



Cold Hard Facts 3



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Glossary

Ammonia Refrigerant	Anhydrous Ammonia (R717) has excellent thermodynamic properties and a GWP of zero, making it effective as a refrigerant, and is widely used in large cold storage facilities 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 of the Montreal Protocol describes the special situation of developing countries. Article 5 countries are developing countries.
Bottom-up model	Method of estimation whereby the average refrigerant charge contained in individual appliances, equipment and product categories that make up the stock of equipment are estimated separately. The individual results are then aggregated to produce an estimate of the refrigerant bank by refrigerant species.
Bulk importers	Companies with a licence to import bulk refrigerant.
Cascade refrigeration system	A cascade system is made up of two separate but connected refrigeration systems, each of which has a vapour compression refrigerant circuit including a compressor, evaporator and condenser that are interconnected via a heat exchanger. The separate refrigerant circuits work in concert to reach the desired temperature(s). Cascade refrigeration systems are also sometimes referred to simply as an 'advanced refrigeration system'. The most common configuration in Australia is with HFC-134a as the primary refrigerant and R744 (CO ₂) as the secondary refrigerant.
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. The second RAC study was undertaken in 2013 based on 2012 data.
Chlorofluorocarbons (CFCs)	Molecules containing carbon, fluorine, and chlorine. CFCs are one of the major ozone depleting substances phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer. CFCs are also potent greenhouse gases. CFCs and HCFCs are not counted as part of the GHGs reported under the Kyoto Protocol or United Nations Framework Convention on Climate Change, as they managed through the Montreal Protocol.
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. COP is also an efficiency measure used for reverse cycle air conditioners when operating in heating mode. Greenhouse and Energy Minimum Standards for split system air conditioning now use an annualised version of these metrics (AEER and ACOP).
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 kW _r to 20 kW _r , they are composed of one (or two) compressor(s), one condenser, and one receiver assembled into a 'condensing unit'.
CO ₂ refrigerant	Carbon dioxide is a widely used industrial refrigerant with high thermodynamic properties, and 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.
CO ₂ 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.

