average application can have 40 kg of refrigerant. Older systems use HCFC-22, however HFC-404A has been the refrigerant of choice for more than a decade with a small portion of systems operating on HFC-134a. Beverage cooling systems are estimated to have a service demand of 75 tonnes per annum.

Milk vat refrigeration units are used by dairy farmers to chill fresh milk from 34°C to 4°C prior to pick up by bulk tankers. There are two common milk chilling technologies used on dairy farms, ‘direct expansion’ cooling and ‘indirect cooling’ systems which are a specialised chiller. A significant portion (around 50%) of the existing fleet of direct expansion milk vat units uses very old belt drive technology charged with HCFC refrigerants. These systems employ drive shaft seals that exhibit high refrigerant leak rates of 20% or more per annum. Milk vat refrigeration units are estimated to equate to around 270 tonnes and consume approximately 40 to 60 tonnes.

Large RCFC: Supermarkets

In Australia there are nearly 3,500 supermarkets (trading floor >400 m2) which contain around 1,130 tonnes of high GWP HFCs, or about 3% of the bank. Demand for servicing and charging of new supermarket systems is estimated to result in the import of approximately 253 tonnes of high GWP HFCs or approximately 7% of total bulk imports in 2013.

Around 141 tonnes of high GWP bulk imports per annum (approximately 4.4% of total HFC imports in 2013) are required to service existing equipment and replace gas lost to leaks. Another 112 tonnes are imported (around 3% of 2013 imports) for use in new supermarket equipment.

Supermarkets can contain a variety of refrigeration equipment including central plant (rack system), remote condensing units servicing display cases and walk-in coolrooms, and self-contained merchandisers located throughout the store. However the discussion here relates only to the large centralised systems that are commonly used to deliver refrigeration to the large display cases and low temperature glass fronted displays used throughout supermarkets.

A centralised supermarket refrigeration system will typically include 8 to 12 compressors ranging in capacity from 7.5 to 22.5 kWr serving both low and medium temperatures, built onto a rack system located in a separate plant room. Large supermarkets employ centralised equipment requiring refrigerant charges greater than 900 kg, with medium and small supermarkets generally requiring 600 kg and 160 kg of gas on average respectively.

In 2010 the large majority (i.e. 85 to 90 %) of refrigerant in supermarkets was HFC-404A, however the supermarket industry and many other medium temperature refrigeration applications are switching from HFC-404A to HFC-134a, where practical, partly because of the lower GWP of the HFC-134a refrigerant.

The main local manufacturers of refrigeration rack systems include Bitzer and supermarket contractors including McAlpine Hussmann (a subsidiary of Ingersoll Rand), Austral Refrigeration (a division of the Hastie Group) and regional players such as John A Gordon, Contract Refrigeration, A.J. Baker and Alkar. Other relatively recent changes in the industry include the closure of a major supermarket contractor Frigrite Refrigeration in 2009 and the relocation of Heatcraft condensing unit manufacturing operations to China in 2011.

**Lower and no GWP alternatives and barriers to transition**

Small RCFC: Self-contained equipment (charge <1.5kg)

The majority of the existing stock of stand-alone commercial refrigeration contains HFC-134a with a portion operating on HFC-404A, mostly in low temperature applications or when greater refrigerating intensity is required.

The use of hydrocarbons (HC-600a, HC-290 and HC-436) and carbon dioxide refrigerants is emerging slowly in new equipment in Australia, however the installed base is very small, estimated to be 2% at most in some equipment classes, and non-existent in others. Examples of equipment using hydrocarbon refrigerants can be found on the Queensland Government, Department of Mines and Energy register of approved hydrocarbon refrigerant appliances. They include a freezer cabinets commonly used in Aldi supermarkets, wine coolers, chest freezers and commercial refrigerators (QGDME, 2014).

At present the largest installed base of hydrocarbon units are thought to be those owned by Unilever, the owner of brands such as Streets Ice Cream whose branded small systems are provided to thousands of small grocery stores and supermarkets. ALDI supermarkets with over 300 stores nationally have hydrocarbon charged refrigeration display cases operating on low and medium temperatures in most stores.

HFC-134a and HFC-404A are still the dominant refrigerants for self-contained equipment.

There are three possible replacements available now for HFC-134a in these small stand-alone applications, with a fourth potential replacement in development:

1. Class 3 flammable refrigerants such as HC-600a, HC-290 and various hydrocarbon blends;
2. CO2 (R744) in relation to the supply of small self-contained vending machines;
3. Class 2L flammable refrigerants such as HFO-1234yf and HFO-1234ze(E); and
4. Non-flammable options on the horizon such as N-13 and XP-10;

There is one possible replacement for HFC-404A, with two more potential replacements on the near horizon:

1. HFC-407F, which is an intermediate solution with a GWP of 1824/2107, i.e. half the GWP of HFC-404A, or other similar lower GWP blends of saturated HFCs (such as HFC-407A);
2. Non-flammable options among the new low GWP HFC blends such as N-40 and DR-33;
3. Low flammable refrigerant blends such as L-40 or DR-7, which enable a further reduction of the refrigerant GWP.

HC-600a and HC-290 are the two main hydrocarbons used for small commercial equipment. HC-600a is chosen for smaller refrigeration capacities. For bottle coolers both refrigerants can be used. Ice machines and small display cases use HC-290. The energy efficiency of hydrocarbon based systems is generally as good or even better compared to HFCs as commonly used in those applications. The small additional cost associated with additional engineering required to ensure safety is integrated in the price, increasing the price a small amount (<15% compared to HFC equipment).

The *EN 378* *Refrigerating systems and heat pumps: Safety and environmental requirements* the technical standard in Europe allows the use of HCs up to 1.5 kg in public areas if the volume of the room is sufficiently large. Additional momentum in this market has come from some large global food companies that have decided not to use HFCs in their new systems. As a result of these two factors, the adoption of HCs in small commercial equipment with refrigerant charges varying from 150 grams to 1.5 kg in international markets is significant.

CO2 (R744) is mainly used in vending machines, refrigeration display cases, and some bottle coolers. The energy efficiency of the vending machine cassettes is found to be similar to HFC-134a machines, although with an energy penalty at high ambient temperature conditions. The cost is also noticeably higher for CO2 (>15%) versus HFC-134a models. However Coca-Cola, the one global beverage company so far ordering this type of equipment, has made a political and environmental choice, specifying CO2 instead of hydrocarbons for all their vending machines. The high technological level of expertise required to manufacture these systems possibly forms something of a barrier to market entry of this application, however there is no doubt that customer support will continue and increase the availability of this technology.

HFO-1234yf can replace HFC-134a in any application but the availability of HFO-1234yf is limited, and therefore there is no large amount of equipment available charged with HFO-1234yf. The energy efficiency of HFO-1234yf will be in the same range as HFC-134a. There are reciprocating compressors that are already approved for the use of HFO-1234yf. Vending machines using this refrigerant have already been introduced in Japan. To some extent, the additional cost of the chemical would increase the cost of the equipment by a small amount.

It can be expected that, until the price of HFOs fall sufficiently, and become widely available, Australia will see more hydrocarbon and CO2 charged equipment in this small equipment class.

Medium RCRC: Remote condensing units

HFC-134a and HFC-404A are the working gases of choice for remote condensing units. HFC-134a is typically chosen for small capacities and medium temperature applications whereas HFC-404A is chosen for refrigeration intensive applications, larger capacities and all refrigeration temperatures down to -35oC. These HFCs form the energy efficiency references for benchmarking emerging refrigerant alternatives.

Some new CO2 (R744) based condensing units (micro-cascade) are sold in Australia and Northern Europe, but the market penetration is low. CO2 systems require a double-stage (cascade) design if high ambient temperatures occur frequently. Single-stage systems are designed for cold climates which have limited scope in Australia until the technology matures. The additional cost for a cascade system is significant and is the main barrier for these CO2 systems. Further development is possible if there was a wide consensus adopted to not employ HCs in this application. However, even if that were to occur, it is likely that the future market share will be relatively limited.

Several indirect condensing units with HC-290 or HC-1270 are operating in Europe with typical refrigerant charges varying from 1 to 20 kg and delivering good energy efficiency. The indirect system energy penalty is limited if the secondary loop is well designed, with larger heat-exchanger areas. Costs for these hydrocarbon based systems are typically 5 to 15% higher compared to HFC systems (UNEP 2013c, p2).

EcoChill, a NZ based company is promoting indirect systems containing hydrocarbon in the region, and several hydrocarbon suppliers have retrofitted hydrocarbons to HCFC-22 systems in chilling applications in wineries, for instance Engas at Naturaliste Vinters as part of the Australian Government’s Clean Technology Food and Foundries Investment Program.

Other projects recently completed in Australia that demonstrate the potential for larger vapour compression systems using hydrocarbons include:

* Cool rooms and a freezer room at the Elite Food Company in Perth, a location that experiences very high ambient summer temperatures. This installation uses a proprietary hydrocarbon refrigerant, Engas M50, which is a hydrocarbon blend with a secondary loop using Glycol;
* A 110 kWr self-contained weatherproof fluid chiller installed for AC clean rooms at a pharmaceutical manufacturing facility using Engas M60 refrigerant. This is a also a blended hydrocarbon refrigerant that replaces HFC-410A;
* A 650 kWr fluid chiller at a private hospital in Western Australia; and,
* A secondary loop heat pump system designed for heating an Olympic size pool.

Further commercial development of hydrocarbons for condensing units depends, in part, on the outcome of the competition with future low GWP HFCs. Hydrocarbons are seen as one possible long-term solution but in general require better refrigerant management during maintenance. It may be that the perceived safety and actual safety issues of using hydrocarbons in remote condensing units, and the need for changed management in the supply chain, could be sufficient obstacles to uptake that only relatively slow market uptake will be seen in the near term and will eventually be overtaken when suitable HFO blends become more widely available.

A number of possible low GWP HFO blends have been developed and are being tested, however, so far there are no commercially available options in this sub-sector. Most of the activities are at the level of trials by manufacturers and the AHRI Low-GWP Alternative Refrigerants Evaluation Program.

While HFC-407F and to a lesser extent HFC-407A are the intermediate lower GWP alternative options to HFC-404A at present, XP-10, N-40, DR-33, L-40, DR-7 and other blends under development may all be future options.

Large RCFC: Supermarkets

Supermarket systems operate with racks of compressors installed in a machinery room. Two main design options are used, i.e., direct and indirect systems. Direct systems are the most widespread. The refrigerant circulates from the machinery room to the sales area, where it evaporates in display-case heat exchangers, and then returns in the vapour phase to the suction headers of the compressor racks. The supermarket cool rooms and freezers are cooled similarly.

Increasing numbers (>100 systems) of CO2 (R-744) systems are in use in Australia, applied in either cascading systems (several refrigerant options) or in trans-critical systems.

CO2 is an efficient alternative for a condensing temperature below 25°C. Based on this energy efficiency in moderate climate zones, two stage transcritical systems have seen a significant expansion in Northern Europe with more than 1,300 centralised systems of various cooling capacities in 2011 (Shecco 2013).

However the trans-critical cycle is likely to create a significant energy penalty at high ambient temperatures, although developments are on-going to make the CO2 technology more energy-competitive under these conditions. The additional cost of these systems is estimated to be 10 to 15%, however the lower energy efficiency for high ambient temperatures forms a barrier. The high pressure under which CO2 operates also requires a higher brazing quality than used for the usual HFC design.

Nonetheless CO2 is seen as a long-term solution for low temperatures in cascade with a medium-temperature refrigerant. The preferred option is HFC-134a at the medium temperature level (-10 to -15°C) cascading with a CO2 direct system for the low temperature (-35 to -38°C), since this is a global option, applicable in all climates (UNEP 2013c, p61).

HC-290 or HC-1270 is efficient in both medium and low temperature stages of commercial refrigeration equipment. However refrigerant charge limits, directly associated with regulations and standards, is a significant barrier to adoption in commercial refrigeration systems. The competition with CO2 as a low GWP option has limited the expansion of HCs in centralised systems. In summary, HCs in large centralised systems will have a limited market share mainly due to safety issues.

For low GWP HFCs, the situation is similar to what has been previously mentioned; there is no available single low GWP HFC currently proposed for centralised systems. Non-flammable options such as the blends N-40 and DR-33, which can be used for retrofit of existing systems, may improve energy-efficiency by approximately 7% (UNEP 2013c, p61).

Lower flammability refrigerants such as L-40 can be used in indirect systems such as with brine or pumped CO2 where the flammability can be addressed. For HFC-134a, there are additional replacements. Non-flammable options such as N-13 and XP-10 can be used for the retrofit of existing systems. Furthermore, lower flammability refrigerants such as HFO-1234yf and HFO-1234ze(E) could be applied in cascade systems at the medium temperature level.

Ammonia is an efficient refrigerant however, because of the use of steel instead of copper, there are additional costs in the range of 10 to 15% compared to indirect systems using HFCs and CO2. At capacities larger than several hundred kWr, economies of scale generally make ammonia systems more competitive. Ammonia competes with HFCs, hydrocarbons and even with CO2 in cold climates, however, ammonia will remain dependent on the user preference, largely to do with safety and handling issues, and proximity of the general public.

Mobile refrigeration: Road transport

The majority of mobile refrigeration includes road, rail and intermodal containers, commonly referred to as ‘transport refrigeration’; or ‘marine’, which is primarily located on fishing vessels.

The transport refrigeration bank is estimated to comprise less than 0.4% (~170 tonnes) of the refrigerant bank and consumes approximately 0.7% (~30 mt) of annual synthetic refrigerant consumption, mostly in service and replenishment following system failures.

Transport refrigeration technology is made up of:

* The transport refrigeration units used on articulated trucks and trailers or intermodal (road or rail) containers described as the trailer/intermodal segment;
* The diesel drive segment largely comprising rigid trucks with a gross vehicle mass of 3 to 8 tonnes; and,
* Off-engine vehicle powered refrigeration units used on small trucks and vans.

Transport refrigeration units are extremely complex systems, powered by dedicated diesel internal combustion engines designed to refrigerate fresh and frozen perishable products. These systems have to operate over a wide range of ambient conditions and insulation specifications.

The large majority of equipment in service has shaft seals and vibra-sorber hoses (i.e. stainless steel braided flexible hoses). Over the equipment’s lifespan it is typical to see at least one compressor replacement, shaft seal failure and a vibra-sorber failure. The shaft seal and hose would most likely result in the total loss of refrigerant charge. Compressor replacement would typically involve reclaim and re-use.

The trailer/intermodal and diesel drive units are imported fully charged, tested and ready to be fitted. Off-engine units are imported with a nitrogen holding charge to keep the system pressurised and clean as they have to be ‘plumbed’ up with piping and a compressor by the installer. Refrigeration systems for trucks, trailers and intermodal are predominantly charged with HFC-404A with a typical charge of between 6 and 10 kg. Some smaller systems can use HFC-134a with charges below 4 kg.

The existing stock is prone to high leak rates estimated at around 20% per annum, however much attention in recent designs has been focused on the elimination of as many joints as possible. As a result fully sealed systems without shaft seals or flexible hoses are now available.

The use of hydrocarbons (mainly HC-290) in transport refrigeration units has been tested. This would be the preferred choice because it can provide lower energy consumption in the order of 20% or more. HFO-1234yf could also be an effective alternative to HFC-134a in transport refrigeration systems due to its lower discharge temperature (UNEP 2013c, p2).

Refrigerated shipping containers, commonly known as ‘Reefers’, have been excluded from this report as the associated refrigerant consumption in manufacturing generally occurs overseas and data on service levels is not presently available.

Some shipping companies, such as Wiltrading provide support services for ships entering Australian ports. An uncertain quantity of refrigerant is consumed in the service of reefers while on shore. While it is thought to be a relatively small quantity in aggregate, there is simply no reliable data to make an informed judgement at this time.[[10]](#footnote-10)

The refrigerant of choice for transport refrigeration systems is HFC-404A which has become a preferred choice for practically all trailers and large trucks. HFC-134a is used in small trucks and vans as well as reefer containers. Testing of low-GWP HFC and non-HFC alternatives are in progress, but not one option seems viable in the short term.

The main issue is that the performance of HFC-404A is difficult to meet. Current and previous tests with trucks using CO2 suggest that introduction of CO2 will be possible when more efficient compressors with more than one compression stage, are commercially available. These dual stage compressors are under development.

Marine refrigeration

Marine refrigeration is estimated to comprise less than 1% (~40 tonnes) of the refrigerant bank yet high annual consumption of 10 tonnes as a result of the extremely high leak rates that exist in fishing vessels of between 25 and 30 % per annum.

Marine refrigeration as defined in this report is for fishing vessels that contain specialised chilling and blast freezing equipment on vessels typically over 20 metres in length, however some refrigeration can be found on vessels of between 10 and 20 metres long.

On vessels, hydrocarbons are technically feasible, but the strict safety concerns currently do not favour application of flammable refrigerants aboard. Natural refrigerants have been commercialised to a small extent aboard marine vessels worldwide. For large European fishing vessels highly efficient ammonia-CO2 cascade systems are the systems of choice (UNEP 2013c, p2). Australian vessels however are generally much smaller and operate in higher ambient temperatures.

A recent study by Expert Group (EG 2013a) for one of Australia’s largest fisheries identified that there were no easy, off-the-shelf, low GWP technology options available for the fleet to move to today that are suitable from both a technical (mission critical) or safety point of view for use on the small fishing vessels that are typical for Australian fisheries.