Direct emissions	Global warming effect arising from emissions of refrigerant from the equipment.
Drop-in refrigerant	Drop-in refrigerant replacements are refrigerants that are intended to replace the original refrigerant with the same refrigerant classification (e.g. A1) and similar technical specification, and keep the system running to the same or similar specification. Examples of HCFC-22/CFC replacements include HFC-422D, HFC-437A, HFC-417A, HFC-422A, HFC-438A, HFC-426A, HFC-424A, HFC-428A, HCFC-508A, HCFC-508B, HCFC-408A and HCFC-409A. Refer to refrigerant supplier instructions for further details.
Energy Efficiency Ratio (EER)	The ratio of the cooling output (kW _r) divided by the total electric energy input. The EER is dimensionless and is used to express the air conditioning system cooling efficiency. Greenhouse and Energy Minimum Standards for split system air conditioning now use an annualised version of this metrics (AEER), refer to COP definition.
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 equipment	Domestic, commercial or industrial device reaching the end of its useful lifespan.
End-of-life (EOL) emissions	End-of-life (EOL) emissions are direct emissions from ozone depleting substance (ODS) and synthetic greenhouse gases (SGG) not recovered for destruction or reclamation.
End-of-life vehicles	Passenger and light commercial vehicles with a gross vehicle mass less than 3.5 tonnes that have been de-registered according to the State and Territory motor vehicle registration authorities (i.e. assumes a one month period of grace with renewals).
Equivalent carbon tax (ECT)	Synthetic greenhouse gases listed under the Kyoto Protocol had an equivalent carbon tax applied through the <i>Ozone Protection and Synthetic Greenhouse Gas Management Act 1989</i> between July 2012 and June 2014. Gases covered were hydrofluorocarbons, perfluorocarbons (excluding gases produced from aluminium smelting) and sulfur hexafluoride, whether in bulk form or contained in equipment.
Equivalent and actual refrigerant charge	Some modern, lower GWP refrigerants, such as hydrocarbons, require much smaller refrigerant charge sizes to do the same work as some older generation higher GWP refrigerants. The 'equivalent charge' is a measure of the amount of high GWP HFC that would have been used in a particular piece or class of equipment had low GWP refrigerants not replaced it. For some charting and visualisation purposes the 'equivalent charge' is then attributed to the lower GWP refrigerant that displaces it. For other measuring and comparison purposes the 'actual' charge of low GWP refrigerants are used. Refer refrigerant charge in glossary.
E3	Equipment Energy Efficiency Committee of the Council of Australian Governments (COAG) which operated under the Ministerial Committee on Energy and was administered by the Department of the Environment and Energy.
Gas	A general term used in reports where applications extend beyond refrigeration and air conditioning equipment as a working fluid and include fire protection, aerosols and foam blowing. The term refers to ozone depleting substances, synthetic greenhouse gases and natural refrigerants.
Global Warming Potential (GWP)	Global warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. A GWP is calculated over a specific time interval, commonly 20, 100, or 500 years and is expressed as a factor of carbon dioxide (whose GWP is standardised to 1). The Kyoto and Montreal Protocol are based on GWPs from pulse emissions over a 100-year time frame abbreviated as GWP-100.
Greenhouse Gases (GHG)	The Kyoto Protocol 2 nd commitment period covers emissions of seven main greenhouse gases, namely carbon dioxide (CO ₂); methane (CH ₄); nitrous oxide (N ₂ O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulfur hexafluoride (SF ₆) and nitrogen trifluoride (NF ₃).
GWh	Gigawatt hours is a unit of measurement for electricity use (1 watt hour x 10 ⁹).
High GWP substances or refrigerants	For the purposes of this report this term is used to refer to refrigerants commonly used today with GWPs greater than 1400. This includes the widely employed HFC-404A (GWP of 3922), HFC-410A (GWP of 2088) and HFC-134a (GWP of 1430). Refer to definition of reduced GWP refrigerants and low GWP refrigerants.
Hydrocarbons (HCs)	Hydrocarbon is a chemical that contains only carbon and hydrogen. The term hydrocarbon used in this report refers to the main types and blends of hydrocarbon refrigerant 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). Hydrocarbons are now widely used in self-contained commercial refrigeration applications with refrigerant charges less than 150 grams. Hydrocarbons are not used as an OEM refrigerant in mobile air conditioning in any production vehicles. HC-436 is a hydrocarbon blend that is sometimes used in the mobile air conditioning after-market (users should refer to equipment manufacturer installation guidelines for further details).
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. CFCs and HCFCs are not included in the GHGs reported under the Kyoto Protocol or United Nations Convention on Climate Change, as they are managed through the Montreal Protocol.
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 and HFO-1234ze were originally cited by industry to have a GWP of 5, and a GWP-100 of 1 based on AR5. Refer <i>Section 3.4</i> for further details.
HVAC&R	Heating, ventilation, air conditioning and refrigeration
Indirect emissions	The CO ₂ 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 CO ₂ emission factor is the mass of CO ₂ emitted by the power generator per kWh of electrical power supplied to the refrigeration installation taking into account efficiency losses in generation and distribution.
Kigali Amendment	The Kigali Amendment to the Montreal Protocol agrees a phase-down of HFC production and imports starting from 1 January 2019.
kWr	Refers to kilowatts of refrigeration capacity whereas kW relates to kilowatts of electrical power.
KWh	Kilowatt hour (1 watt hour x 10 ³).
Kyoto Protocol	The Kyoto Protocol sets binding emissions limits for the seven greenhouse gases listed in the Protocol. The Australian Government has committed to reducing emissions of the seven main greenhouse gases, which includes the synthetic greenhouse gases (SGGs) listed under the Kyoto Protocol, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF ₆) and nitrogen trifluoride.
Lifespan	Lifespan is the expected useful life of the equipment in years.
Low GWP substances or refrigerants	For the purposes of this report this term is used to refer to refrigerants with a GWP of less than or equal to 10, including the 'natural' refrigerants (CO ₂ , ammonia, hydrocarbons), and the newly commercial HFOs sometimes referred to as low GWP HFCs. Refer to the definitions for High GWP Refrigerants and Reduced GWP Refrigerants.
Low temperature refrigeration	Temperatures below 0°C.
Minimum energy performance standards (MEPS)	The Minimum Energy Performance Standard is a specification, containing a number of performance requirements for energy-using devices that effectively limits the maximum amount of energy that may be consumed by a product in performing a specified task. MEPS is regulated under the Greenhouse and Energy Minimum Standards Act 2012 and in the RAC sector covers domestic refrigerators, refrigerated display cases, and most air conditioners (excluding single duct portable, spot coolers, and chillers below 350 kW _r).
Montreal Protocol	The Montreal Protocol on Substances that Deplete the Ozone Layer sets binding obligations for all countries to phase out import and production of ozone depleting substances and phase-down obligations for HFCs.