Industrial refrigeration

More than 90% of the large industrial refrigeration installations in Australia use ammonia (R717). The energy efficiency of ammonia in these large installations is in general 15% better than HFCs systems. As this application segment has already transitioned to low GWP refrigerants it was not modelled in the high GWP bank.

Hydrocarbons are not widely used, other than in situations where safety measures are already required, for example in a petrochemical plant or in compact chillers (UNEP 2013c, p3). This is similar in Australia.

It is considered likely that all large industrial systems in Australia will be ammonia charged where safety concerns can be addressed and ammonia-CO2 cascade refrigeration systems are an option where the charge is significantly reduced to mitigate the risk.

**Scope for Australian industry to transition**

Small self-contained equipment is likely to migrate entirely to low GWP refrigerants as the existing stock of equipment reaches end of life and is replaced with new equipment. Their relatively small contribution to demand for bulk high GWP HFC imports is likely to decrease steadily throughout the period of the projection. The transition model projects import demand from this sub-sector falling from approximately 87 tonnes in 2013 to around 42 tonnes in 2025. New equipment is projected to be charged with hydrocarbons and CO2 (R744), both growing steadily off a low base at present, with larger numbers of equipment charged with HFOs entering the market after around 2016 and growing strongly.

Remote condensing units are a very high consumer of high GWP HFC bulk imports. The transition model projects growth in overall numbers of remote condensing units from around 300,000 in 2013 to more than 375,000 units in 2025, while demand for import of high GWP HFCs in bulk in this sub-sector falls from an estimated 660 tonnes in 2013 to 386 tonnes in 2025.

During this period the large stock of remote condensing units charged with HFC-404A is expected to decline steadily from more than 190,000 units in 2013 to about 140,000 units in 2025. At the same time units charged with HFC-134a are expected to increase from around 48,000 units now to nearly 90,000 units in 2025. CO2 and hydrocarbon charged systems will grow steadily from their present low base. HFO charged units, projected to first become available after 2016, are expected to grow strongly. By 2025 the transition model projects that around 20% of the stock of remote condensing units will be charged with a refrigerant gas with a GWP <10.

Given the relatively high levels of consumption of bulk imports in this sector, relative to the size of the bank, a focus on prevention, early detection and repair of leaks can make a real contribution to reducing demand from this sector. In general it is important for the RAC industry to maintain a focus on both leak reduction, refrigerant recovery and re-use, and viable options to migrate any of the applications and products in this diverse and challenging sector to low GWP refrigerants.

While overall numbers of supermarkets are expected to increase from around 3,400 units now to as many as 4,300 in 2025, demand for bulk imports of high GWP HFCs from supermarkets are predicted to fall strongly from around 253 tonnes in 2013 to just 61 tonnes in 2025. During the period HFC-404A units are predicted to fall strongly from 2,400 units in 2013 to just 700 units in 2025. However HFC-134a units are expected to increase from around 5600 units now to a peak of 1,120 in 2022 before beginning to decline. At the same time systems employing CO2 are projected to rise to more than 1,100 in 2025. Hydrocarbon charged systems are also projected to increase steadily off a low base to more, while HFO charged systems are predicted to first become available after 2016 and are expected to grow strongly. Overall, while the mix of final technology employed may diverge from the projections due to other influences in the period, the transition model projects that around 44% of supermarkets will employ refrigerant with a GWP <10 in these large systems by 2025.

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 19: Small RCFC - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
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| *Figure 20: Small RCFC - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 21: Medium RCFC - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
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| *Figure 22: Medium RCFC - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 23: Large RCFC - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
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| *Figure 24: Large RCFC - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

**Assumptions of modelling and level of confidence**

* New remote condensing units and supermarket systems will continue to be charged from refrigerant bulk imports.
* Growth rate of sales of equipment in the refrigerated cold food chain post 2013 through to 2025 is 2% per annum.
* HFC-404A and HFC-134a will be phased out of use in new equipment (except where equipment designs struggle to overcome high glides found in emerging blends) and replaced with refrigerants with lower GWP refrigerants by 2025.
* Linear growth trend for all substitutes to 2025. With HFC-404A making up the balance.
* The aggregate leak rates of small RCFC devices was 6% with remote condensing units 15%, and supermarket leak rates improving from 12.5% to 9.8% per annum in 2025.
* The average charge of refrigeration equipment remains constant for each equipment class. Whereas in practice charges are expected to decline in the order of 25% or more between 2013 and 2025 depending on the equipment class.

Efforts to project the rate and success of commercialisation of alternative technologies that are currently ‘under development’ will always carry greater uncertainties than those for which commercial supply is already established. These uncertainties can be both in terms of available quantities and timing or market release. The eventual price of a product under development is always a considerable source of uncertainty which will always be impacted by a range of issues such as the scale of investment in initial production, the rate of adoption, and the development of supply lines against incumbent competition and technologies, all of which go towards changing the dynamics of the supply/demand relationship.

*Table 6: Predicted transition scenario for refrigerated cold food chain sector.*

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| --- | --- | --- |
|  | Predicted proportion of refrigerant contained in new products by volume | |
| 2020 | 2025 |
| **Small RCFC: Self-contained equipment** | | |
| HFC-404A | 27% | 5% |
| HFC-134a | 25% | 0% |
| GWP <2150 | 10% | 10% |
| GWP <1000 | 10% | 20% |
| GWP <10 | 28% | 65% |
| Predicted scenario has a medium level of confidence, and low level of complexity. | | |
| **Medium RCFC: Remote condensing units** | | |
| HFC-404A | 33% | 5% |
| HFC-134a | 25% | 5% |
| GWP <2150 | 10% | 25% |
| GWP <1000 | 10% | 20% |
| GWP <10 | 22% | 45% |
| Predicted scenario has a low level of confidence, and high level of complexity. | | |
| **Large RCFC: Supermarket** | | |
| HFC-404A | 10% | 0% |
| HFC-134a | 25% | 0% |
| GWP <2150 | 10% | 15% |
| GWP <1000 | 10% | 20% |
| GWP <10 | 45% | 65% |
| Predicted scenario has a medium to high level of confidence, and high level of complexity. | | |

# Stationary air conditioning

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| **2013 bank and consumption (tonnes)** |
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| *Figure 25: Stationary air conditioning refrigerant bank and consumption in 2013 in tonnes.* |

**The bank and annual consumption**

Stationary AC equipment in Australia contains the largest portion of the total bank of refrigerant gases (>28,700 metric tonnes) operating in an estimated 12 million stationary AC devices. With over 1,500 tonnes of refrigerant required for service, charging new equipment and use by OEMs each year.

Around 8,900 tonnes or 31% of the working gases found in stationary AC equipment are HCFCs. From the early 1990’s until the early years of the century nearly all stationary AC was either imported pre-charged with HCFC-22 or was manufactured in Australia and then charged with it. As the restrictions on HCFCs under the Montreal Protocol took effect, the new generation of HFCs began to replace HCFCs. By 2006 only about 30% of refrigerant imported in pre-charged equipment was HCFC-22. More recently, the combined effects of technological advances, minimum energy performance regulations, and the ban on HCFC pre-charged ACs in 2010 reduced the proportion of HCFC refrigerant imported in equipment to around 3% in 2010.

Today, the very large majority of AC equipment installed contains HFC-410A with small amounts of HFC-407C. HFC-134a and to a lesser extent HCFC-123 are the most common refrigerant used in various capacities of centrifugal and screw chillers. HFC-134a is also used by all local manufacturers of hot water heat pumps in Australia, although the total volume of HFCs consumed in locally manufactured heat pumps is estimated to be around 22 tonnes per annum, a very small contributor to total annual consumption.

The bank of HFC-410A is estimated at 16,700 tonnes, 58% of the AC bank and 37% of the total bank, followed by 1,950 tonnes of HFC-134a and over a 1,000 tonnes of HFC-407C.

**The stock of equipment, annual sales, industry trends**

Stationary AC as a broad class of equipment includes all forms of stationary AC equipment that use the vapour compression cycle to provide human comfort, mainly in homes and commercial properties, and to provide close temperature control in data processing areas.

The equipment types in this sector can be reverse-cycle (heating and cooling) or cooling only, single phase or three phase and range in size from a small 2 kWr domestic portable AC, with a refrigerant charge of less than 600 grams, to large 4,000 kWr commercial chillers containing more than a tonne of refrigerant.

The main product formats include:

1. Portable AC for domestic use;
2. Packaged room AC units intended to be inserted through a hole in a wall or through a window aperture of a home, shop or worksite demountable, now predominately a replacement market and generally referred to as ‘window/wall’ units;
3. Hot water and swimming pool heat pumps for domestic and commercial applications;
4. Portable space coolers for spot cooling in commercial and industrial applications, or to provide temporary relief where normal AC systems are inadequate or have broken down;
5. Non ducted split systems covering a broad class of equipment including single or multiple indoor units in a variety of styles such as wall hung, cassette, console and under ceiling, all designed for different applications;
6. Ducted split systems used in domestic and light commercial applications where the indoor unit is connected to rigid or flexible duct which is ducted around the building to supply air to the conditioned space;
7. Variable refrigerant volume split systems with multiple indoor units, which is emerging as the preferred technology option for medium sized commercial buildings;
8. Close control or precision AC systems employed in applications where air quality requirements are specified such as in computer rooms, data processing centres, telecommunication facilities, medical technology, clean rooms for production of electronic components and pharmaceuticals, and other industrial process areas;
9. Roof top packaged AC systems that use high static pressure fans which allow long duct runs, (these systems are mostly sold now only as replacements for existing units roof top packaged systems already installed in commercial buildings with suspended tile ceilings); and,
10. Chillers for space cooling in large commercial buildings.

For the purposes of this study, partly because of the limitations and characteristics of the technology, and the opportunities that presents for alternative working gases, the stationary AC sector is being dealt with in three broad categories;

* Small self-contained AC – broadly covering products listed in (i) to (iv) above, except swimming pool heat pumps are covered in Medium AC;
* Medium AC, Split Systems and Light Commercial – including products listed in (v) to (ix) above; and,
* Large AC, primarily chillers.

Australia is largely a ‘technology taker’ of AC equipment, driven by innovation and product development from overseas manufacturers and suppliers. The vast majority of new equipment in any year (90% by refrigerant volume) is imported.

Trends and developments in the international market are therefore reflected in changes in the Australia stock of equipment and bank of working gases.

In this sector the changes brought by the Montreal Protocol, combined with rapid development of the smaller and domestic AC products in the last two decades means that Australia still has a considerable legacy of HCFC charged equipment, and a large stock of relatively new HFC charged equipment. The main HFCs employed are HFC-410A, HFC-407C and HFC-134a.

* AC units charged with HFC-410A has been the fastest growing segment with more than 1,700 tonnes of HFC-410A gas imported in pre-charged equipment in 2013 (totalling around 64% of all refrigerant imported in equipment that year).
* Bulk consumption of HFC-410A are estimated to be 575 tonnes in 2013, which suggest the leak rates of HFC-410A split AC equipment are around 3% per annum, compared to 8% annum or more on similar but older equipment;
* HFC-407C pre-charged equipment imports are in decline and totalled 39 tonnes in 2013 (only 1.5% of all refrigerant imported in equipment that year), with a slight increase in bulk consumption to 150 tonnes to service existing stock and new installations;
* Local AC unit manufacturers (Powerpax, Actron Air, Accent Air, Temperzone, GWA-Brivis, Air-Change, Comm Air and Specialised Engineering, and a few others) collectively consume over 300 tonnes of refrigerant per annum, mostly HFC-410A, HFC-134a with some HFC-407C;
* Local hot water heat pump manufacturers (Rheem, DUX and Quantum, and a few others) manufactured around 20,000 to 25,000 units in 2013 (requiring around 20 tonne of HFC-134a). Hot water heat pump annual sales peaked at over 66,000 units per annum and have recently declined due to changes to Renewable Energy Certificate Scheme (RECS) allowances, product reliability issues and customer perception issues (i.e. not delivering hot enough water in low temperature climates). This decline in sales also contributed to Saxon Industries in Queensland going into voluntary liquidation in 2010.

**Lower and no GWP alternatives and barriers to transition**

Small AC

There is a large stock of small AC equipment in the economy, estimated to contain close to 1,700 tonnes of high GWP refrigerant gases, although more than 1,100 tonnes of that is HCFCs.

Total demand for bulk imported gas to service the stock of equipment is an estimated 55 tonnes in 2013.

Opportunities for a transition to lower GWP working gases in the small AC appliances are limited to equipment replacement. Viable and commercially available low GWP options in new equipment are available now.

Nonetheless imports of small AC appliances pre-charged with high GWP HFCs are continuing and will increase service demand somewhat in the next 5 years.

The majority of all equipment classified as small AC are Window/Wall units, many charged with HCFCs. Of the approximately 2.4 million window/wall and portable AC units estimated to be in operation, more than 1.5 million are charged with HCFCs representing a bank of some 1,100 tonnes of HCFC. With a leak rate of around 3% this bank required around 33 tonnes of HCFCs in 2013 to service equipment.

This stock of HCFC charged equipment is not being replenished and as such is declining rapidly. It is estimated that by 2025 it will be virtually non-existent.

Approximately 680,000 units charged with HFC-410A contain some 490 tonnes of this high GWP HFC. On present projections this number will double, growing to a peak of about 1.3 million units by 2020, requiring about 28 tonnes of bulk imports of HFC-410A in that year (up from around 14 tonnes per annum now) to service the equipment.

After 2020 the HFC-410A stock of small AC equipment is expected to decline, gradually at first, but more rapidly by 2025 as older equipment reaches end of life. In 2025 the transition model predicts that this equipment will still create demand for some 18 tonnes of bulk imports for service.

A smaller population of HFC-407C charged small AC, of around 130,000 appliances containing an estimated 95 tonnes of this high GWP HFC was estimated to have required about 3 tonnes of bulk imports for service needs in 2013. This stock of equipment is expected to decline reasonably rapidly until it is essentially gone from the economy by 2025.

The total stock of small AC equipment from 2014 to 2025 is expected to decrease overall from around 2.4 million units now to around 1.44 million units as window/wall units reach end of life and are replaced by modern and more efficient wall hung split systems.

Generally speaking, like refrigerators, when appliances from this class of small AC are disposed of it is because they have stopped working, many of them because of either compressor failure or loss of refrigerant charge. This fact, combined with the very small charges in small AC at any rate, makes end-of-life recovery of HFCs from small AC economically challenging. As a result many will contain very little residual charge, so the existing stock of equipment that is charged with HFCs is not likely to provide much material for recovery that might reduce demand for bulk imports for some other equipment type.

New small AC equipment charged with low GWP refrigerants is readily available. HC-290 seems to be preferred over HC-1270 for smaller capacity systems (UNEP 2013c, p3). As an example, in Australia DeLonghi has been importing portable AC units in commercial volumes containing HC-290 for three to four years. Several other companies are producing small portable systems charged with HCs that are sold into other markets.

HC-290 charged window units are under development and available in some overseas markets, and are expected to emerge as a technically and commercially feasible option in Australia.

Small AC units charged with less than 1 kg of HCs are expected to grow steadily from their present low base to reach more than 190,000 units in 2025, equal to 13% (by equivalent refrigerant volume) of the total stock of equipment in this class.

HFC-32 models are in advanced stages of development and are expected to be available in Australia in 2015. Small AC appliances charged with HFC-32 are expected to grow strongly from 2015 reaching a total stock greater than 420,000 units by 2025.

HFO blends affordable enough to be suitable for small AC are expected to be commercially available after 2020 and are predicted to grow slowly as a late entrant into this relatively small market.

Ammonia (R717) has so far not been used in these systems due to limitations on its use in occupied spaces related to safety and toxicity concerns, and commercial barriers (cannot construct with copper or copper alloys).

CO2 (R744) is not widely considered for use in small AC. The main barriers are related to efficiency and the cost implications of its very high operating pressure. However, there is development work underway on units for specific purposes, where both cooling and heating is needed (UNEP 2013c, p3).

**Medium AC**: Split systems including wall hung, ducted and VRF, and roof top packaged systems

By far the largest group numerically, containing the largest aggregate bank of working gas, and requiring a significant volume of all annual HFC bulk imports to service it, the medium AC class of equipment has a number of demonstrated and rapidly emerging options to shift away from high GWP working gases, at least for new equipment. HFC-32 particularly is likely to rapidly grow a substantial share of this class of equipment as the predominant high GWP HFCs are phased out.

With an estimated total stock of equipment in 2013 of around 9.4 million pieces, containing a total of approximately 23,500 tonnes of refrigerant gases (around 16,900 tonnes of HFC, and 6,600 tonnes of HCFCs), this class of equipment presently results in the import of more than 480 tonnes of bulk HFCs every year to service leaks, and a further 164 tonnes per annum for use by OEMs and charging new equipment (together a total of some 670 tonnes of bulk HFCs or more than 17% of all consumption in 2013).

Overall, compared to the extraordinary market growth witnessed in the decade to 2012, the transition model is projecting this class of medium AC to grow at a relatively modest rate from the total of about 9.4 million units now to around 12.1 million units in 2025.

Of the estimated 6.6 million units charged with high GWP HFCs in 2013 the majority (around 6.5 million) are charged with HFC-410A.

This predominance of HFC-410A was a result of its rapid adoption from 2003, particularly for mini-split air conditioners, as HCFC-22 was phased out. In a period of 8 years up to 2010 HFC-410A charged systems have grown from being approximately 1% of new units installed to comprising approximately 97% of all systems in the medium AC class.

The transition model projects that the stock of HFC-410A charged equipment will grow substantially to around 9.5 million units in 2019 with containing approximately 24,000 tonnes of refrigerant. This stock is then predicted to decline rapidly to some 5.8 million units containing around 16,500 tonnes of HFC-410A in 2025 as the first generation of this equipment reaches end-of-life and is retired. The potential for gas recovered from end-of-life equipment to be re-used in the market and reduce imports has not been modelled, although it is apparent that the sum of gas in end-of-life equipment in the period is substantial as compared to total bulk HFC imports to service this equipment.

During the same period the still significant stock of HCFC-22 equipment of some 2.6 million units now, is expected to decline precipitously to just a few thousand units in 2025. Similarly the much smaller stock of HFC-407C charged equipment is predicted to fall from around 300,000 units now to just 40,000 units by 2025.

Lower GWP gas alternatives are available on the market now for some applications in this medium AC class of equipment and predictions for transition in the smaller end of this sector are relatively rapid, although the most prospective alternative, HFC-32, is classified as an A2L mildly flammable refrigerant.

Irrespective of whether a refrigerant is classified as mildly flammable like HFC-32, or classified as flammable such as HC-290, should the robust rate of change come to pass, it would not be without potential problems for the Australian industry. While both HFC-32 and HC-290 have some commendable properties in terms of lower GWP, higher efficiency as refrigerants and competitive price, wide use will effectively mean that the entire industry has to develop and hone its capacity to deal with flammable substances. Hydrocarbons are projected to achieve a 5% share of new equipment (by equivalent refrigerant volume) in this class by 2025.

When the AC industry migrated from HCFC-22 to higher pressure HFC-410A, there were accidents resulting in personal injury. Major equipment suppliers went to great lengths to ensure their customers were adequately trained to handle the new refrigerant, which minimised corporate risk and exposure to litigation.

It is unclear to what extent potential liabilities of personal injury to installers, or owners of equipment might create barriers for mildly flammable refrigerants including possibly future HFO blends developed for AC applications.

To some extent, setting aside the impact of possible regulatory hurdles or incentives, the prospects of mildly or highly flammable refrigerants used in stationary AC in Australia will mostly depend on the commercial benefits or competitive advantages gained, outweighing the risks and associated costs.

Ultimately global equipment and compressor suppliers are seeking replacement refrigerants with similar characteristics to HCFC-22 and HCFC-410A (i.e. operating pressures, non-flammable, equivalent operating efficiency, etc.) that have a low GWP and are non-ozone depleting. If they could source effective refrigerants that were not flammable, they would almost certainly select those over substances that were flammable, simply because of the long term benefits of avoiding known risks. Manufacturers are already investing in development of non-flammable HFO blends looking for a replacement for HCFC-22 and HFC-410A. As such it is predicted that an HFO blend will be available to this market later in the projection period that will provide some competition to the demonstrated transition options available now.

**HC-290** has been used in split ACs for several years on a limited scale. Several companies are now developing and beginning to produce them on a larger scale. Although HC-290 seems to be the preferred hydrocarbon option, HC-1270 is under evaluation by some companies (UNEP 2013c, p3). In Australia HC-290 charged wall hung split units are available from several companies although the current stock of equipment is estimated to be just 0.06% of the total market and annual sales are running at just 0.1% of total new sales per annum, despite reasonable price competitiveness and excellent energy efficiency.

In August 2011 one of the largest Chinese manufacturers of AC equipment, Gree Electric Appliances, announced plans to convert 18 of the 32 AC production lines in China to HFC-290 as part of China’s HCFC Phase out Management Plan. Other equipment manufacturers known to be using hydrocarbons include Godrej & Boyce in India and De’Longhi.

At present Benson Air Conditioning is the only notable supplier of air conditioners containing HC-290 hydrocarbon refrigerants in Australia.

The Queensland Government, Department of Mines and Energy maintains a register of approved hydrocarbon refrigerant appliances and lists a range of Benson wall hung and ducted split systems with cooling capacities ranging from 2.3 kWr to 16.4 kWr. Benson Air Conditioning advertise other products using hydrocarbons including roof top packaged units, chillers, pool and spa heat pumps, and combination AC/hot water split systems, however the full range of products currently available is unclear.

With this technology firmly established, and despite the general barriers to flammable refrigerants discussed at the end of this section, the transition model predicts appliances charged with HC-290 to increase from an estimated 5,000 units now to more than 230,000 units in 2025, or approximately 2% of the total stock or equipment in this class at that time.

Nonetheless, because of its higher flammability than HFC-32, the early starter advantage of HC-290 is likely to be rapidly eroded by the arrival of a wide range of equipment charged with HFC-32.

**HFC-32** has a GWP of 650/675 (around a third of the most common refrigerants currently used) and is classed as mildly flammable.

HFC-32 has comparable efficiency to that of R-410A and HCFC-22 in many existing mini-split ACs designs. As the theoretical COP, heat transfer properties and transport properties are better than HFC-410A, optimisation of equipment designs to HFC-32 is likely to result in better COP than HFC-410A and HCFC-22. Despite the rating of mildly flammable, the UNEP TEAP assessment considered that HFC-32 has a high potential to penetrate this market due to the balance of cost, energy efficiency, and safety (UNEP 2013c, p69).

The transition model projects rapid growth in sales of HFC-32 charged equipment with the stock of equipment increasing from effectively zero in 2014 to around 4.0 million units in 2025, or approximately 33% of the total stock of equipment in this class at that time.

Other than the issue of its classification as an A2L mildly flammable refrigerant discussed above, other potential barriers to HFC-32 include equipment and compressor suppliers concerns with long-term reliability arising from hotter compressor discharge temperatures, and additional costs and risks associated with training industry to handle ‘mildly flammable’ refrigerants.

Nonetheless, while HFC-410A is expected to maintain some market share in the larger and more demanding applications in this sector for some time, in the absence of any other lower GWP and non-flammable alternative that can deliver the same performance, it is expected that HFC-32 will enjoy robust growth in market share in the projection period.

HFOs and Developmental Refrigerants - DuPont and Honeywell are developing and trialling HFO blends that are potential replacements for HCFC-22 and HFC-410A.

Honeywell cites several refrigerants in varying stages of development, including N-20 (GWP of 975, A1 non-flammable classification) and L-20 (GWP of 331 with a mildly flammable classification) that are potential replacements for HCFC-22, and L-41 (GWP 460 with a mildly flammable classification). The benefits include having the same operating pressures as existing HFC refrigerants, compatibility with existing equipment designs and compressors, resulting in familiar serviceability and potential for retrofitting in some cases. These factors support a more rapid, cost-efficient adoption by the industry than refrigerants with higher flammability ratings.

Honeywell also has a product under commercial evaluation to compete in the HFC-32 space. This new HFO A2L blend known as HFC-447A, will reportedly have a slightly lower GWP than HFC-32. However with the charge size required by HFC-32 being a little smaller than that needed by HFC-447A, overall GWP of impact on the future bank and consumption of both products will be similar.

DuPont cites and DR-5, among other refrigerants, that are under development made up of mixtures of HFO-1234yf and other stable refrigerants, including HFCs. These blends benefit from the low GWP and high coefficient of performance of HFO-1234yf, and deliver more refrigeration capacity from other ingredients. DR-4 has a lower direct GWP value of around 300. However DR-5 with a GWP value of closer to 500 exhibits better total environmental performance due to higher energy efficiencies in AC applications (JARN 2011).

The September 2013 TEAP report assessed these and several other refrigerants in development (see *Section 3.5 Summary of emerging HFO blends on the near horizon*) and concluded that a number of them could be in the market within 1 to 2 years. Although release to market of new refrigerants with novel properties is likely to require rigorous testing to comply with environmental and safety standards.

As such it is considered possible that not all of these promising new compounds will enjoy rapid approval for commercial release, even if the manufacturers can scale up to production levels that make them economically viable.

However the expected global adoption of HFO-1234yf as the standard for the automotive AC market, and the release of other HFO compounds such as HFO-1234ze(E) and HFO-1233zd with GWPs of just 6, will likely make final commercialisation of HFO based blends only a matter of time, if no serious adverse safety or environmental impacts are identified.

On the basis of the number of alternative substances under development, the transition model has predicted at least one other viable lower GWP alternative is introduced to the market by 2016 and grows at a steady rate to reach some 1.3 million units by 2025, or approximately 11% of the total stock of equipment in this class at that time.

As such, when combining the expected growth of HFC-32 in this class of medium AC equipment, and the smaller contribution of HC-290 charged equipment, the transition model predicts that by 2025 around 52% of medium AC equipment, or around 6.1 million units, is expected to be charged with low GWP refrigerants.

This sector of the RAC markets is one of the largest and most lucrative for all of the participants in the supply line. As such there are large incentives to be successful early starters when new technologies are released. Because of the size of the market and the potential rewards it is very likely that this area in particular could see rapid developments in both the new refrigerants being developed and trialled and new technology under development.

There are a number of parallel technological development efforts underway that may yet have an impact within the period of the projection.

Solar adsorption chillers could potentially start to take up some market share towards the end of the period depending on both the advancement of the technology and supporting policies. CO2 charged systems, also in their relative infancy, are also a potential to achieve commercial release in the period.

More immediately ‘indirect’ evaporative cooling systems that combine both highly efficient refrigerating circuits with evaporative cooling systems have potential to develop a reasonable market share as the combined effects of drives for higher energy efficiency and lower GWP/lower working charge systems, influence design.

**Large AC**: Space chillers

There are no immediate options available for a transition of large commercial AC chiller systems to low GWP refrigerants, although Ammonia (R717) is established in niche applications. However alternatives are expected to be commercially available and proven within 2 to 5 years. Opportunities to change the refrigerant gas employed in a chiller plant may occur both when replacing chillers that have reached the end of their useful service life and when procuring equipment for a new construction. However as these are large capital items with long service lives, many chillers also undergo a major refurbishment during the course of their working life, and this too will present opportunities for refitting chillers with lower GWP gases.

There are estimated to be about 28,400 chillers operating in Australia, containing in total approximately 3,400 tonnes of refrigerant gases. Approximately 34% of this gas is HCFC-22 (~1,170 tonnes) with a smaller quantity of HCFC-123 (~160 tonnes). The balance of gases employed (around 2,070 tonnes) are high GWP HFCs including around 1,800 tonnes of HFC-134a and small quantities of HFC-410A and HFC-407C.

The installed base of high GWP HFC charged equipment created demand for approximately 130 tonnes of bulk consumption in 2013 to replace material lost to leaks (about 3% of all high GWP HFC consumption in that year). A further approximately 150 tonnes was imported in bulk to supply OEM demand and to charge imported equipment that is imported without any refrigerant in place (about 4% of all high GWP HFC imports in that year).

New chillers sales are expected grow at around 1% per annum or in line with construction activity, however the stock of chillers is expected to decline to about 25,000 units in 2025. However during that period more than 14,000 units presently charged with HCFC-22 and HCFC-123 are expected to decline to around 1,000 units.

As these are long life capital items much of the newer HFC charged equipment in place now can be expected to be still operating for potentially decades into the future. However these large systems, that should enjoy regular servicing and close performance monitoring, also have greater potential for being refitted during their working life.

Nonetheless the transition model projects that the estimated 15,000 HFC-134a chillers in operation now will grow to almost 17,000 units by 2018 before slowly beginning to decline in number. Similarly the estimated 2,200 HFC-410A and HFC-407C units operating now are expected to grow to more than 3,500 units by 2021 before beginning a similar slow decline.

HFO-1234ze(E) is a refrigerant that can be used in existing HFC-134a technologies with minor modifications (compressor sizing), and it has been trialled in systems in Europe. When used in reciprocating, scroll or screw type of compressors, it produces efficiency levels comparable to HFC-134a. In centrifugal compressors, this refrigerant produces efficiency levels slightly better than HFC-134a. In chiller applications HFO-1234ze(E) should perform very well in warm climates, due to their high critical temperatures (UNEP 2013c, p3).

The transition model assumes that HFO charged systems are first introduced around 2015 and grow strongly until 2025 by which time some 3,400 are installed.

During that period chillers charged with HFC-32 are expected to be introduced by around 2015 and grow at a somewhat slower rate than HFO charged equipment until by 2025 there are almost 1,000 HFC-32 charged chillers in the economy.

It is assumed that at least one of the other developmental blends that are being prepared for the market is available for commercial use in 2016, and optimised for certain applications, sales build until in 2025 there are nearly 1,600 units in the market.

Ammonia systems can already be found in very large commercial applications with refrigerating capacities up to 30,000 kWr to condition mining operations and large industrial facilities. Recent advancements in micro-channel heat transfer technology and engineering design have resulted in reduced refrigerant charges and created opportunities for ammonia in other applications such as chillers for smaller commercial AC systems down to 20 kWr. Limited industry experience with ammonia systems, and particularly toxicity risks, restrict expansion into applications where ammonia has potential to come in contact with consumers. As such no significant contribution is expected from new ammonia charged systems outside of the large industrial applications they presently provide.

As a result by 2025 more than 24% of the stock of equipment, around 6,100 units, are charged with lower GWP refrigerants.

**Scope for Australian industry to transition**

The international development of new refrigerants, and technologies which employ them, will drive significant changes in the Australian stock of AC equipment over the next 10 years.

In general terms the options for transition away from high GWP HFCs, while at the same time replacing the stock of end-of-life equipment that were charged with HCFCs, point to a diversification in the supply of refrigerant gases. While this may present some difficulties for manufacturers supply and assembly lines, the most significant implication of this diversification is the introduction into the market and wider use of flammable, even if only mildly flammable, refrigerants.

Management of flammable refrigerants in the supply chain will require new systems and processes. For instance warehouse facilities, storage requirements and handling procedures must all be reviewed and/or revised as compared to shipping and handling of the existing range of effectively inert and non-flammable gases in use.

Obstacles to the widespread use of flammable and mildly flammable refrigerant gases include:

* Standards – the timely development of effective and workable international and domestic standards;
* Skills gap – industry practitioners have limited experience dealing with flammable refrigerants in new or existing equipment;
* Industry practices vary significantly in relation to management of new refrigerants, for example incorrect labeling can result in contaminated refrigerant or create an unknown hazard for future service personnel;
* Corporate risk – many wholesale companies refuse to supply hydrocarbon refrigerant for fear of public liability claims and concern regarding legal precedent from previous cases where a significant portion of the duty of care lies with the manufacturer or importer. The majority of equipment suppliers and manufacturers have similar concerns; and,
* Regulatory risk - government regulators have a duty of care to ensure policies do not endanger the public, industry practitioners or property.

However these issues can be managed as stakeholders apply themselves to the issues they can most directly control in their part of the supply chain.

This effort has already started with ASHRAE recently creating a new 2L sub-class to the existing Class 2 flammability classification. This is intended to capture ‘mildly flammable’ refrigerants like HFC-32 and HFO-1234yf as it covers Class 2 refrigerants with a burning velocity less than or equal to 10 cm/s. Gases with a low burning velocity do not propagate horizontally and are difficult to ignite.

The 2L classification is characterised by lower heat of combustion, higher LFL and lower burning speeds. This class is proposed for use in various international and regional standards, such as ISO 817 and ISO 5149, and has already been adopted into the ASHRAE standard 34. It is intended to help differentiate between certain refrigerants such as ammonia (R717), HFC-32 and HFO-1234yf and another lower flammability refrigerant, HFC-152a, in that the former are difficult to ignite, difficult to sustain a flame under prescribed conditions and are not likely to evolve overpressures that could cause damage, whereas the latter behaves more like a fuel gas.

However, this change is yet to be recognised or endorsed in Australia (AS/NZS 1677.1) or internationally under ISO 817.

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 26: Small AC - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
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| *Figure 27: Small AC - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 28: Medium AC - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
|  |
| *Figure 29: Medium AC - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

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| **Predicted transition of bank and consumption (tonnes)** |
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| *Figure 30: Large AC - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
|  |
| *Figure 31: Large AC - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

**Assumptions of modelling and level of confidence**

* Existing local manufacturers will continue at similar production levels until 2025.
* Growth rate of stationary AC sales post 2013 through to 2025 is 1.5% per annum for the larges class (medium AC), with small AC in decline by 3% per annum and chiller sales are estimated to grow at 1% per annum.
* HFC-410A will be phased out of production and replaced with imports with refrigerants with lower GWP refrigerants by 2025.
* Refrigerant blends with GWPs as low as 300 are expected to emerge before 2025, the model categorizes them as GWP <1000.
* The model predicts a high penetration of HFC-32, however it is possible that HFC-32 may be substituted with blends with a lower GWP ranging from 300 to 500 depending on the availability, cost and energy efficiency.
* Linear growth trend for all substitutes to 2025. With HFC-410A making up the balance, except in the case of chillers where HFC-134a makes up the balance.
* Leak rates of small AC is 3% per annum for all refrigerant types whereas medium AC has experiences a significant improvement in containment design from older generation HCFC equipment to current models. The leak rates for medium AC containing HCFCs is 8% per annum and HFCs is 3% per annum to 2025. Large AC is modeled based on a leak rate to improve from 4% per annum, except in the case of HCFC-123 systems that have very low leak rates in the order of 1% per annum.