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) and are controlled under the Montreal Protocol. The Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 controls the manufacture, import and export of ozone depleting substances in Australia.
PJ	Petajoule (1 Joule x 10 ¹⁵).
Pre-charged equipment (PCE)	Pre-charged equipment is defined as any equipment, primarily air conditioning equipment or refrigeration equipment, (including equipment fitted to a motor vehicle) that is imported containing a SGG and any air conditioning or refrigeration equipment that is imported containing a HCFC.
RAC	Refrigeration and air conditioning.
RAC Stock model	The Expert Group RAC Stock Model is an age-cohort mass balance stock model. Inputs include bulk imports by HFC and HCFC species since 2005; pre-charged equipment (PCE) imports by HFC species by equipment class since 2005; PCE containing HCFCs (largely banned in 2010); motor vehicle registrations; monthly sales (\$ and quantity) of HCFCs and HFCs by species including refrigerant re-use; equipment sales data (air conditioning and refrigeration equipment by type); data from targeted surveys including usage of HFC-134a in mobile AC aftermarket; annual sales of natural refrigerants (HC, CO ₂ and ammonia) last 5 years; retail market survey of HC in domestic refrigerators on showroom floors; penetration of CO ₂ in various equipment categories and applications; and, in-confidence interviews.
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 with a value of 1 indicating that the entire charge is recovered.
Reduced GWP substances or refrigerants	This term has been used for the purpose of this report. A number of recently developed or used HFC substances or refrigerants that have significantly reduced GWP relative to those commonly used high GWP refrigerants they are designed to replace. HFC-32 (GWP 675) and blends with GWPs less than 1400 and greater than 10, are referred to as reduced GWP refrigerants. For example, N40 (R-448A) with a GWP of 1387 is a zeotropic blend designed to serve as a replacement for HCFC-22 (GWP of 1810) and HFC-404A (GWP of 3922) in supermarket refrigeration retrofits, or in new systems. Refer to definition of High GWP Refrigerants and Low GWP Refrigerants.
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 with more than 50 million mechanical devices using the vapour compression cycle in Australia. Refrigerant in pre-charged imports is included in this value in the year of import. Refrigerant in equipment that is estimated to have retired from service in any year is not included. The 'Full Bank', or fully charged bank, is calculated based on the number of devices in the product category multiplied by the average original charge of that type of equipment when it is initially installed/purchased. The 'Partially Charged Bank' generally referred to in this report simply as 'the Bank', or sometimes as the 'working bank', will in practice, be less than the fully charged bank as the charge in individual pieces of equipment in the category declines over time until the equipment retires.
Refrigerant charge	The original refrigerant charge of refrigerant used as the working fluid for heat transfer inside a piece of equipment.

Refrigerant classifications AS/NZS ISO 817: 2016 Refrigerants - Designation and safety classification assigns safety classification to refrigerants based on toxicity and flammability data; and provides a means of determining the refrigerant concentration limit.

	Safety Group	
	Lower Toxicity	Higher Toxicity
Higher Flammability	A3	B3
Flammable	A2	B2
Lower Flammability	A2L	B2L
No Flame Propagation	A1	B1
<p>A1 group refrigerants include the majority of HFCs and HCFCs. A2L group refrigerants include HFO-1234yf and HFC-32. B2L group refrigerants include R717 (Ammonia). Refer to AS/NZS ISO 817, Supplier Material Data Sheets and equipment supplier Installation Guidelines for further details.</p>		

Refrigerant consumption The Montreal Protocol definition of consumption is bulk imports plus refrigerant manufacture minus bulk exports. Australian has not manufactured refrigerant since 1996. Bulk refrigerant is imported and used largely for servicing the existing refrigerant bank of equipment, as well as charging new equipment not imported as pre-charged equipment (PCE) and in other applications including foams, fire protection, aerosols, export and other. Refer definition refrigerant usage.

Refrigerant decanting into tradable quantities There are three significant import/decanting facilities in Australia. Gas is decanted at these sites into thousands of cylinders ranging in size through 10 kg, 18 kg, 60 kg and larger transportable tanks. Transportable tanks with a volumetric capacity of approximately 900 litres are commonly referred to as 'one tonners', and 'half tonners' for tanks with a 450 litres capacity. These transportable tanks can contain between 400 kg and 700 kg of product depending on the gas involved.

Refrigerant glide The difference between the saturated vapour temperature (or dew point, 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 or effective leak rate The leak rate referred to in this report is expressed as a percentage of the initial charge lost per annum and is calculated as the sum of gradual leaks during normal operation plus: catastrophic losses amortised over the life of the equipment; losses during service and maintenance; and, gas is lost along the supply chain. 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.

Refrigerant reclamation Refrigerant reclamation refers to the reprocessing of used refrigerants to AHRI 700 specifications, most commonly by a process of fractional distillation. AHRI 700 establishes purity specifications and specifies methods of testing for fluorocarbon refrigerants to verify composition regardless of source (new, reclaimed and/or repackaged). The quality of the reclaimed product must be verified by chemical analysis and meet or exceed AHRI 700 specifications which are the same standards required of virgin refrigerants.

Refrigerant recovery Recovery refers to the removal of refrigerants from equipment and collection in an approved recovery container. As defined by the AHRI, recovery does not involve processing or analytical testing.

Refrigerant species A refrigerant 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.

Refrigerant usage	Refrigerant usage is the refrigerant used in the economy installing and manufacturing new equipment and maintaining existing equipment. Refer definition refrigerant consumption.
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 (condensing unit or refrigeration plant) sited remote from the cabinet structure that is located inside the supermarket or store.
Self-contained RDC	Refrigerated display cabinet with its refrigerating machinery sited inside the cabinet structure.
Second Assessment Report (AR2)	Second Assessment Report of the Intergovernmental Panel on Climate Change for the United Nations Framework Convention on Climate Change, released in 1996. Australia's legally binding emission obligations under the first Kyoto Protocol commitment period were calculated based on AR2.
Fourth Assessment Report (AR4)	Fourth Assessment Report of the Intergovernmental Panel on Climate Change for the United Nations Framework Convention on Climate Change, released in 2007. Australia's legally binding emission obligations under the second Kyoto Protocol commitment period are calculated based on AR4. AR4 GWP values are used throughout this report, unless stated.
Specific Energy Consumption	Energy consumption benchmark used in large cold storage facilities in kWh per m ³ per annum.
Synthetic greenhouse gases (SGGs)	SGGs listed under the Kyoto Protocol and regulated under the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 , hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) sulfur hexafluoride (SF ₆) and nitrogen trifluoride (NF ₃).
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 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 2°C and frozen -20°C.
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 of the IPCC
AR4	Fourth Assessment Report of the IPCC
ABS	Australian Bureau of Statistics
ANZSCO	Australian and New Zealand Standard Classification of Occupations
ARC	Australian Refrigeration Council
BCA	Building Code of Australia
CHF	Cold Hard Facts
CO ₂ e	Carbon dioxide equivalent
DoEE	The Department of the Environment and Energy, formerly: Department of the Environment (DoE) Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) Department of Climate Change and Energy Efficiency (DCCEE) Department of Environment, Water, Heritage and the Arts (DEWHA)
ELV	End-of-life vehicle
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	Kilotonnes, or thousand tonnes
LPG	Liquefied petroleum gas
L	Litre
MEPS	Minimum energy performance standards
MAC	Mobile air conditioning
MJ	Megajoule, or million joules
Mt	Megatonne, or million tonnes
ODS	Ozone depleting substances
OEM	Original equipment manufacturer
OHS	Occupational Health and Safety
OPSGGM Act	Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, including amendments
PCE	Pre-charged equipment
PJ	Petajoule, or 10 ⁹ Joules
RAC	Refrigeration and air conditioning
RCFC	Refrigerated cold food chain
RHL	Refrigerant handling licence

ROI	Return on investment
RRA	Refrigerant Reclaim Australia
RTA	Refrigerant trading authorisation
SEC	Specific Energy Consumption
SGG	Synthetic greenhouse gas
TAFE	Technical and Further Education
Tonne or t	Metric tonne
UNFCCC	United Nations Framework Convention on Climate Change

1 Executive summary

The refrigeration and air conditioning (RAC) industry is an essential part of the Australian economy. Without its services our major cities and much of our agriculture, telecommunications and health sectors would not be able to function as they presently do.

This report presents the findings of a detailed examination of the RAC industry in Australia. Using data largely from primary sources on supply of goods and services in the industry in 2016, Cold Hard Facts 3 (CHF3) has been able to make comparisons with two previous studies published in 2007 (CHF1) and in 2013 (CHF2).

This study aims to provide policy makers, industry, and any of the general public who may be interested, with a broad view of the size and value of the industry. The Cold Hard Fact series of reports also establishes benchmarks for the industry that can be used in future years as reference points against which to measure growth and change.

The most obvious responsibility of the industry is the essential service of refrigeration it delivers in the production, preservation and transport of all seafood, dairy products, meat and poultry products, beverages, confectionary and frozen foods, from farm to domestic refrigerator or to export. Perishable food production in Australia in 2016 was worth an estimated \$38 billion.

In the process these refrigerated and frozen foods pass through tens of thousands of cool rooms and are served and sold through hundreds of thousands of restaurants, grocery stores, delis, takeaways, more than 4,000 supermarkets, thousands of clubs, hotels, and hundreds of pre-made meal and home delivery enterprises, all of which employs more than 38,000 refrigerated trucks in the process.

Specialised and energy intensive RAC services are vital for the operation of the country's hospitals and pharmaceutical supply lines. RAC systems also provide the essential climate control services for millions of workers and visitors in non-residential buildings. RAC systems maintain tightly controlled operational temperatures for the thousands of data centres that run our telecommunications, internet, banking and finance systems.

Air conditioning is now installed in the majority of the country's estimated 8 million homes and in the majority of the country's nearly 18 million registered road vehicles.

Around 300,000 people are employed in more than 20,000 businesses operating in the RAC industry. Those employees earned approximately \$24 billion in wages and salaries in 2016. A proportion of these wages are earned in the process of designing, delivering and installing new equipment in supermarket refrigeration systems, large commercial air conditioning systems, a huge variety of specialised and bespoke industrial and commercial RAC systems and residential AC systems. However, a large portion of this wages bill is earned servicing the very large national stock of already installed equipment and driving the refrigerated transport fleet.