*Table 7: Predicted transition scenario for stationary air conditioning sector.*

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| --- | --- | --- |
|  | Predicted proportion of refrigerant contained in new products by volume | |
| 2020 | 2025 |
| **Small AC: Self-contained** | | |
| HFC-410A | 60% | 0% |
| HFC-32 | 30% | 60% |
| GWP <1000 | 0% | 10% |
| GWP <10 | 10% | 30% |
| Predicted scenario has a medium to high level of confidence, and a low to medium level of complexity. | | |
| **Medium AC: Split systems incl. Wall hung; Ducted and VRV, and RT packaged** | | |
| HFC-410A | 59% | 0% |
| HFC-32 | 30% | 70% |
| GWP <1000 | 10% | 25% |
| GWP <10 | 1% | 5% |
| Predicted scenario has a medium level of confidence, and a medium level of complexity. | | |
| **Large AC: Space chillers** | | |
| HFC-134a | 55% | 0% |
| HFC-410A | 5% | 0% |
| HFC-32 | 10% | 10% |
| GWP <1000 | 10% | 28% |
| GWP <10 | 20% | 62% |
| Predicted scenario has a medium level of confidence, and a medium level of complexity. | | |

# Mobile air conditioning

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| **2013 bank and consumption (tonnes)** |
|  |
| *Figure 32: Mobile air conditioning refrigerant bank and consumption in 2013 in tonnes.* |

**The bank and annual consumption**

The mobile AC bank of high GWP HFCs is estimated to be around 9,500 tonnes, equivalent to around 21% of the total bank of high GWP HFCs in the stock of RAC equipment in Australia.

It is estimated that of the 15.7 million registered passenger vehicles and light commercial vehicles, more than 95% have an air conditioner, each containing as little as 610 grams of gas when fully charged. Other registered vehicles in the fleet include 664,000 rigid, articulated and non-freight trucks, and buses (commuter and larger buses greater than 7 meters in length) (ABS 9309.0 2014).

Due to the timing of the roll out of mobile AC as a standard feature in passenger vehicles, and later in heavy vehicles and public transport, mobile air conditioning largely skipped the transition from CFCs to HCFC refrigerants in the 1990s. The vast majority of AC mobile equipment was manufactured with HFC-134a, while a smaller population of earlier model vehicles that had AC factory installed, or installed after market, migrated directly from CFCs to HFCs.

HC-600a (hydrocarbon), while only a small proportion of the total bank, is the second most widely used refrigerant in mobile AC, as a result of its use in the service market for second hand vehicles. As this is an ‘after-market’ phenomena, the penetration of hydrocarbons in automotive AC is somewhat uncertain. However industry estimates and anecdotal evidence from service providers indicates that hydrocarbon is used in as many as 937,000 passenger and light commercial vehicles on road or approximately 6% of vehicles base on a cumulative leak rate of 15% per annum. When the hydrocarbon charged fleet is modelled with a cumulative leak rate of 10% per annum, the number of vehicles employing hydrocarbons is estimated at 1,095,000 with or approximately 7%[[11]](#footnote-11) of the total passenger and light commercial vehicle fleet.

Other refrigerants employed in mobile refrigeration applications include HCFC-22 and HFC-407C in large buses greater than 7 meters in length, locomotive, passenger rail and off-road applications. Relatively rarely HFC-124 can be found in extreme ambient applications such as mobile cranes. Small amounts of HFC-410A is used on miscellaneous applications such as luxury vessels and yachts.

Mobile AC consumed an estimated 1,250 tonnes or around 31% of all bulk HFCs imported into Australia in 2013. This gas was consumed to replace gas lost from vehicles in operation service and used by OEMs.

The majority of this gas (~80%) was consumed servicing AC systems in existing vehicles, (which have an estimated leak rate of 10% per annum). The stock model used to calculate the sum of all losses includes an allowance of 1.5 % per annum for gas lost from passenger and light commercial vehicles that had some form of collision or catastrophic failure (i.e. compressor failure).

Consumption of bulk gas by OEMs in automotive and truck manufacturing was estimated to be 135 tonnes in 2013. Automotive passenger vehicle manufacturing declined from 326,960 (including light commercial vehicles) in 2006 to 211,429 in 2013, partially due to global competition and the closure of the Mitsubishi factory in 2008. This decline removed demand of between 50 to 60 tonnes per annum from HFC-134a consumption.

The announced closures of the Ford Motor Company manufacturing operations in Geelong and Broadmeadows in Victoria by 2015, the GM Holden manufacturing facilities in Adelaide and Fishermans Bend in Victoria by 2016, and the Toyota manufacturing operations in Victoria by 2017, are expected to further reduce bulk imports of high GWP HFCs to around 130 tonnes per annum by the end of 2017.

There are three truck OEMs in Australia, Kenworth, Iveco and Mack trucks, that collectively manufacture around 4,000 trucks per annum and consume around 4 tonnes of HFC-134a. The model assumes the last motor vehicle manufactured in Australia will be in 2017 but that truck manufacturers will continue at existing levels.

**The stock of equipment, annual sales, industry trends**

Mobile AC systems are found in passenger vehicles, light commercial vehicles, buses, trucks, and a number of unlicensed and off road applications including locomotives, passenger rail, mining equipment, harvesters, fork trucks, road making vehicles, mobile cranes, military vehicles and earthmoving equipment.

It is estimated that in total there are more than 15.6 million vehicles of all types that employ mobile AC systems. More than 1.13 million new passenger vehicles were sold in 2013 (ABS 9314.0 2014).

Total registered and unregistered vehicle numbers are predicted to grow by about 2% per annum as new vehicle sales outstrip vehicle retirements and write offs.

The vast majority of new vehicles are imported. Imports relative to locally manufactured vehicles will increase as local manufacturing contracts and eventually ceases.

**Lower and no GWP alternatives and barriers to transition**

There are several options for mobile AC systems to migrate to lower GWP technologies.

In passenger and light commercial vehicles hydrocarbon has established a presence in the stock of mobile air conditioning as a result of its use in after market servicing of vehicles.

However, despite this early advantage, global developments suggest that there are a number of other options that are likely to be competing for the major market shares of this significant sector.

In 2008, as a response to European Union regulations (EC Directive 2006/40/CE) that place a ban on use of refrigerants with a GWP greater than 150 in all new vehicles from 2017, the global automotive industry commissioned SAE international to evaluate and compare the Life Cycle Climate Performance (LCCP) and characteristics of a number of working gases thought suitable for use in passenger vehicle AC.

HFO-1234yf, HFO blends, carbon dioxide (R744) and HFC-152a were assessed and compared to the LCCP of HFC-134a.

CO2 (R744)

SAE International found CO2, with a GWP of 1, to be as efficient as the best in class HFC-134a system, with comparable cooling performance, energy efficiency and fuel use to HFC-134a systems, except under high ambient conditions (above 35°C).

CO2 equipment saw a number of developments from 2000 to 2010 and several manufacturers reportedly reached “implementation readiness”. German OEMs announced their intention to develop CO2 systems and some of which stated their preference to stay with HFC-134a until CO2 systems were commercialised.

Leading component suppliers and car manufacturers developed several technical options with CO2 including internal heat exchangers, external control compressors, micro-channel gas coolers, and evaporators dedicated to CO2. New hoses with ultra-low permeation have also been developed (UNEP 2013c, p80).

However, higher equipment costs associated with economies of scale, higher pressures, system reliability concerns, and the need to develop and create a new servicing infrastructure were predicted to restrain the widespread use of CO2 technology.

The main barriers for CO2 systems have been issues of costs, concerns about reliability and servicing aspects. It has been calculated that even for a series of at least 150,000 CO2 systems per year, costs would at least double compared to the baseline, according to Tier 1 suppliers (in the year 2010). With CO2 not being globally deployed any automotive manufacturers that adopted this technology path would need to install two AC systems (one for CO2, another one for HFC-134a) to be mounted on the same assembly line. Two other barrier issues were related to reliability and servicing, particularly:

* The shaft of the open-type compressor was a potentially highly leak-prone component with no lessons learned at large scale; and,
* CO2 servicing requires special training and also specific equipment making it necessary to develop a new world-wide servicing network for global car companies (UNEP 2013c, p81).

Some global suppliers of industrial gases are reported to be investing in R&D efforts to resolve technical issues associated with CO2 in small mobile AC systems. However with nothing more than unconfirmed reports and rumour available at this time, it is not possible to properly assess the potential for these efforts to overcome technical issues and provide the basis for a competitive CO2 based mobile AC technology to global automakers, although it has to be considered that this could potentially provide competition to HFO systems.

In summary, CO2 is a very effective refrigerant, however technically difficult in small mobile AC applications creating a significant technical barrier for suppliers; only the best auto parts suppliers have been able to develop efficient CO2 compressors (UNEP 2013c, p81). As a result, to date, no global OEM has installed CO2 for automotive AC (UNEP 2013c, p80).

HFOs

In November 2009, SAE released its assessment of HFO-1234yf which concluded that this gas was “a suitable and environmentally friendly refrigerant with comparable cooling performance and fuel use to HFC-134a that can be safely accommodated through established industry standards and practices for vehicle design, engineering, manufacturing, and service”.

Since that time sufficient numbers of the leading vehicle manufacturers, such as GM, Ford, Chrysler and Honda, have endorsed the use of HFO-1234yf in mobile AC for industrial gas manufacturers to commit to large scale production facilities. In May 2010, DuPont and Honeywell announced a manufacturing joint venture in China to produce HFO-1234yf. Daikin-Arkema also announced its intention to produce HFO-1234yf on an industrial scale in Europe to meet the time frame for the automotive industry established under European Directive (EC Directive 2006/40/CE).

In the US new regulations underpinning improvements in fleet vehicle fuel economy, known as CAFE (Corporate Average Fuel Economy) includes a concession for auto makers who use HFOs in mobile AC systems, giving them some credit towards meeting total greenhouse emission targets of vehicles over their life. As a result US auto makers are also preparing to employ HFOs in mobile AC in passenger and light commercial vehicles.

In December 2013, citing this emerging demand from US auto makers, Honeywell announced plans to invest $300 million in expanding HFO production at one of their existing refrigerant gas manufacturing plants in Louisiana. Claiming that there were already half a million cars on the road that use HFOs, Honeywell said the plant would be in production by 2016. In 2013 Honeywell also announced the launch of a repackaging (bottling) plant for HFO’s in Japan to better serve Asian demand (presumably from Japanese and Korean auto makers).

As a result of these developments the change from HFC-134a to HFO-1234yf seems to be the most likely outcome for MACs, because many of the main players in global auto industry have decided to employ this working gas. This would suggest that remaining auto makers will have to follow as the auto industry is one that favours global options for components and consumables like AC systems.

Even so it has to be noted that, for the time being there is resistance to the global adoption of HFOs by German automakers (Daimler, BMW and Volkswagon), even though the clear preference of companies outside Germany would be to change to HFO-1234yf. Such a transition is likely to garner regulator support as well as the logic of it is also supported by LCCP analysis, which shows that HFO-1234yf would be superior to CO2 for most ambient temperatures (UNEP 2013c, p81).

The most recent announcement (March 2014) on this topic is that the European Commission's scientific and technical body has concluded that new low global warming potential mobile AC refrigerant, HFO-1234yf, is safe for use in automobiles, marking the final word in a thorough and inclusive evaluation process. Following a three month evaluation during which it thoroughly reviewed the extensive testing done by a range of leading automakers as well as the world's foremost automotive engineering body, SAE International, and independent test agencies. The European Commission said in statement. "The review reinforces the conclusions by the German market surveillance authorities, the KBA (Kraftfahrt Bundesamt), which stated that there is no sufficient supporting evidence of a serious risk that would entail the intervention of the authorities."

A final consideration for the auto industry is that it has been announced by chemical companies that the cost of the chemical is expected to be 5 to 7 times more than that of HFC-134a. However it has to be noted that in the chemical industries, prices could vary by a factor of 10 depending on production and sales volume. One OEM that has proceeded with implementing this refrigerant stated that the total cost of the system, including the chemical and other components, was US$75 more than an HFC-134a system (UNEP 2013c, p82).

Other Options

HFC-152a (GWP of 140) was considered as a potential alternative in the original SAE International study as it exhibited good energy efficiency and cooling performance. However no international vehicle manufacturer has adopted this alternative, as it requires additional safety requirements to mitigate higher flammability risks than some other options.

The concern about the use of flammable refrigerants in cars was expressed particularly strongly by the German auto makers. These same safety concerns are a strong barrier against the use of HCs in cars (UNEP 2013c, p81).

It should be noted that hydrocarbons (HC-290 or blends) were not even considered in the SAE International evaluation due to the high flammability classification, the additional safety requirements, regulatory and skills barriers that have been widely documented, and the potential for public liabilities. There are at least five hydrocarbon refrigerant suppliers in Australia that collectively supply around 60 tonnes of refrigerant per annum to the automotive aftermarket, and HC-436 (a blend of R600a and R290) is the most common retrofit option (Source: Natural refrigerant survey 2012 and 2013).

This fact of the Australian mobile AC industry provides a local alternative pathway for aftermarket retrofits of HFC-134a charged systems, and may be able to contribute to a more rapid migration of the existing fleet away from HFC-134a than would be achieved through the natural attrition of vehicles reaching end-of-life or being written off.

Larger mobile AC systems

There is a global and Australian market for large mobile systems, most often used in public transport such as in buses and trains, but also used in unregistered vehicles, heavy equipment and off-road vehicles, that could potentially migrate along a different path to the smaller private vehicle and light commercial vehicle systems.

AC systems for these specialised vehicles, such as harvesters, trains and buses are similar and are produced in small series of some hundreds per year. The cooling capacities vary from 10 to 35 kWr depending on the size of the bus or the train carriage to be serviced (UNEP 2013c, p82).

Because of the small batch production runs and higher value of the individual units, makers of these systems can potentially afford to adopt working gases and technical solutions that are not supported by the auto makers.

In buses greater than 7 metres, passenger rail and locomotives, future options that can be considered include HFO-1234yf, CO2, new blends, and possibly the relatively novel Brayton-Joule air cycle (UNEP 2013c, p4).

CO2 systems have been under development and deployed by one company in Germany since 1996 and now boasts a total fleet of about 50 city buses. In moderate climates, CO2 performs well and lessons learned from several years of experiences do not show significant issues. Another German manufacturer sells CO2 based AC systems for trains (UNEP 2013c, p82). The alternative air cycle (Brayton-Joule) technology has also been installed on more than 100 ICE trains (UNEP 2013c, p80).

While these alternatives are proven and promising, as Australia is largely a technology taker in this area as well, the HFO-1234yf development for car AC systems will have direct consequences for bus and train AC systems currently operated on HFC-134a (UNEP 2013c, p82).

The refrigerant cost, although greater than the usual price, is not a strong barrier, because its cost represents less than 1% of the total cost of those AC systems. The change from HFC-134a to HFO-1234yf is a relatively easy technical option. The possible shift from HFC-407C, also found in larger mobile AC systems, to new low GWP blends is also assessed as being technically low risk (UNEP 2013c, p82).

Once again hydrocarbons are thought to generally not be applicable in trains and bus AC systems due to safety issues in public transportation (UNEP 2013c, p82).

**Scope for Australian industry to transition**

The move by global automakers to support HFOs as the standard working gas for MACs suggests that the Australian market will move steadily away from the domination of HFC-134a in this application over the period to 2025.

Projections of the transition of the bank and service demand away from HFC-134a indicate that by 2025 around 46% of the fleet, or approximately 9.1 million registered vehicles, will have MACs that are charged with low GWP gases including hydrocarbons, CO2 and HFOs.

Sales of vehicles equipped with HFO charged MACs commenced in small numbers in 2013 and will increase from now on. Seven years later, by 2021, the transition model projects that the total number of vehicles on the road, equipped with HFO charged MACs will surpass the total number of vehicles with hydrocarbon charged MACs.

By 2025, out of a projected total fleet of more than 19.9 million registered vehicles, HFOs are expected to be the dominant low GWP working charge, followed by hydrocarbons charged systems and a smaller portion of CO2 systems equating to 9.1 million vehicles with AC containing refrigerant with a GWP <10.

Based on the assumptions listed below *Figure 37*, these projections indicate that in 2025 the fleet will still contain some 10.8 million vehicles fitted with MACs charged with HFC-134a that will continue to consume approximately 550 tonnes per annum of bulk imports at that time. This is a significant reduction in demand, down around 640 tonnes per annum from the presently estimated 1,190 tonnes of bulk imports required for service and OEMs in 2013.

As part of this projection it is assumed that both Ford and Holden cease making cars in Australia by 2016 as previously announced, and that Toyota continues at the current level of production until the end of 2017. As a result OEM demand for HFCs drops to just 4 tonnes in 2017 (from around 135 tonnes in 2013) after the closure of Ford and Holden. With Toyota’s production ceasing in 2017 all demand for bulk imported high GWP HFCs in this sector after that time is expected to be entirely for service of MACs in existing vehicles.

There is potential for this service demand to be lower at that time if, for instance, the existing and predicted rate of conversion to hydrocarbons in the aftermarket servicing of MACs, and possibly conversions to HFOs, are higher than expected.

However there are uncertainties regarding the future adoption rates of emerging HFOs and HFO blends that are classed as ‘mildly flammable’, or A2L under *ISO 817, Refrigerants - Designation and safety classification*.