Nearly \$8.1 billion was spent purchasing and installing new equipment in 2016, and a further \$161 million is estimated to have been spent on the refrigerants that make up the refrigerant 'charge' found in every piece of RAC equipment that uses the vapour compression refrigeration cycle. To avoid double counting expenditure, a 'discounted wages cost' has been calculated, that when added to the cost of hardware purchases, refrigerant purchases and the cost of energy consumed arrive at an overall figure of some \$38 billion spent on purchasing, installing, maintaining and operating RAC equipment and services in 2016. This total expenditure on RAC was equivalent to 2.3% of national GDP in 2016.

The question of the total value of the services that the RAC industry provides to its clients, such as the value added to agricultural produce moving through the cold food chain, is difficult to determine. Setting aside all of the essential services to health, telecommunications and the built environment, if just the value of perishable food products in 2016 was also attributed to the RAC industry, that additional value alone would double the economic impact of the industry in Australia.

RAC technology in all its forms is the single largest electricity consuming class of technology in Australia. There are more than 54 million individual pieces of RAC equipment operating in Australia that consumed

more than an estimated 61,000 GWh of electricity in 2016, slightly more than 23.6% of the 258,000 GWh of electricity production in Australia that year.

Owners of RAC equipment spent an estimated \$14 billion to pay for that electricity and the liquid fuels required to run mobile AC and mobile refrigeration systems.

Table 1: Main economic indicators of RAC industry activity 2016.

Expenditure categories	Economic spend in 2016 (\$ Billion)
New hardware costs installed	\$8.18
Annual refrigerant cost to end user	\$0.16
Energy costs to end users	\$14.04
Discounted wages cost	\$15.73
Total spend	\$38.11

This vast stock of equipment, from small portable refrigerators and air conditioners to enormous commercial chillers and refrigeration plants, employs a bank of more than 50,000 tonnes of synthetic refrigerants that have high global warming potential (GWP) values. The bank of refrigerant has an estimated current replacement value of around \$2.7 billion.

Nearly 5,400 tonnes of low GWP refrigerants are also found working in major refrigeration plants, mostly in cold storage distribution facilities, in more than 740,000 registered road vehicles, in an increasing number of supermarket refrigeration systems and in millions of domestic refrigerators.

As a result of the huge quantity of electricity used, and leaks from the significant bank of high GWP refrigerants employed, use of RAC equipment can be considered one of the largest sources of greenhouse gas emissions in Australia.

Total indirect greenhouse gas emissions from electricity consumption by RAC are estimated to be 58.7 Mt CO₂e per annum, equivalent to 10.9% of Australian national greenhouse emissions in 2016 (DoEE 2018).¹

Annual losses of HCFC and HFC refrigerants directly to air from operating RAC systems are calculated to be equal to another 6.4 million tonnes CO₂. A further 3.6 million tonnes CO₂e of refrigerants are lost annually from equipment retired at the end of its useful life. The resulting total direct and EOL emissions of HCFCs and HFCs in Australia in 2016 equates to 10 million tonnes of CO₂e. Around 29% of these 2016 emissions of refrigerants (direct 0.85 million tonnes CO₂e and EOL 2.06 million tonnes CO₂e) were the result of HCFC² emissions, the balance were HFC emissions.

It is important to note that under the terms of the UN Framework Convention on Climate Change, for which the Australian Government prepares and publishes the annual Australian National Greenhouse Gas Inventory (NGGI), there is no requirement to report the global warming impact of emissions of HCFCs. CHF3 calculates the CO₂e values of HCFC emissions to provide a comparative measure of the scale of HCFC losses to air for the RAC industry. As such the CHF3 estimates of the CO₂ equivalent value of direct and EOL emissions of refrigerants cannot be compared with those published in the NGGI, which only reports HFCs.

¹ Total Australian emissions reported by the NGGI for calendar year 2016 were 533 Mt of CO₂e. National Inventory by Economic Sector, DoEE Feb 2018.

² As well as being potent greenhouse gases, HCFCs are Ozone Depleting Substances.

CHF3 calculates that RAC technology was responsible for total greenhouse gas emissions equivalent to approximately 68.7 million tonnes CO₂e in 2016 (including HCFCs), equivalent to 12.4% of all greenhouse gas emissions reported in Australia's National Greenhouse Gas Inventory for 2016.³

Based on the 2016 analysis, and prior studies, CHF3 provides projections of RAC industry activity and refrigerant use in the Australian economy out to 2030.

All indicators point to continued strong growth in demand for refrigeration and air conditioning services in the years ahead, driven by the same mix of factors that has seen an expansion of the refrigerant bank by more than 50% over the last decade from 2006 to 2016 - a strong economy, population growth, reduced costs of equipment, and higher summer temperatures.