Therefore the modelling does not consider retrofit of A2L refrigerants into existing equipment designed for class 1, non-flammable refrigerants.

It is technical plausible, and likely that class 1 non-flammable HFO blends will be developed and marketed to be retrofitted into equipment designed for class 1, non-flammable refrigerants, providing manufacturers retrofit guidelines are followed (much in the same way that CFC 12 systems were retrofitted to HFC-134a when CFCs were phased out in Australia). However the timing of that likely development is too uncertain to include in modelling at this time.

Ultimately it has to be said that even if the technical and commercial barriers to CO2 systems are rapidly overcome, and CO2 systems are aggressively marketed to automakers, achieving a rapidly growing market share, and resulting in a lower share of the global mobile AC market for HFOs than predicted, the outcome for the CO2-e value of the Australian bank of refrigerant gas and annual consumption will not be much different.

Further, the early commercialisation advantage achieved by HFOs, the commitment to HFO production facilities by major manufacturers, the number of vehicle makers adopting HFOs, and the supportive regulation for low GWP mobile AC systems, all support the authors conclusions that HFOs will be manufactured at sufficient volume for the projections of the use of HFOs and blends in other sectors will be achieved, irrespective of the near term success or otherwise of CO2 mobile AC systems.

Beyond the projection period the increasing numbers of electric vehicles being produced could provide a further incentive to move more of the vehicle fleet to highly efficiency CO2 systems, assuming the issue of high ambient temperature operation can be addressed. It has been suggested that HFOs could, when viewed in a timeframe of the next 20 years, be regarded as an interim step in MACs before an eventual shift entirely to a mix of CO2 or hydrocarbon charged systems. Given the rate at which technology develops and can be adopted by global automakers, that is quite plausible, although beyond the horizon of this projection.

Other factors in the short to medium term that could impact the proportion of low GWP refrigerants in the fleet of vehicles include the potential for a relaxation on restrictions on importation of second hand passenger vehicles. This change has been mooted in recent work by the Productivity Commission, and if implemented, could result in a slightly larger fleet of older cars, which may lead to a larger share of imports containing HFC-134a and market for hydrocarbons. However it is not definite that this will occur, or when it may occur.

Another factor that could impact the projections for the bank and consumption in registered vehicles is the rate at which Asian automakers adopt HFOs. Even if as predicted, the Japanese and Korean automakers move quickly to adopt HFOs to avoid any possible restrictions on the European market, it is not certain that they would migrate their entire production line to the use of HFOs all at the same time. In which case a country like Australia, which has no regulatory restrictions in place on the gas charge in new vehicles, may still get vehicles charged with high GWP HFCs from some Asian manufacturers.

|  |
| --- |
| **Predicted transition of bank and consumption (tonnes)** |
|  |
| *Figure 33: Registered vehicles - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
|  |
| *Figure 34: Registered vehicles - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

|  |
| --- |
| **Predicted transition of bank and consumption (tonnes)** |
|  |
| *Figure 35: Off-road vehicles - predicted bank in tonnes by refrigerant type from 2013 to 2025.* |
|  |
| *Figure 36: Off-road vehicles - predicted consumption in tonnes by refrigerant type from 2013 to 2025.* |

**Assumptions of modelling and level of confidence**

* Ford and Holden close manufacturing by the end of 2016, and Toyota continues until the end of 2017 at similar production levels to current.
* Growth rate of vehicle sales and mobile AC post 2013 through to 2025 is 1.5% per annum.
* HFC-134a will be phased out of production and imports with refrigerants with GWP less than 10 by 2025.
* Linear growth trend for all substitutes to 2025 with HFC-134a making up the balance.
* Leak rates improve from 11.5% to 8% per annum in 2025.
* The average charge of registered vehicles remains constant at 625 grams (i.e. weighted average of passenger and light commercial vehicles; rigid, articulated and other trucks; and commuter buses). The weighted average charge of off-road vehicles (including buses > 7 meters) is 5.3 kg. The charge size relates to the amount of high GWP refrigerant that will be displaced, not the actual charge of the lower or no GWP refrigerant.

Efforts to project the rate and success of commercialisation of alternative technologies that are currently ‘under development’ will always carry greater uncertainties than those for which commercial supply is already established. These uncertainties can be both in terms of available quantities and timing or market release. The eventual price of a product under development is always a considerable source of uncertainty which will always be impacted by a range of issues such as the scale of investment in initial production, the rate of adoption, and the development of supply lines against incumbent competition and technologies, all of which go towards changing the dynamics of the supply/demand relationship.

*Table 8: Predicted transition scenario for mobile air conditioning sector.*

|  |  |  |
| --- | --- | --- |
|  | Predicted proportion of refrigerant contained in new products by volume | |
| 2020 | 2025 |
| **Registered vehicles (excl. buses > 7 m)** | | |
| HFC-134a | 60% | 0% |
| GWP <10 | 40% | 100% |
| Predicted scenario has a medium to high level of confidence, and a low level of complexity. | | |
| **Off-road vehicles (including buses > 7 m)** | | |
| HFC-134a | 35% | 0% |
| HFC-407C | 25% | 0% |
| GWP <1000 | 20% | 50% |
| GWP <10 | 20% | 50% |
| Predicted scenario has a medium level of confidence, and a medium level of complexity. | | |

**Potential actions to support a smooth transition**

With the international market positioning for what appears to be a collaborative transition of MACs to HFOs, at least in passenger and light commercial vehicles, Australia has a number of opportunities open to it to assist a transition in this sector. The Federal and State Governments could follow European and US government programs aimed at accelerating the market for vehicles fitted with HFO charged MACs by, for instance;

* Harmonising Australian regulations with the European Union regulations (EC Directive 2006/40/CE) that place a ban on use of refrigerants with a GWP greater than 150 in all new vehicles from a certain date;
* All new government vehicles requiring the use of a refrigerant with a GWP <10 from a certain date;
* Provide a small registration rebate for new fleet vehicles equipped with MACs charged with a refrigerant with a GWP <10;
* Investigate options for public transport systems that can operate CO2 charged MACs; and,
* Investigate opportunities for refitting of public transport systems, where the vehicles themselves are very long lived pieces of capital equipment, with new MACs charged with zero or lower GWP refrigerants.

# Foam

Foam blowing agents comprised around 4%  (~200 tonnes) of all bulk ODS and SGGs imported into Australia in 2013. Unlike almost every other major and minor application of ODS and SGGs, a proportion of this material is emitted to air in the year of import, and the balance is gradually released over several decades as the foam cells and structures break down either whilst in use or in land fill.

The Montreal Protocol has had a significant impact on the phase out of the use of ODS use in foam applications with most large scale manufacturing facilities migrating to pentane foam blowing, and smaller facilities moving to HFC based systems. In 2006 there were 300 tonnes of bulk HCFCs imported for foam blowing. The last bulk HCFCs imported for foam applications, approximately 49 tonnes, were brought in during 2010. There were reports that some participants in the foam industry developed stockpiles of HCFC as the import cap constrained future imports, however it is believed these stockpiles were consumed several years ago.

The HFCs consumed in the foam sector mostly comprise HFC-365mfc (GWP of 794AR4) and HFC-245fa (GWP of 1030AR4), with small volumes of HFC-227ea (GWP of 2900) consumed in blends (87% HFC-365mfc and 13% HFC-227ea with a weighted GWP of 1109).

Notable changes in this industry over the past 5 years include:

* Rheem converted its foam blowing manufacturing facilities in Rydalmere, NSW, to pentane in around 2008, removing demand for around 25 tonnes of HCFC-142b/22 blend per annum;
* The 2008 closure of Fisher & Paykel’s domestic refrigerator manufacturing plant in Cleveland, Queensland did not displace ODS or SGGs foam blowing demand as they had already converted to pentane;
* Dux (division of GWA) have converted their foam blowing for their hot water system manufacturing operation to pentane;
* Saxon Industries, a hot water heat pump manufacturer in Queensland went into voluntary liquidation in 2010;
* Orford Refrigeration, a commercial refrigeration manufacturing operation based in Toowoomba, Queensland that was using both HCFC-141b and water blown foams closed in 2011;
* Fridgrite, a commercial refrigeration manufacturing facility based in Melbourne that was using HFC-134a for foam blowing, closed its operations in around 2010; and
* Williams Refrigeration based in Melbourne manufactures a variety of refrigerated cabinets which migrated from HCFC foam technology to a HFC blend of HFC-245fa and HFC-365mfc several years ago.

Manufacturing rationalisation, refurbishments and closures have contributed to a significant portion of the decline in consumption of HCFC foam blowing agents in Australia. However, HFC and low GWP alternative technologies have evolved considerably over the last five years and the HCFC phase out in this sector is virtually complete with no more bulk substance imports expected for foam applications in the future.

There are a number of ‘system houses’ including Huntsman, ERA Polymers, Chemind, Australian Urethane Systems, Ariel Industries (division of ERA Polymers), Pacific Urethanes, and a few smaller participants in this segment, who blend HFC foam blowing agents and chemicals for foam manufacturers, large and small, and who produce foam to order for OEMs. Rebain International also competes with systems houses with imported formulations and BASF recently closed its blending facilities in Melbourne.

HFC formulations are generally used where thermal insulation properties are critical, or for manufacturing in emerging markets or by small to medium sized enterprises, due to the low investment costs (compared with using a flammable blowing agent) and a range of end-use applications. End use applications include commercial refrigeration cabinets, refrigerated transport for road and intermodal containers (road and rail), insulation panel produced in batches on a small scale, block or moulded foam and spray insulation in agricultural applications such as chicken sheds, piggeries and mushroom farms.

There is a wide variety of alternative blowing agents that have been or are being developed (UNEP 2010b, 2013c), some of them such as hydrocarbons (n-pentane, cyclopentane, isobutane, and various blends) have flammability issues during manufacturing that can be overcome with economies of scale to justify the investment in fireproofing equipment. Other technologies such as water blown CO2 are progressively overcoming technical barriers such as dimensional stability for certain applications, however they are limited in some applications as they may generally require increases in foam thickness compared to HCFC and HFC formulations. Methyl formate and methylal are two other technologies that are in commercial use, but do not yet have significant market penetration in Australia.

The main commercial barriers to transition to low GWP alternatives in applications where high GWP foam blowing agents are used are mostly as a result of insufficient economies of scale. Major international chemical companies DuPont, Honeywell and Arkema are all actively developing and commercialising low GWP synthetic foam blowing agents such as HFO-1234ze(E) (GWP of 6), HFO-1233zd (GWP of 1) and other HFOs with no to mild flammability with GWP values of less than fifteen (e.g. Arkema AFA-L1 claiming to be a non-flammable replacement for HFC-245fa offering excellent insulation capability or   
k factor along the Cold Chain).

Honeywell International claim in their brochures that Solstice Gas Blowing Agent, HFO-1234ze is a near drop-in replacement for many extrusion processes currently using CO2, HFC-134a and HFC-152a blowing agents, and that Solstice Liquid Blowing Agent HFO-1233zd are a near drop-in replacement for liquid HCFC, HFC, hydrocarbons and other non-fluorocarbon blowing agents.

Some of these products have been evaluated for building and construction foam applications and that could be available in major global markets as early as 2014. Apart from the market and regulatory intervention, one of the key drivers may ultimately be the improvement in thermal efficiency offered by low-GWP substitutes such as unsaturated HFCs, unsaturated HCFCs or blends containing them (UNEP 2013c).

In a recent press release Whirlpool Corporation announced a partnership with Honeywell to use its next generation liquid blowing agent (Solstice® LBA, a hydrofluoro-olefin HFO-1233zd(E) with a GWP of 1) in US refrigerators as it not only has a very low GWP it provides superior insulating properties to pentane blown insulation.

HFO-1234ze(E) has been approved by NICNAS (National Industrial Chemicals Notification and Assessment Scheme) for registration and accreditation to allow importation in commercial volumes into Australia. This HFO is expected to provide a technically viable solution for foam blowing in Australia.

HFC-365mfc and HFC-245fa were not subject to the ECP, as they do not have AR2 values, whereas HFC-227ea has $71.05 per kg ECP imposed on it, (based on $24.50 per tonne of carbon) which has resulted in a decline in its use in blends. All these substances were included in the future projections, as they are included in the AR4 assessment.

The transition model predicts that consumption of bulk imports will transition to 50% of substances with GWP<1000 and 50% of substance with a GWP <10 by 2025. The predicted scenario has a medium level of confidence, and a medium level of complexity as this sector is very capable with specialist industrial chemists and sound technical solutions with similar or better properties are on the horizon.

# Fire protection

Fire protection applications consumed approximately 1.2% (~50 tonnes) of all bulk ODS and SGGs imported into Australia in 2013. FM-200 (FE-227, HFC-227ea, GWP of 2,900) is the main gas used in the vast majority of gaseous fire suppression applications. Small amounts of FE-25 (HFC-125, GWP of 2,800) and FE-13 (HFC-23 GWP 11,700) are used in flooding applications, and FE-36 (HFC-236fa, GWP of 6,300) can occasionally be found in specialist streaming applications such as portable fire extinguishers for oil platforms, etc. Fire protection consumption in GWP terms is slightly higher due to the high GWP values of these gases, however consumption declined from around 70 to 80 tonnes in 2007 to around 50 tonnes.

HFC and HCFC gases were predominantly introduced as a replacement for Halon 1301. HFC and HCFC gases were predominantly introduced as a replacement for Halon 1301. HCFC blends (NAF-S-III and NAF-P-III) can be found in existing systems, however have not been installed in new systems for several years.

HFCs are used in fire suppression applications for their unique efficacy and safety properties where the application of water (by hose stream or sprinkler heads); dry chemical agents; or aqueous salt solutions is problematic. HFC fire protection systems can be found in telecommunication facilities, computer rooms, data centres, process control centres, military vehicles, aircraft, museums, archive vaults for document storage and other electronic facilities. HFC systems are typically only used in applications where waterless fire suppression is required, and when speed, space and safety are critical.

There is a range of low GWP alternatives that provide an immediate transition path for the majority of applications where HFC fire protection systems are currently used; they include a fluoroketone called Novec 1230 and following inert gases and blends:

* IG-01 (argon)
* IG-100 (nitrogen)
* IG-55 (nitrogen/argon blend)
* IG-541 (nitrogen/argon/CO2 blend)

Novec 1230 (GWP of 1), a patented 3M product, is the most widely used replacement for HFC fire protection systems. There are technical challenges in applications involving large spaces as it cannot be piped long distances (i.e. boils off) and requires pocket systems that need to discharge together to be effective. In addition to this, inert gas systems are heavier, have a larger footprint and can take 60 seconds to discharge when compared to 10 seconds for HFC systems. These are important technical disadvantages in certain applications such as military planes or naval vessels.

Fixed fire protection equipment is rarely imported as pre-charged equipment, however systems are sometimes designed, specified and constructed overseas. For example, LNG projects and some mining projects have had equipment pre-assembled overseas and imported with complete fire protection systems containing FM 200.

A potential barrier to inert gas systems is infrastructure such as filling stations. Novec 1230 filling stations only exist on the eastern seaboard. FM 200 is the main alternative used in the mining industry in Western Australia.

Global market forces resulting in shortages of Fluorspar, an ingredient used in the production of HFCs resulted in the cost of FM 200 increasing in Australia by as much as 40% around 2011, and the limited supply volumes based on consumption in previous years.

Inert gas systems can be relatively expensive which may present a commercial barrier to wider deployment of inert gas systems. There is concern that the planned removal of the Carbon Based Levy and Fluorspar supplies returning to normal, that the price gap between HFC systems and low GWP alternatives will widen. The barriers do not appear to be insurmountable and any meaningful economic incentive would almost certainly accelerate the transition to low GWP alternatives. An unintended consequence of the observed decline in the use of HFC fire protection systems is that fewer companies may be interested in maintaining licensed personnel to maintain existing systems.

The transition model assumes that the majority of applications will migrate to these new systems and high GWP import demand will decline to around 20 tonnes of HFC-227ea in 2025. The predicted scenario has a medium level of confidence, and a low to medium level of complexity as sound technical solutions are already in use.

# Aerosols (including medical)

Obtaining accurate information on the consumption of bulk ODS and SGGs imported into Australia for use in aerosols has proved to be difficult for the past several years. In 2011 the authors identified around 30 tonnes of consumption of HFCs in aerosols, and estimated that there was potential for as much as 40 tonnes consumed across all applications packed and filled in Australia. The volumes consumed in 2013 are at the similar levels, however they are consumed in different applications.

The main uses in Australia include:

* Technical aerosols (including dusters for computers and instrumentation, freeze sprays, flux removers, mould release agents and, electronic contact cleaners);
* Products for use in hazardous areas (including paint marking applications for underground mining, blast bags for setting explosives);
* Safety aerosols (including tyre inflators, safety signal horns and insecticides for use in planes and restricted areas);
* Medical inhalers for asthma or sports medicine pain relief;
* Consumer aerosols (including cosmetic and hair care products), and
* Novelty aerosols (including silly string, wine cork removers, spray snow and noise makers).