The absolute quantum of combined HCFC and HFC refrigerant losses is expected to rise throughout the projection period. This is an inevitable result of the total stocks of RAC equipment employed in the economy continuing to steadily grow, and stocks of older equipment more likely to employ HCFCs being taken out of service. However the CO₂e value of annual direct emissions from operating equipment, excluding EOL emissions, is expected to fall by more than 27% from an estimated 6.4 million tonnes CO₂e now to 4.7 million tonnes CO₂e in 2030. This reflects the expected rate of transition of the bank to the use of lower GWP HFCs, and increasing use of low GWP non-HFC refrigerants.

As the growing stocks of RAC equipment are retired and replaced through the projection period, a corresponding rise in EOL emissions is also expected. The CO₂e values of EOL emissions are likely to fall more slowly than those of direct emissions, as the refrigerants released from EOL equipment will lag the rate of change of the bank to lower GWP refrigerants.

Importantly, during the last decade total energy consumption of RAC equipment has grown at a slower rate than growth in the stock of equipment. More efficient equipment designs, coupled with better performing refrigerants that are better contained, combine to reduce energy consumed across the life of the equipment.

Projections of the bank predict the peak GWP value of the bank will be reached around 2020 at more than 102 million tonnes of CO₂e, before beginning to decline steadily as new generations of lower GWP refrigerants are introduced to the stock of equipment.

The CO₂e value of the bank reduces to an estimated 80 million tonnes CO₂e by 2030. Similarly, the GWP of direct emissions from supply lines and operating equipment, and eventually from end-of-life equipment, falls as the average GWP of the bank falls in line with the phase down of HFC imports and their replacement with lower GWP refrigerants.

³ The estimates of greenhouse gas emissions in CHF3 are derived from a purpose-built model of RAC stock. The emission factors used to calculate indirect and direct emissions in CHF3 are based on National Greenhouse Accounts Factors July 2017, Department of the Environment and Energy. CHF3 estimates of refrigerant emissions value does not include the refrigerant collected and destroyed by Refrigerant Reclaim Australia (RRA). Collections destroyed by RRA in 2016-17 FY totalled 324 tonnes, assuming an average GWP of 1800 this equates to around 0.6 million tonnes CO₂e.

2 Introduction

Cold Hard Facts 3 (CHF3) is the third edition of the *Cold Hard Facts* series. This report presents a technological and economic snapshot of the refrigeration and air conditioning (RAC) industry in Australia in 2016 and compares the main findings with the findings of the previous editions of the series published in 2007 and 2013.⁴

The Cold Hard Facts series includes both a written report and an extensive database built on a stock model of all RAC equipment employed in the Australian economy. Developed over more than a decade, it is believed that the Expert Group '*RAC Age-Cohort Mass Balance Stock Model*' is the most comprehensive and extensive stock model of RAC equipment for any economy in the world. The model has been able to provide unique insights into the changing face of this industry in Australia, benefitting policy makers and the industry.

The equipment that is used in this industry is often referred to as HVAC&R equipment (heating, ventilation, air conditioning and refrigeration equipment), and the industry itself is often referred to as the HVAC&R industry.

However, this report excludes gas heating and evaporative cooling from the analysis, and in most cases does not include fan energy in ventilation. Notably throughout the report the industry being studied is referred to as the RAC industry, and the stock of equipment is a stock of RAC equipment, with rare exceptions.

This extensive, bottom-up, stock model provides detailed insights into a significant portion of the economy that primarily provides one energy service – cooling - in an extraordinary range of applications and for a great many different purposes.⁵

The RAC Stock model has been built largely from primary data, including equipment and refrigerant imports, manufacturer and sales surveys, licensing data and numerous other sources of data from various component supply lines such as suppliers of compressors, condensing units and evaporators.

The stock model allows analysis of equipment stocks in more than 50 product categories using parameters including refrigeration capacity, average refrigerant charge, leak rates, hours of use based on location and climate zone, retirement rates, and energy use. As a result, the CHF3 model can calculate the scale of the total bank of working refrigerant employed in Australia, or the bank in any category of equipment, estimate the electricity consumed, the total value of the equipment involved and several other outputs that ultimately allow us to produce an estimate of the size of the industry and of the cooling economy.

Taking into consideration the common and nation-wide extent of the services provided, the wide range of RAC applications and the number of dependent industries that must have reliable, affordable cooling and refrigeration services to operate, the entire activity can be considered in its own right as 'the cooling economy'.

Most importantly this cooling economy is reliant on a significant bank of refrigerant - the thermal media that facilitates the primary energy service of moving heat from one point to another to control the temperature of an enclosed space.

As such the cooling economy is the main consumer of, and emitter of a variety of refrigerants that include classes of ozone depleting substances (ODS) and synthetic greenhouse gases (SGGs) that are the subject of international treaties and are regulated in Australia.

⁴ At the time of the first *Cold Hard Facts* report, published in 2007 using 2006 data, the possibility of a series of *Cold Hard Facts* investigations and reports being done over the course of many years had not been considered. As such many of the findings in 2012 and 2016 have no comparable data point in the first edition.

⁵ While cooling services are the sole function of refrigeration systems, an increasing portion of the stock of smaller formats of stationary air conditioning equipment also provides space heating in reverse cycle mode. Heating can also be supplied by other technologies entirely or partially (e.g. gas ducted heater with add on refrigerative cooling). When air conditioning is installed it is primarily purchased and sized to provide space cooling.

CHF3 reveals significant changes underway in the cooling economy, and throughout the RAC industry. The changes are evident in the changing shape of the bank of working refrigerants. The report includes projections out to 2030 of the changing constituents of the bank of refrigerant, shaped by technological changes, market forces and regulatory drivers.

CHF1 was downloaded 45 times a month on average until the publication of the CHF2 report and database in 2013. CHF2 has been available for download from the Australian Government's Department of the Environment and Energy's website for around five years and has been viewed around 4,000 times over that period equating to more than 60 times per month on average. To the best of our knowledge there is still no similar study of the RAC industry anywhere else in the world.

In the course of the last decade a number of other research projects conducted by the authors into various sectors of the RAC industry have helped expand the stock model and provided further detail and insights into some of the many specialised segments within this sprawling and varied industry.

2.1 Structure of Cold Hard Facts 3

For readers who are not familiar with the RAC industry, it may be effective to take a few minutes to read the glossary which explains many of the key terms commonly used in the industry.

The structure of this report mirrors, to some extent, the operation of the stock model, examining the populations and attributes of the array of equipment involved in delivering refrigeration and air conditioning services, and then exploring the mostly imported, and some locally manufactured, inputs to this ever-growing stock.

This data underlies the next section that examines the stock of equipment and the changing characteristics of that stock. The report then examines the bank of refrigerant employed in the stock of equipment and the major environmental impacts of the industry. Finally, the outputs of the model are incorporated in a process of estimating the economic value of the RAC industry in Australia.

Throughout the report there are comparisons made with some of the main data points reported in prior editions of Cold Hard Facts, and these comparative measures are often summarised in tables that compare at least the 2012 and 2016 values.

Appendices to the report explain the main elements of the methodology used in the CHF3 RAC stock model as well as outputs and projections that are the product of the model, which is constructed in a separate Excel work book.

Following on from the *Executive Summary* and *Introduction*:

Chapter 3, 'Taxonomy of technology' is a brief explanation of the way the many applications of refrigeration and air conditioning are categorised.

Chapter 4, 'The stock of equipment', employs the taxonomy of the technology to describe the variety of equipment that delivers RAC services, describing all of the major equipment applications, the format and design features of the equipment in each of the major applications, and the refrigerant predominantly used in each application.

Chapter 5, 'The refrigerant bank', explores the dimensions and characteristics of the bank of refrigerant, examining the economic and technological forces that drive the growth in the bank of refrigerant, trends observed in the make-up of the bank, and detailing the refrigerant types most commonly used in the major equipment types.

Chapter 6, 'Natural refrigerants', provides a summary of the technologies that operate on natural refrigerants, and an assessment of bank and annual consumption for the main species; hydrocarbon, carbon dioxide and ammonia.

Chapter 7, 'The future bank – projections of the bank to 2030', presents a series of projections of the changing demands for refrigerant and the impacts those changes have on the refrigerant bank.

Chapter 8, 'Refrigerant use and direct emissions', examines the annual usage of refrigerant, rates of losses to air of refrigerants from the supply lines and from operating equipment, and looks at the state of the banks in individual classes of equipment depending on the rate at which they are serviced.

Chapter 9, 'Energy and indirect emissions', analyses the energy used to deliver RAC services and the greenhouse emissions that result from it.

Chapter 10, 'Economics and employment', presents estimates of direct spending and employment in the industry and touches on some of the elements of the wider economy that are effectively dependent on the delivery of RAC services.

3 Taxonomy of a technology

At the core of RAC technology is the vapour compression refrigeration process. This process, invented and patented by James Harrison⁶ in Geelong Victoria, in the 1850s, is the technical foundation of the transformative technology of modern refrigeration.

At its simplest level the industry relies on the physical stock of equipment that delivers the energy services of cooling, refrigeration and, in some cases, heating.

These energy services are delivered by an enormous stock of highly varied equipment, all employing the refrigerants that act as a medium to transfer heat, and the electricity (or liquid fuel in the case of mobile air conditioning or truck refrigeration) that is necessary to drive the compressors and fan motors that are the two main electro-mechanical components of all RAC equipment.