The main barrier for Australia to migrate to alternative propellants is globalisation. Many of these uses are serviced by aerosol products filled and packed overseas, or are based on formulations specified overseas, and as a consequence are designed to comply with overseas regulations. Some examples are as follows:

* Cosmetic and hair care products such as TRESemme imported by Alberto Culver (a division of Unilever) contains HFC-152a in order to comply with volatile organic compound requirement under the US Federal Clean Air Act;
* Callington Haven used to consume as much as 20 tonnes of HFC-134a mostly for aviation insecticides that require non-flammable propellants. These products are now manufactured overseas;
* HFC-134a is widely used as the propellant in medical treatments for asthma and chronic obstructive pulmonary disease, although these products are no longer manufactured in Australia;
* Laser hair and skin treatments consume sizable volumes of HFC-134a in Australia where it is used as a cryogen spray cooling that device delivers a spurt of HFC-134a to the treatment area just prior to the laser treatment pulse, and,
* All novelty aerosols products are imported, mostly from China.

The main synthetic gas consumed in Australia for aerosol applications is HFC-134a (GWP of 1,300) with some HCFC-123 consumed for sports medicine applications. The introduction of the ECP or GWP based levy on HFC-134a and rise of the value of the Australian dollar resulted in many manufacturers moving aerosol packaging off shore and importing finished product without the levy. The removal of the levy and decline of the strength of the Australian dollar could see some of this consumption return.

In January 2011 Honeywell announced that HFO-1234ze(E) had been accepted by the U.S. Environmental Protection Agency for use in non-medical aerosol applications. HFO-1234ze (GWP of 6) is non-flammable and is considered the main low GWP alternative to replace HFC-134a or HFC-152a (GWP of 140) as a propellant when available in commercial quantities. HFO-1234ze is currently under review by some Australian manufacturers and Honeywell has reported that sales have commenced in Australia in this sector.

Metered dose inhalers have no near term low GWP alternative and HFCs will be required for many years in order to provide reliable and effective therapy for asthma and chronic obstructive pulmonary disease. However, dry powder inhalers are already used in some instances as a not-in-kind technology and hydrocarbons are being trialled as an alternative to HFC-134a in Argentina as part of a UNDP program, these are promising developments. Aerosols are increasingly becoming the delivery mechanism of choice for medications and although dry powder is an accepted technology it could not replace aerosols in all instances. If HFO-1234ze(E) or other unsaturated HFCs were found to be a suitable substitute, it would take many years before it would be approved for medicinal use in Australia.

It is very difficult to make future consumption prediction in this sector, as there are many unknown and highly complex technical, scientific and commercial factors to consider.

As aerosol applications account for around 1% of (~40 tonnes) of all bulk ODS and SGGs imported into Australia in 2013, a reasonable prediction is to assume consumption remains at these levels until 2025.

# Training for transition

Australia is largely a technology taker of RAC technology, including to some extent refrigerant gases. The recent commencement of HFC-32 pre-charged equipment imports (December quarter 2013), in advance of the rest of the industry being fully prepared to install or supply consumables for them, is an example of the adjustment pressures that the Australian industry faces as the international market drives innovation and new product commercialisation A HFC phase down would constitute an additional driver for change and new product commercialisation in the industry.

Right as the Australian industry is contemplating a third historical wave of evolution in the technology, it is also facing increasingly tight labour market conditions, a situation that has been developing for many years as new intake of industry trainees has fallen steadily, while demand for services has consistently grown faster than the economy.

Refrigeration engineers and technicians are the critical market intermediary required to willingly participate in training and skills acquisition if a widespread transition of the climate control and refrigeration industries is to be successful.

Any discussion about training and education in Australia, that might assist a transition from the present generations of refrigerants to non-HFC or lower GWP refrigerants, can only be conducted in the context of the training, education and human resources requirements of the industry as a whole.

For some time the HVAC&R industry has been straining to provide trained service personnel to satisfy the demands of rapid growth in the mining and resources sector, explosive growth in installation of smaller AC systems, and steady growth in commercial and industrial refrigeration. This is not a trivial problem.

Estimates of the size of the industry, in terms of direct expenditure and employment, range from 1.2% to 1.8% of GDP. However the essential nature of the services provided by this industry to the community and the economy at large, and the additional value that the HVAC&R industry creates for other economic activity, means that the raw assessment of economic scale considerably understates the importance of this industry to the wider economy.

In its ‘*Australian Workforce Futures*’ report in March 2010, Skills Australia identified air conditioning and refrigeration mechanics as one of the specialised occupations in which Australia is facing a critical shortage in the short and medium term. A further report (SA 2011) on the skills needed to deliver national energy efficiency targets from May 2011 has also identified the shortage of AC, refrigeration and mechanical services personnel as one of the limiting factors in improving the energy performance of the built environment.

Skills Australia made a number of recommendations about applying additional resources to improving training and educational resources in this field, and HVAC&R featured among a short list of priority areas in the Australian Workforce Development Strategy.

While it is heartening that the chronic shortage of air conditioning and refrigeration skills have been recognised as a priority the recommendations to date, viewed from an industry perspective, could be said to look like more of the same - more reports but few resources being actually made available to industry to drive training, education and increase the uptake of apprentices and cadet engineers.

The importance of this issue for this industry, and for any plans to drive or even manage a transition in this sector, cannot be understated. The fact is that it is not just an issue any more of a ‘skills gap’, as identified by Skills Australia. Far more critically, because the industry has been unable to take on enough new entrants for most of the past two decades to even replace those retiring, and because the training system does not reward those with the expertise to pass on their knowledge, the industry has for some time been enduring a period of ‘skills loss’ that could be extremely difficult to reverse.

The Australian Institute of Refrigeration Air conditioning and Heating (AIRAH) has been driving development of a whole of industry plan to achieve a low emissions future called PRIME.[[12]](#footnote-12)

PRIME stands for Professionalism, Regulation, Information, Measurement, and Emission abatement and is the HVAC&R industry’s own blueprint for a successful transition to a low-emissions future. The PRIME initiative has revealed significant deficiencies within the training infrastructure with regard to developing the HVAC&R workforce competencies in low-emission practices and technologies.

Given the constant changes that are occurring within the HVAC&R field PRIME has identified significant shortfalls in the coverage and content of current apprentice, technician and engineering professional training and education regimes. To try to address the skills and labour shortfall PRIME has listed objectives that include:

* VET/TAFE course competencies should include courses on the effective and appropriate use and handling of all alternative low GWP (natural or synthetic) refrigerants;
* VET/TAFE course competencies and teaching resources need to be updated to cover all new and emerging applications of natural and low GWP synthetic refrigerants and made freely available;
* Delivery of the updated VET/TAFE course units incentivised to improve trade take-up. It is also important to find a mechanism that will allow Industry organisations, major companies and SMEs to agree to and fund increased apprentice training; and.
* PRIME also recommends development of a skills maintenance system for ARC licence holders and an industry-endorsed list of approved skills maintenance for licence holders and CPD activities for building professionals to assist in professional development.

The projected human resources shortfall and training inadequacies have led AIRAH to start to engage directly with university level education providers on the possibility of, and process for, developing a dedicated undergraduate engineering degree program in ‘Building Services and Refrigeration’.

At the very least they are pushing to update existing University based training in engineering and related courses to include HVAC&R energy efficiency and emission reduction as a core component including Australian based case studies, data and financial benefits of energy efficiency.

AIRAH is also working with universities to determine the best mechanism for incorporating basic low-emission HVAC&R awareness units into existing university training courses for significant end-users, e.g. agricultural sciences training, process engineering, architecture and building designers, town planning and civil engineering, etc. Furthermore, it is engaging with VET/TAFEs to determine the best mechanism for invigilating basic low-emission HVAC&R awareness units into existing VET/TAFE training courses for significant end-users (e.g. retail training and the like).

# Technical standards and Codes of Practice

In response to the rapid diversification of refrigerants that technicians are likely to encounter on a daily basis, standards and codes of practice for:

* Clear, long lasting and easy to find labelling and identification of equipment with regard to the refrigerant charge;
* Refrigerant handling, storage and management; and,
* Detection and reporting of refrigerant leakage;

These initiatives will necessarily require a tightening in construction and maintenance standards for refrigeration, AC, and heat pump systems. A long standing proposal for a refrigeration and air conditioning equipment log book for larger classes of equipment would be one initiative that would, over time, address many of the data, maintenance and identification issues the industry is facing.

This is a complex and multi-faceted issue. Improved system construction standards will also benefit the wider expansion of natural refrigerants into these sectors. The PRIME initiative has identified several actions that could be considered to improve standards and emission performance in the installation, commissioning, operation and maintenance of these systems.

AIRAH suggests that Australia does not at this time have enough data regarding direct emissions of refrigerants, how they occur, where they occur and why they occur. Refrigerant logging at the site (point of use) level, and the development of a database on refrigerant consumption and use would assist any future HFC phase down or control initiative, and wider spread introduction of natural refrigerants and mildly flammable lower GWP synthetic refrigerants. Again, the PRIME initiative has identified several actions that could be considered to help develop a refrigerant use data base.

# Potential perverse outcomes of transitioning to low GWP alternatives

Claims of safety risks associated with the management of flammable and mildly flammable refrigerants have notably declined as most stakeholders are now becoming familiar with the requirements for handling these new products, at least with the A2L classed refrigerants.

At the same time some suggestion of environmental and health risks associated with break down products of new refrigerants are emerging, but no scientific substantiation has been offered of such claims. The history of perverse outcomes resulting from the introduction of new refrigerants suggests such claims will be carefully investigated.

An overall trend to lower charge sizes, and an almost comprehensive awareness by the industry at large of the need for energy efficiency, suggests that the few actual risks of energy penalties will be mitigated in hardware design and refrigerant choice.

Equipment churn prior to the end of its useful life is always a risk when industries comprehensively adopt new generations of technology and, for either reasons of supply chain limitations or possibly to accelerate adoption and churn, remove service support for older generations of technology.

This industry also bears a risk of higher end of life direct emissions of refrigerant. However other than observing that there is a risk of higher churn rates of equipment, there is no way at this point to quantify or easily document that risk.

# Costs to transition to low and no GWP alternatives

Any assessment, and certainly any attempt at quantification of costs to the RAC industry, and to the broader economy, of a transition to lower or zero-GWP alternatives, under a business as usual scenario (with no incentives for transition), as compared to an accelerated transition scenario (with regulated or other incentives), requires a much more detailed and extensive economic and market study following the completion of this report.

At this stage, and in brief, there is no doubt that there will be costs involved to both the industry and the broader economy in any HFC phase down, and thus a transition to zero and lower GWP refrigerants. However depending on the mechanisms employed by regulators, and the investment programs and employment of capital undertaken by industry, in the longer term, costs that may be borne by the broader economy upfront, in some sectors could be recouped many times over.

Long term savings to end users and thus the broader economy could flow from new technology that requires lower maintenance, has lower leak rates, and enjoys higher energy efficiency. The potential for higher energy efficiency over the life of some of this long lived equipment has the potential for significant economic upside. In the end, due to the total cost of energy provision and use, energy efficiency at any point in the economy, is inevitably economic efficiency.

In terms of early and direct costs that could be expected in a HFC phase down, new synthetic refrigerants generally follow a market based pricing cycle dependent on:

* Manufacturing supply and customer demand;
* Manufacturing costs and ingredients;
* Economies of scale of logistics and distribution;
* R&D recovery costs and intellectual property (IP) rights; and,
* Market prices of competitive products.

HFC-410A started with a price of around $100 per kg when first released in the early to mid-2000s and declined to around $20 per kg within five years. HFC-134a and HFC-404A followed similar patterns in the 1990s.

The new HFO refrigerants are flagged to start at around $100 per kg at wholesale level and are expected to follow a similar market based pricing pattern to other refrigerants. New equipment containing HFOs will be very similar to existing equipment and thus have existing economies of scale and similar costs.

While the cost of natural refrigerants is generally lower than the cost of HFC refrigerants, the cost of equipment that can operate using natural refrigerants is generally somewhat, higher and the cost of maintaining this equipment is generally higher. These economic obstacles are to some extent the effect of scale, and it is expected that as deployment of natural refrigerant systems increases some of these costs will come down.

For example, at present the average contractor pays around $30 (± $3) per kilogram for hydrocarbon refrigerants, which equates to around half the cost of HFC-134a (~$50 to $60 per kilogram including the ECP) to perform the same task. This is only partially attributable to the hydrocarbon refrigerant being cheaper than HFCs and bears no ECP. The fact is that the hydrocarbon charged equipment simply requires less charge (i.e. based on an equal molar basis, 100 grams of HFC-134a is required to do the same work as approximately 57 grams of HC-600a).

The cost differential between a HFC charged domestic refrigerator and a hydrocarbon charged one has vanished in the last two years as volumes of hydrocarbon charged domestic refrigerators have increased, and now represent the majority of equipment found in retail outlets.

Suppliers of commercial refrigeration display cases however indicate products containing hydrocarbon refrigerants are typically 15% more expensive than the competing HFC charged products.

In the supermarket or process refrigeration sector a hybrid supermarket refrigeration system comprising a ‘CO2 only’ direct expansion rack for low temperature, and a HFC-134a rack for medium and high temperatures, would cost an additional 15 to 20% compared to a conventional direct expansion system operating on HFC-404A (with no ECP), and the gap is significantly less with an ECP. Alternatively, a system with ‘CO2 only’ direct expansion used for low temperature and a cascade refrigeration system with a reduced charge of HFC-134a as the primary refrigerant and CO2 as the secondary refrigerant for medium and high temperatures would add 30 to 35% to the capital cost. The designs of these advanced refrigeration systems are still evolving and incur higher maintenance costs. However, as the designs and skills mature, the costs to install and maintain advanced refrigeration systems will decline.

In process refrigeration applications, both ammonia and CO2 systems are typically more complex than conventional commercial refrigeration systems using HFC refrigerants as each solution is fully engineered for individual applications. In many instances, full life cycle costing is undertaken in the feasibility stage and the efficiency gains and increasing energy prices are considered. These market factors are driving many facilities owners to commission or develop their own customised solutions, and driving market share growth for natural refrigerants, despite the generally higher up-front capital investment required.

On top of higher costs of new refrigerants for a period, and higher capital costs of equipment that employs natural refrigerants, there are direct costs incurred along the supply chain that flow from management of bulk quantities new classes of mildly flammable refrigerants, and indeed from management of simply more refrigerants as the diversification of the working bank accelerates.

These costs include obvious costs associated with handling, storage and transport of the A2L class refrigerants, a process that has recently begun to require process changes and investment to service demand for HFC-32. Additional costs are also involved in the expansion of the cylinder fleet, introduction of new administration, communication and marketing materials, and training of staff in the supply chain.

There are many other smaller and possibly larger costs which require significant research and analysis to properly estimate the impacts that industry and the community may expect in the course of a HFC phase down. Further, and most importantly, any expected costs that can be quantified should be assessed against the significant potential benefits and savings that some expected outcomes of a HFC phase down should deliver.

# Conclusions

There are very few industries in the world that have the opportunity to plan global and co-ordinated adoption of a new generation of technology. And of the few that could, the opportunities to do so are rare. For various reasons, the refrigeration and air conditioning (RAC) industry, is one such industry, where the supply lines are effectively so concentrated, and require such large capital investments to deliver, that the stakeholders are capable of co-ordinating generational change in the core technology – the refrigerant gases.

These substances are the thermal media that play a central role in the global economy, particularly in the essential role of preserving food along the cold food chain, but also in innumerable health, science, industrial, manufacturing and building environment applications. The scale of the global industry, and its central role in our modern way of life, also mean that a great deal of refrigerant gases are required, and a great deal of energy is consumed in delivering the energy services that refrigerating technology provides.

Decisions on the nature and performance of refrigerant gases can have profound impacts in the long term on the global economy, and as has been previously proven, on the global environment. In recent decades for instance the world has witnessed both a serious threat to global health, the impact of CFCs on the ozone layer, minimised and indeed reversed by global action, and a resulting co-benefit in avoided greenhouse climate forcing.

For these reasons, participating in and possibly influencing a generational change in this technology is both a significant responsibility and an important opportunity.

Australia is in a strong position to meet HFC consumption limits if an eventual international phase down was based on something similar to the NAA proposal.

There is reasonable confidence that lower or zero GWP working gas options and technologies are either viable now, or will be viable and commercially available on the near horizon – 2 to 3 years - for the majority of applications.

A small number of very demanding applications – for instance the fishing fleet – do not have a clear, economically and technically viable path to a low GWP option at this time, however those applications are in the minority.

The industry is rapidly approaching a fourth wave of evolution in the core technical elements of RAC equipment, that is the refrigerant gas employed as the thermal medium, and dozens of incremental but significant improvements in component design including to compressors, heat exchangers, condensers and materials employed. As a result a new wave of design options are opening up for equipment designers, and further diversification of product lines and of refrigerants can be expected.

This raises a number of potential supply line, trade practice and work skills obstacles that need to be addressed to prepare for the inevitable diversification of the working bank to include a higher proportion of flammable and mildly flammable refrigerants.

General support of the industry’s own comprehensive program supporting transition to a low emissions future, PRIME, championed by AIRAH, would directly address many of the main obstacles and identified risks of a transition to fourth generation refrigerating and air conditioning technology.

Significant churn of equipment and appliances before their optimal end-of-life could flow from a rapid transition, with subsequent increases in direct emissions of older generations of refrigerants from retiring equipment. Enhanced controls on end of life emissions from retiring equipment could significantly alleviate that potential environmental impact.

Finally, given the estimate that the industry makes up something between 1.5% and 1.8% of GDP directly, with significant value adding to many other sectors, and the technology involved consumes as much as 22% of all sent out electricity in the country, a detailed assessment of the potential costs and benefits of a HFC phase down, and the potential for magnifying cost savings with appropriate policy settings, is recommended.

None of the obstacles to transition to a lower and zero GWP refrigerants are deemed to be insurmountable. Government has a range of options to consider in regard to the role it could play in preparing for this next phase of evolution of the central technologies employed in this sector, in supporting industry adoption of new technology, and in facilitating a smooth and least costly transition.

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|  |  |
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**Appendix A: The NAA Proposal**

**A1: Summary of NAA proposal baseline calculations**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| HCFC Bulk imports (tonnes) | 2008 | 2009 | 2010 | Average  (AR2) | 85% of av. | GWP (AR4) | kt CO2-e (AR4) |
| HCFC-22 | 1,447.8 | 1,591.3 | 1,105.1 | 1,381.4 | 1,174.2 | 1810 | 2,125.3 |
| HCFC-123 | 13.6 | 37.3 | 5.7 | 18.9 | 16.1 | 77 | 1.2 |
| HCFC-124 | 0.9 | 0.0 | 1.9 | 0.9 | 0.8 | 609 | 0.5 |
| HCFC-141b | 155.0 | 76.1 | 48.9 | 93.4 | 79.4 | 725 | 57.5 |
| HCFC Blend 142b/22 | 15.2 | 0.0 | 0.0 | 5.1 | 4.3 | 2110 | 9.1 |
| HCFC-142b | 0.0 | 0.0 | 0.7 | 0.2 | 0.2 | 2310 | 0.5 |
| HCFC-225 | 0.0 | 0.5 | 0.3 | 0.3 | 0.2 | 122 | 0.0 |
| HCFC-406A | 1.7 | 4.4 | 2.6 | 2.9 | 2.5 | 1943 | 4.8 |
| HCFC-408A | 13.6 | 8.1 | 3.1 | 8.3 | 7.0 | 3152 | 22.2 |
| HCFC-409A | 35.7 | 42.1 | 17.9 | 31.9 | 27.1 | 1585 | 43.0 |
| Total HCFC imports | 1,683.6 | 1,759.8 | 1,186.2 | 1,543.2 | 1,311.7 |  | 2,264.1 |
| HFC Bulk imports (AR2 kt CO2-e) | 2008 | 2009 | 2010 | Average  (AR2) | - | GWP | kt CO2-e (AR4) |
| HFC-134a | 2,313.6 | 2,480.0 | 2,216.4 | 2,336.7 | - | 1430 | 2,570.3 |
| Secondary | 4,162.1 | 4,421.5 | 4,235.8 | 4,273.1 | - | 3370 | 5,088.4 |
| Exotic | 10.9 | 34.5 | 42.0 | 29.1 | - | 1650 | 32.0 |
| Total HFC imports |  |  |  | 6,638.9 |  |  | 7690.7 |
| NAA proposal calculated baseline | | | | | | | 9,954.9 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 2013 Consumption estimate | | | | | 2013 (tonnes) | GWP (AR4) | kt CO2-e (AR4) |
| HCFC-22 |  |  |  |  | 565.0 | 1810 | 1,022.7 |
| HCFC Mix |  |  |  |  | 20.0 | 77 | 1.5 |
| HFC-134a |  |  |  |  | 1,700.0 | 1430 | 2,431.0 |
| HFC-404A |  |  |  |  | 640.0 | 3922 | 2,510.1 |
| HFC-407F |  |  |  |  | 40.0 | 2107 | 84.3 |
| HFC-407C |  |  |  |  | 150.0 | 1774 | 266.1 |
| HFC-410A |  |  |  |  | 575.0 | 2088 | 1,200.6 |
| HFC-Mix |  |  |  |  | 300.0 | 3220 | 966.0 |
|  |  |  |  |  | 3,990.0 |  | 8,482.3 |
| Reduction from baseline | | | | | | | 14.8% |

**A2: Comparison of key elements of the 2013 HFC Amendment Proposals**

| **North American proposal** | **Micronesian Proposal** |
| --- | --- |
| **Transfer of consumption**  Non-A5 can transfer consumption to another party on certain conditions. | **Transfer of consumption**  Non-A5 parties can transfer consumption to other non A5 on certain conditions. |
| **Reduction schedule for non-A5s**  2016 – 10% reduction  2022 – 35% reduction  2029 – 70% reduction  2033 – 85% reduction | **Reduction schedule for non-A5s**  2016 – 15% reduction  2019 – 30% reduction  2022 – 45% reduction  2025 – 55% reduction  2028 – 70% reduction  2031 – 85% reduction  2034 - 90% reduction |
| Consumption baseline: average of 85% HCFC and 100% HFC consumption for 2008, 2009 and 2010. | Consumption baseline: average of 2004, 2005 and 2006 HCFC and HFC consumption. |
| **Trade ban with non-Parties**  Import and export ban introduced one year after entry into force. | **Trade ban with non-Parties**  Import and export ban introduced 12 months after entry into force.  Within 3 years, an annex of products containing HFCs to be elaborated. Imports from non-Parties to be banned.  Within 3 years, Parties will determine the feasibility of banning imports of products produced with HFCs. |
| **Licensing**  Import and export licensing requirements for new, used, recycled and reclaimed HFCs. A5 parties can delay to 2018. | **Licensing**  Import and export licensing requirements for new, used, recycled and reclaimed HFCs from 2016. A5 parties can delay to 2018. |
| **Reduction schedule for A5s**  2018 – 0% reduction (2 year delay, +10%)  2025 – 25% reduction (3 year delay, +10%)  2030 – 60% reduction (1 year delay, +10%)  2043 – 85% reduction (10 year delay, +10%) | **Reduction schedule for A5s**  2016 – 15% reduction ([X] year delay +10%)  2019 – 30% reduction ([X] year delay +10%)  2022 – 45% reduction ([X] year delay +10%)  2025 – 55% reduction ([X] year delay +10%)  2028 – 70% reduction ([X] year delay +10%)  2031 – 85% reduction ([X] year delay +10%)  2034 - 90% reduction ([X] year delay +10%) |
| Consumption baseline: 90% of average of 2008, 2009 and 2010 HCFC consumption. | Consumption baseline: average of [20XX to 20XX] HCFC consumption. |
| **Reporting requirements**  Annual reports on production, imports, exports, feedstock and amount destroyed. | **Reporting requirements**  Annual reports on production, imports, exports, feedstock and amount destroyed. |
| **Funding**  Article 10 to include funding for reducing consumption and production of HFCs. | **Funding**  Article 10 to include funding for reducing consumption and production of HFCs. |
| **Annex F**  Group I – 18 HFC based on 100 GWP. Two HFOs were excluded. Group II – HFC-23 | **Annex F**  Group I – 20 HFCs incl two HFOs with GWPs based on 100 GWP. Group II – HFC-23 |
| **Relation with UNFCCC and Kyoto**  This amendment is not intended to exempt HFCs from UNFCCC and Kyoto Protocol. | **Relation with UNFCCC and Kyoto**  This amendment is not intended to exempt HFCs from UNFCCC and Kyoto Protocol. |

**Appendix B: Methodology**

The data presented in this report has been derived from an extensive Excel workbook that has, at its core, a stock model of RAC employed in Australia.

**Data underlying the stock model**

This stock model was first developed in 2006 during research for what became the first edition of Cold Hard Facts (CHF1). Primary data sources used for the construction of the original stock model included:

* Australian Customs import reports for various product categories (primarily air conditioning equipment by capacity, and some categories);
* Department of Environment Water Heritage and the Arts (DEWHA) data on pre-charged equipment imports for 2005 and 2006;
* Commercial market research estimating the numbers of residential and small commercial split and packaged air conditioning systems sold in the few years prior to 2006 (by capacity and product type);
* Various sales datasets, some partial, from 2004 and going back as far as 1995 for domestic refrigeration, residential and small commercial air conditioning was collected from a number of importers, manufacturers and from published market research, constructed into the early years of the model and then exposed for industry comment and review;
* Personal communications and interviews with manufacturers and importers of commercial split systems and chillers, and
* Personal communications and interviews with manufacturers of commercial and domestic refrigeration systems.

This extensive stock model eventually included estimates of stocks of equipment in all of the major classes of equipment and main applications from as early as 1996 through to 2006.

Equipment retirement rates were developed using knowledge of manufacturers’ warranty conditions, interviews with suppliers, designers and engineers.

Since 2007 when the CHF1 was published, the stock model has been used by the original authors for several major studies in this field, each one adding something to the scope and substance of the model.

As a result, the original stock model has been extended and refined with new sources of data and market intelligence that included:

* The latest issue the Department of Sustainability, Environment, Water, Population and Communities data including bulk and pre-charged equipment import statistics by quantity, mass, species, licence holder, product category from 2006 to 2013 (DoE 2014); [[13]](#footnote-13)
* Reviews of data included in Regulatory Impact Statements and product profiles for air conditioning equipment (i.e. split systems, chillers, close control, portable, etc.), domestic refrigerators and freezers, non-domestic refrigeration (E3 2009), and other products such as hot water heat pumps (E3 2012);
* Reviews of data created for models of domestic energy production;
* Interviews with and surveys of manufacturers, importers and resellers of equipment, and with importers and wholesalers of refrigerant gas, parts and tools for the purpose of other RAC industry related studies;
* Interviews with industry associations and professional bodies for the purposes of other industry and government programs;
* In-confidence industry wide surveys of major participants selling commercial refrigeration condensing units and compressors dissected by capacity and refrigerant;
* In-confidence industry wide surveys of suppliers, up-stream processors and end-users of natural refrigerants to establish aggregate industry measures.
* Surveys of stock on the floor of domestic equipment retailers.

The authors were unable to identify any similar stock model for any other economy to compare the methodology with, the main outputs or the structure of the model.

**Product category stock models**

More sophisticated stock models have been developed for major product categories where sufficient quality historical sales data has been discovered. These models use a cumulative distribution function of the normal distribution function to develop survival curves, stock models and equipment retirement estimates by refrigerant species or type.

Where data was available, the model calculates the number of units of a particular vintage that remain in service at the end of a given year as the total number of units sold in the year of the vintage, minus the proportion of units that have been scrapped prior to the end of the given year.

We assume that the lifetime of a unit is normally distributed with a mean lifespan (in years) and standard deviation (in years). The model assumes that on average, units are sold in the middle of a year. So for example, the number of units that were sold in the year 2000 that remain in service at the end of 2012 is given by, N2000 (1-p), where N2000 is the number of units sold in 2000, and p is the proportion that have been scrapped between 2000 and 2012 inclusive and is given by the following function:

Φ (2012-2000+0.5;μ,σ) = Φ (12.5;μ,σ)

Where Φ (x;μ,σ) is the cumulative distribution function (CDF) of the normal distribution with mean μ and standard deviation σ evaluated at x.

The number of units of a particular vintage that are retired in a given year equates to the number of units sold in the year of the vintage that remained in service at the beginning of the given year, minus the number that remain in service at the end of the given year.

The historical sales data is dissected by refrigerant species or type to predict the refrigerant mix of the bank and retiring equipment.

**Gas charges and species**

The size of the gas charges in various equipment classes are known from manufacturers’ documentation and checks of equipment and appliances in the market and for sale. The size of gas charges can be correlated (to some extent) with the input power and size of the compressor employed and the resulting refrigerating capacity of a piece of equipment.

The gas species most commonly employed in the different products are known, although these are not entirely uniform. The proportion of any product in the stock of equipment that is estimated to employ a particular gas species can be checked in many cases by the mix of species employed in pre-charged equipment imports in any year, and against information gleaned from bulk importers and wholesalers of gas.

From 2006 to July 2012 DSEWPaC pre-charged equipment import data was dissected into specific equipment categories including;

* Air conditioning chillers;
* Packaged air conditioning equipment;
* Window/wall units;
* Portable air conditioning;
* Splits systems (single and multi-head/variable refrigerant flow);
* Aircraft;
* Other heat pumps;
* Mobile air conditioning (vehicles less than and greater than 3.5t gross vehicle mass);
* Commercial refrigerated cabinets;
* Domestic refrigerators and freezers;
* Transport refrigeration (self and vehicle powered truck refrigeration), and;
* Other commercial refrigeration categories.

This information provided seven years of history that was reviewed in great detail to form or confirm views about average gas charges in various products, and the dissection and transition of refrigerant species in products.

**The bank of working gas**

Average charges of working gas in each product are used to calculate the total bank of working gas by equipment category and segment, and by gas species.

Leak rates for products operating on HFCs or HCFCs are used to calculate the volume of refrigerant gas applied to servicing equipment segments in any year. This service demand is reconciled against the known volumes imported. Refer *Appendix C Technical resources and assumptions* for details of average charge and leak rate values used in calculations.

DSEWPaC bulk import data provided detailed dissection of HCFC imports by type and blend, whereas HFC bulk import dissection was estimated based on reporting of HFC-134a, secondary refrigerants (HFC-23, HFC-32, HFC-125, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, HFC-365mfc, HFC-43-10mee, which are largely used in common refrigerant blends such as HFC-404A, HFC-410A and others) and ‘exotic’ refrigerants typically used for laboratory research. Mid-way through 2011 full details of HFC bulk imports were provided by type and blend. Bulk gas is primarily imported for servicing and manufacturing RAC equipment, however other uses include charging new commercial refrigeration equipment with remote condensers which are predominantly manufactured or imported with a nitrogen charge and gassed on site. Smaller volumes are used in non-RAC applications including foam blowing, aerosols, fire protection, as cleaning agents (solvents) and electricity distribution.

The volumes of refrigerant gas required for manufacturing is known by directly surveying equipment manufacturers with regard to their manufacturing output, the species employed in the equipment they make and sell, or charge and sell, and the charges employed in that equipment. Many manufacturers have also provided data on the volumes of bulk gases purchased in any year for their production.

**Global Warming Potential (GWP)**

This report often has to refer to the GWP value of refrigerant gases. Unless otherwise stated, the GWP of any gas, or blend of gases is calculated using the values published in the Second Assessment Report (AR2) of the United Nations Framework Convention on Climate Change (UNFCCC), released in 1996 by the Intergovernmental Panel on Climate Change.

Revised GWP values were reported in the Fourth Assessment Report (AR4) in 2007 and have been accepted for the 2nd commitment period of the Kyoto Protocol, Australia’s legally binding emission obligations under the 1st commitment period of the Kyoto Protocol are calculated based on AR2 and therefore Australian legislation, including the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 (OPSGGMA), cite GWPs from AR2.

Where gases that were not included in the AR2 assessment are referred to, the AR4 value is used, if it is available, and that is noted in a superscript after the GWP value (e.g. GWP of HCFC-409A is 1,585AR4).

A new class of substances, very low GWP HFCs or HFOs, was not available at the time of publication of AR4 and the claimed GWPs are based on industry data.

A table has been provided in Appendix B that compares the GWP values published in the Second and the Fourth Assessments, and the chemical mass composition used to calculate the GWP values of common blends.

The GWP values of HFO substances (HFO-1234yf) are those cited by DuPont (DuPont 2010) and Honeywell as based on AR4. The IPCC, Fifth Assessment Report (AR5) is well advanced, however is not publically available at the time of writing this report.

**Direct Emissions**

Annual emissions of refrigerant gases from each product are calculated using an annual leak rate from each product, and applying that to the bank of working gas that has been calculated as being employed in each product.

There are four main types of direct emissions from RAC equipment:

* Gradual leaks during normal operation;
* Catastrophic losses during normal operation;
* Losses during equipment service and maintenance, and
* Losses at end of equipment life.

The annual leak rate referred to in this report is expressed as a percentage of the initial charge per annum and is calculated as the sum of gradual leaks during normal operation plus; catastrophic losses amortised over the life of the equipment plus; losses during service and maintenance.

In the case of mobile air conditioning equipment, the annual leak rate takes into account losses from vehicle crashes, which are classed as catastrophic losses.

**Appendix B: Technical resources and assumptions**

This appendix summarises the main assumptions used in the study, and provides other technical resources used in calculations.

*Table 9: GWP factors of main refrigerant gas species*

|  |  |  |
| --- | --- | --- |
| Common substances | AR2 GWP-100 Year | AR4 GWP-100 Year |
| Substances controlled by the Montreal Protocol | | |
| CFC-11 (1) | 3800 | 4750 |
| CFC-12 (1) | 8100 | 10900 |
| HCFC-123 | 90 | 77 |
| HCFC-22 | 1500 | 1810 |
| HCFC-141b | - | 725 |
| HCFC-142b | 1800 | 2310 |
| HCFC-406A | - | 1943 |
| HCFC-408A | - | 3152 |
| HCFC-409A | - | 1585 |
| HCFC-225ca (3) | - | 122 |
| HCFC-225cb (3) | - | 595 |
| Hydrofluorocarbons (HFCs) | | |
| HFC-125 | 2800 | 3500 |
| HFC-134a | 1300 | 1430 |
| HFC-236fa | 6300 | 9810 |
| HFC-404A (2) | 3260 | 3922 |
| HFC-407C | 1526 | 1774 |
| HFC-407F | 1824 | 2107 |
| HFC-410A | 1725 | 2088 |
| HFC-417A | 1955 | 2346 |
| HFC-428A | 2930 | 2265 |
| HFC-438A | 1890 | 3667 |
| HFC-507A | 3300 | 3985 |
| HFC-227ea (3) | 2900 | 3220 |
| HFC-245fa (3) | - | 1030 |
| HFC-365mfc (3) | - | 794 |
| Lower or nil GWP alternatives | | |
| HC-600a (4) | - | 3 |
| HC-290 | - | 3 |
| CO2 (R744) | - | 1 |
| Ammonia (R717) | - | 0 |
| HFO-1234yf (5) | - | 4 |
| HFO-1234ze(E) | - | 6 |
| HFO-1233zd | - | 6 |
| HFC-152a | 140 | 124 |
| HFC-32 | 650 | 675 |

1. No longer in common use, banned in 1996. GWP values of blends such as HFC-404A and others are calculated based on the mass composition of substances listed in the IPCC assessment reports.
2. All references to HFC-404A include both HFC-404A with a chemical composition of HFC-125/143a/134a (44.0/52.0/4.0) and HFC-507A with a chemical composition of HFC-125/143a (50.0/50.0) as they are very similar in mass composition and service the same applications.
3. Not used as refrigerant in RAC applications, substances used for foam blowing applications, fire protection and as solvents.
4. HC-600a and HC-290 are not published in the AR2 or AR4.
5. These are new substances and were not reviewed, included or published in the IPCC, Fourth Assessment Report published in 2007. The GWP values of HFO substances are those cited by DuPont and Honeywell as based on AR4. The GWPs of HFOs has recently re-evaluated by the UN with HFO-1233zd and HFO-1234ze with a GWP of 1; and HFO-1234yf with a GWP of less than 1. This report uses previous cited values to maintain consistency.

The ASHRAE refrigerant mass chemical compositions are used to calculate the GWP values of these blends from the Second Assessment Report (AR2) of the United Nations Framework Convention on Climate Change (UNFCCC), released in 1996 (IPCC 1996). While these values have since been superseded by the Fourth Assessment Report (AR4) in 2007, all of the Australian legislation that refers to the GWP of HFCs use the values listed originally in AR2, based on Australia’s obligation under the Kyoto Protocol.

*Table 10: ASHRAE Refrigerant designation and refrigerant mass composition of common blends used in Australia*

|  |  |
| --- | --- |
| ASHRAE Refrigerant designation | Refrigerant composition (Mass %) |
| Refrigerant blends: Zeotropes | |
| 404A | R-125/143a/134a (44.0/52.0/4.0) |
| 406A | R-22/600a/142b (55.0/4.0/41.0) |
| 407C | R-32/125/134a (23.0/25.0/52.0) |
| 407F | R-32/125/134a (30.0/30.0/40.0) |
| 408A | R-125/143a/22 (7.0/46.0/47.0) |
| 409A | R-22/124/142b (60.0/25.0/15.0) |
| 409B | R-22/124/142b (65.0/25.0/10.0) |
| 410A | R-32/125 (50.0/50.0) |
| 436A | R-290/600a (56.0/44.0) |
| 436B | R-290/600a (52.0/48.0) |
| Refrigerant blends: Azeotropes | |
| 507A | R-125/143a (50.0/50.0) |

1. The contents of this table is from ANSI/ASHRAE 34-2010, Designation and Safety Classification of Refrigerant, which is published on the ASHRAE website.

*Table 11: Technical characteristics for product categories (average charge, leak rates, lifespan, end-of-life percentage)*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Category code | Product category | Average charge (kg) | Leak rates (%) | | Av. Lifespan (Yrs) | EOL (%) |
| HCFCs | HFCs |
| STATIONARY AIR CONDITIONING | | | | | | |
| AC1 | Single split: non-ducted: 1 & 3 phase | 1.7 | 8.0% | 3.0% | 12 | 80% |
| AC2 | Single split: ducted: 1 & 3 phase | 4.7 | 8.0% | 3.0% | 12 | 80% |
| AC3 | Non-ducted: unitary 0-10 kWr | 0.75 | 4.0% | 3.0% | 10 | 80% |
| AC4 | Portable AC 0-10 kWr | 0.6 | 1.0% | 1.0% | 7 | 90% |
| AC5-1 | <500 kWr | 60 | 8.0% | 4.0% | 15 | 80% |
| AC5-2 | >500 & <1000 kWr | 210 | 8.0% | 4.0% | 20 | 80% |
| AC5-2 | >500 & <1000 kWr (HFC-123) | 180 | 1.0% | n.a. | 20 | 80% |
| AC5-3 | >1000 kWr | 620 | 8.0% | 4.0% | 25 | 80% |
| AC5-3 | >1000 kWr (HFC-123) | 670 | 1.0% | n.a. | 25 | 80% |
| AC6-1 | RT Packaged systems | 12.2 | 8.0% | 4.0% | 15 | 80% |
| AC6-2 | Multi split/VRF | 8.0 | 8.0% | 4.0% | 15 | 80% |
| AC6-3 | Close control | 30.0 | 8.0% | 4.0% | 15 | 80% |
| AC6-4 | HW heat pump: commercial | 110.0 | 8.0% | 4.0% | 20 | 80% |
| AC6-5 | Pool heat pump | 2.8 | 8.0% | 4.0% | 15 | 80% |
| AC7 | HW heat pump: domestic | 0.9 | 3.0% | 3.0% | 10 | 80% |
| MOBILE AIR CONDITIONING | | | Crash | HFCs |  | |
| MAC1-1 | Passenger vehicles | 0.61 | 1.5% | 10.0% | - | 60% |
| MAC1-2 | Light commercial vehicles | 0.61 | 1.5% | 10.0% | - | 60% |
| MAC2-1 | Rigid truck and other | 1.00 | 1.0% | 10.0% | - | 60% |
| MAC2-2 | Truck: articulated | 1.00 | 1.0% | 10.0% | - | 60% |
| MAC2-3 | Commuter buses | 1.00 | 1.0% | 10.0% | - | 60% |
| MAC2-4 | Buses (> 7m) | 9.00 | 1.0% | 12.0% | - | 60% |
| MAC3-1 | Passenger rail | 7.00 | - | 12.0% | 10 | 60% |
| MAC3-2 | Locomotive | 4.00 | - | 12.0% | 10 | 60% |
| MAC4 | Off-road, defence and other (boat, etc.) | 2.75 | - | 12.0% | 15 | 60% |
| DOMESTIC REFRIGERATION | | | | | | |
| DR1 | Domestic refrigerators & freezers | 0.140 | n.a. | 1% | - | 80% |
| DR2 | Portable and vehicle refrigerators | 0.06 | n.a. | 1% | 8 | 90% |
| REFRIGERATED COLD FOOD CHAIN | | | | | | |
| RCFC1-1 | Refrigeration cabinets | 2.00 | 10.0% | 7.0% | 15 | 80% |
| RCFC1-2 | Refrigeration beverage vending machines | 0.25 | 5.0% | 2.0% | 12 | 80% |
| RCFC1-3 | Ice makers | 0.7 | 4.0% | 3.0% | 10 | 80% |
| RCFC1-4-1 | Walk-in coolrooms: mini | 1.0 | 20.0% | 17.5% | 12 | 70% |
| RCFC1-4-2 | Walk-in coolrooms: small | 5.0 | 20.0% | 17.5% | 12 | 90% |
| RCFC1-5 | Walk-in coolrooms: medium | 17.0 | 20.0% | 17.5% | 12 | 70% |
| RCFC1-6 | Walk-in coolrooms: large | 23.0 | 20.0% | 17.5% | 15 | 70% |
| RCFC1-7 | Beverage cooling (post mix) | 1.60 | 8.0% | 5.0% | 8 | 80% |
| RCFC1-8 | Beverage cooling (beer) | 40.0 | 17.5% | 15.0% | 15 | 70% |
| RCFC1-9 | Water dispensers (incl. bottle) | 0.05 | 2.0% | 1.0% | 8 | 80% |
| RCFC1-10 | Packaged liquid chillers | 60.0 | 12.5% | 10.0% | 15 | 70% |
| RCFC1-11 | Milk vat refrigeration | 40.0 | 25.0% | 15.0% | 20 | 70% |
| RCFC1-12 | Portable refrigerators (commercial) | 0.355 | 2.0% | 1.0% | 14 | 80% |
| RCFC2-1 | Mobile refrigeration: road: trailer - inter-modal | 10.0 | 25.0% | 20.0% | 10 | 70% |
| RCFC2-2 | Mobile refrigeration: road: diesel drive | 7.0 | 25.0% | 20.0% | 10 | 70% |
| RCFC2-3 | Mobile refrigeration: road: off engine | 4.0 | 25.0% | 20.0% | 10 | 70% |
| RCFC2-4 | Mobile refrigeration: marine | 130.0 | 35.0% | 25.0% | 25 | 70% |
| RCFC3-1 | Supermarket refrigeration: small | 160.0 | 20.0% | 15.0% | 15 | 70% |
| RCFC3-2 | Supermarket refrigeration: medium | 600.0 | 15.0% | 12.0% | 12 | 70% |
| RCFC3-3 | Supermarket refrigeration: large | 900.0 | 15.0% | 12.0% | 12 | 70% |
| RCFC4 | Process and large kitchens | 160.0 | 20.0% | 15.0% | 15 | 70% |
| RCFC5-1 | Cold storage and distribution | 80.0 | 15.0% | 15.0% | 15 | 70% |
| RCFC5-2 | Process chilling | 2.00 | 10.0% | 7.0% | 15 | 80% |

The technical understanding of the product categories listed in *Table 11* has evolved over a series of research papers in this area. In the course of various projects all available research in this area was reviewed to build a database of findings and observations of leak rates by other researchers.

Further, a great deal of work was undertaken by the authors in the course of several projects to reconcile consumption of bulk refrigerant gas imports for all major refrigerant species, with all possible end uses of the gas to deduce the total volume of gas required to replace lost gas across the Australian economy.

This top down assessment of bulk gas consumed servicing equipment, when applied to what is known about the stock of equipment, produced results that were remarkably similar to leak rates observed in the field on individual classes of equipment.

The annual leak rate referred to in this report is expressed as a percentage of the initial charge per annum, and is calculated as:

* The sum of gradual leaks during normal operation; plus,
* Catastrophic losses amortised over the life of the equipment; plus,
* Losses during service and maintenance.

In the case of mobile air conditioning equipment, the annual leak rate takes into account losses from vehicle crashes, which are classed as catastrophic losses.

The actual leak rates of different equipment categories vary significantly depending on the class of equipment, refrigerant type, vintage, equipment design (i.e. flared connections, Schrader valves, type of condenser), workmanship of installation, vibration elimination, refrigerant leak detection, maintenance, operating conditions and several other factors.

The main technical papers undertaken by the authors that assisted in determining the leak rate estimates used in this report include:

* *A study into the HFC Consumption in Australia* prepared by the Expert Group for DSEWPaC, Ozone and Synthetic Gas Team, October 2011. This assignment involved the development of a bottom up model of the national inventories of synthetic greenhouse gases in order to reconcile the tonnes of each HFC imported with consumption in key industry sector/sub-sector/applications. This report is unpublished.
* *Giving Teeth to TEWI* prepared by Expert Group for Refrigerants Australia in association with AIRAH Natural Refrigerants Steering Group. This project developed a best practice guideline and methodology for calculating Total Environmental Warming Impact (TEWI) to facilitate more informed investment decisions in low emission technology in the HVAC&R industries. This research commenced in 2010 and resulted in *The AIRAH Best Practice Guidelines: Methods of calculating TEWI* being published in 2012. The guideline includes a range of lower, upper and typical leak rates for key air conditioning and refrigeration applications. The upper range being those cited in the NGERS Technical Guidelines and the NGERS Act 2007 that prescribes 9% for commercial air conditioning, 23% for commercial refrigeration and 16% for industrial refrigeration. Research involving reconciling consumption concludes that whilst these upper leak rates can occur with some systems they are not the current weighted average across the economy.
* *Refrigerant Emissions in Australia: Sources, Causes and Remedies* prepared by Expert Group for DEWHA, Ozone and Synthetic Gas Team, March 2010. DEWHA commissioned this study to establish a greater understanding of the sources and causes of refrigerant leaks and technical standards that could reduce leaks on small to medium commercial refrigeration, and the quantitative benefits of such standards. This study involved extensive research and improved understanding on leak rates found in commercial refrigeration.
* *Leak rate database for Refrigerants Australia, 2009*. This assignment involved developing leak rate benchmarks for each main application supported by a database of global references. This involved investigation into leak minimisation best practice and a greater understanding of the range of factors influencing leak rates.

When considering average economy wide leak rates it is important to recognise that they generally reduce over time. As older equipment retires and is replaced with new designs that employ improved containment, leak rates of the new equipment are generally found to be lower. The evolution of wall hung and ducted split air conditioning equipment demonstrates this evolution in improved design and manufacturing capability, and global economies of scale. This is why older generation equipment containing HCFC-22 have higher leak rates, in the order of 8% per annum, versus current generation models with leak rates of around 4% per annum or less. Reconciling the total service consumption for the existing stock of equipment for each refrigerant type, with bulk imports after deducting consumption for local manufacture, confirms the validity of the leak rates used.

In addition as field practices improve, and as the cost of the refrigerant increases, for instance as the supply of HCFC-22 is restricted, leak rates decline and can do so very rapidly. The Australian supermarket industry is a good example where leak rates at the beginning of the century were thought to be above 20% per annum, and hence the use of a leak rate of 23% in the NGERS Act 2007. Whereas current market intelligence and reconciling consumption shows leak rates of HFC-404A less than half this value within the main supermarket chains.

Other research used to inform these leak rate estimates include the various United Nations Environment Programme (UNEP), Technology and Economic Assessment Panel reports prepared by the Refrigeration, Air Conditioning and Heat Pumps, Technical Options Committee, technical papers by the Institute of Refrigeration in the UK, and a series of papers undertaken by Denis Clodic and his various associates over the last decade for various policy makers is the US and EU.

The average charges listed in *Table 40* are derived from a combination of sources including statistical analysis of pre-charged equipment import data (DSEWPaC 2013), and from supplier data sheets (i.e. averages of most common products by capacity by brand), and other industry design rules of thumb (i.e. commercial refrigeration with remote condensers has twice the pump-down capacity of the liquid receiver for commonly sold models).

Average equipment lifespans were mostly used for calculating end-of-life emissions, except when sufficient historical data was available to develop a detailed retirement function.

The end-of-life factors are generally consistent with others cited internationally (e.g. ICF 2010) and in good practice guides by the IPCC.

1. The GWPs of HFOs has recently re-evaluated by the UN with HFO-1233zd and HFO-1234ze with a GWP of 1; and HFO-1234yf with a GWP of less than 1. This report uses previous cited values to maintain consistency. [↑](#footnote-ref-1)
2. Du Pont and Honeywell have manufacturing plants and Arkema announced the construction of production capacities for new refrigerant fluorinated gas HFO-1234yf in a press release in September 2013. [↑](#footnote-ref-2)
3. Honeywell International Inc. SolsticeTM Gas Blowing Agent and Liquid Blowing Agent brochures. Solstice LBA is a near drop-in replacement for many extrusion processes currently using CO2, HFC-134a and HFC-152a blowing agents. Solstice FBA is a near drop-in replacement for liquid HCFC, HFC, hydrocarbons and other non-fluorocarbon blowing agents. [↑](#footnote-ref-3)
4. HFE substances are fluorinated ethers. [↑](#footnote-ref-4)
5. Honeywell International Inc. SolsticeTM Performance Fluid Brochure. [↑](#footnote-ref-5)
6. The ‘bank’ of refrigerant gases is the aggregate of all HFC, HCFC and CFC refrigerants, and natural refrigerants (excluding large capacity cold storage and process applications where ammonia is widely used as the transition away from HCFCs and HFCs is considered virtually complete) employed as working fluids in the estimated 46.5 million mechanical devices using the vapour compression cycle in Australia. [↑](#footnote-ref-6)
7. ‘Pre-charged equipment’ is defined as refrigeration or air conditioning equipment that contains a HFC or HCFC refrigerant when it leaves the factory gate. [↑](#footnote-ref-7)
8. kWr refers to kilowatts of refrigeration capacity where as kW relates to kilowatts of electrical power. [↑](#footnote-ref-8)
9. The nominal 7% improvement quoted is highly dependent on the style of refrigerator and the efficiency of the components used, in particular available compressor technology. [↑](#footnote-ref-9)
10. *A possible method for assessing consumption in this sector may be to survey major shipping agents. When shipping some types of highly temperature sensitive cargo, refrigeration technicians are required to calibrate the controls on reefers and ensure correct operation of the reefers refrigerated unit. The refrigeration technician provides a certificate to the shipping agent to use as evidence of the proper operation of the reefer prior to loading. These reports to shipping agents, along with other data on the charge sizes and reefer numbers, could be used to estimate demand in this sector.* [↑](#footnote-ref-10)
11. A previous estimate in Cold Hard Facts 2 of around 8% (1,200,000 passenger and light commercial vehicles) in 2012 did not account for cumulative leak rates of the fleet. [↑](#footnote-ref-11)
12. PRIME – a whole of industry pathway to a low emissions future.

    See http://www.airah.org.au/iMIS15\_Prod/AIRAH/PRIME/AIRAH/Navigation/PRIME/PRIME.aspx [↑](#footnote-ref-12)
13. Not all refrigerants need to be reported to Customs at the point of import, however all of the major classes of HCFCs and HFCs, the ‘synthetic greenhouse gas’ refrigerants must be reported. [↑](#footnote-ref-13)