The range of formats in which RAC equipment is manufactured is very wide. To manage the large number of equipment formats and end-use applications the authors, over the years, have found it useful to develop a taxonomy of the technology, categorising the equipment types based on end-uses, refrigerating capacity, and features such as the condenser type (remote or self-contained), refrigerant charge sizes, electricity requirements (single or three phase) and the physical formats of products.

This system of classification works across the spectrum of RAC technology including air conditioning equipment types that use vapour compression refrigeration technology.

This RAC Taxonomy uses a system of classification that involves four broad ‘classes’ as a starting point, comprised of fourteen ‘segments’, which cover more than fifty ‘product categories’.

The classes of RAC equipment are:

- **Stationary air conditioning (AC)**, the largest class in the stock model, providing comfort conditions and technical services using systems that range from small split air conditioning systems and portable units, up to very large chiller driven systems used for space cooling, with extensive ducted distribution of air. This class includes close temperature control and extremely fine air quality systems employed in infrastructure, laboratories, hospitals and other specialised controlled environments;
- **Mobile air conditioning (MAC)**, a class that includes large numbers of very small systems for passenger cars, incorporating air conditioning in all private and commercial, registered and unregistered road, rail, marine and aviation transport;
- **Refrigerated cold food chain (RCFC)**, a broad and complex class of equipment involved in preserving perishable food stuffs and captures all commercial, process and industrial refrigeration employed from farm, through transport refrigeration, to the final retail food outlet; and,
- **Domestic refrigeration (DR)**, a class of small equipment that ranges from the tiny portable refrigerators found in caravans, the small ‘bar fridges’ found in nearly every hotel room and workplace, to the ‘tub’ freezer and the sometimes very large double door fridge freezer combinations that are found in homes but also in commercial kitchens, restaurants, takeaways and sandwich shops.

These four *classes* are divided into the 14 technology *segments* and 59 product *categories* as discussed in *Appendix A, Section 11.1: Taxonomy of a technology*.

The RAC Stock model, the interactive database that underlies this report, is built on these 59 product categories.

For the purpose of modelling, some categories are further dissected in the model into ‘capacity bins’ to provide more precise energy consumption modelling (e.g. AC1-1: split systems: non-ducted: single-phase, is dissected into four capacity bins of 0 to 4 kW_r; 4 to 6.5 kW_r; 6.5 to 8.5 kW_r and >8.5 kW_r, as the stock levels are significant, and the energy efficiency ratios vary depending on the refrigerating capacity of the products).

⁶ <http://adb.anu.edu.au/biography/harrison-james-2165>

Data in the majority of these product categories is discussed in *Chapter 4: The stock of equipment*. Even with this number of categories, some categories are still quite large, covering a number of different formats and sizes and many individual manufacturer brands and models.

As the quality of the data discovered or developed by the authors in the course of the last decade has improved, greater resolution has been achieved in various product categories, and resulted in some changes to the taxonomy to reduce uncertainty in model outputs.

The authors acknowledge that to further increase confidence in the data, in some areas, more definitive stock surveys would be valuable and are always interested in opportunities to work with industry to improve the stock model data. Assumptions and factors used in the CHF3 RAC Stock model and applied to each equipment class, segment or category are set out in *Appendix A*.

A list of the main commercial and industrial applications where RAC systems are found across the Australian economy is provided in *Appendix A: Section 11.4: HVAC&R Supply chain business types and end use applications*. This list provides a view of the essential role of the technology in the economy, that the Taxonomy does not directly provide.

4 The stock of equipment

4.1 The scale of events

The Expert Group RAC Age-Cohort Mass Balance Stock Model (RAC Stock model) shows that RAC equipment in all its forms is delivered in Australia via over 54 million individual pieces of equipment (*CHF2, 45 million*). The stock model also estimates that in the last few years Australians have spent around \$8.2 billion (*CHF2, \$5.8 billion*) every year buying and installing new devices across all classes of RAC equipment.

Every year an estimated 2 million devices containing more than 1,990 tonnes of refrigerant reach the end of their useful life, including 110 tonnes in domestic refrigerators and freezers, 1,240 tonnes in air conditioners, 420 tonnes in motor vehicles of all types, and 220 tonnes in commercial refrigeration equipment.

The authors note frequent anecdotal reports of refrigeration and air conditioning equipment that continues to operate for many decades, well beyond the average life used in the stock model.⁷

While these anecdotes do not provide a sufficient basis for adjusting the assumptions on average equipment life that are used, they are persistent, and frequently report similar types of equipment as being particularly long lasting. Many people, for instance, are likely to have encountered a 25, 30 or even 40 year old domestic refrigerator that still runs, possibly as a ‘beer fridge’ in someone’s garage. Industry participants also report exceptional longevity in some well-made commercial refrigerators and in medium sized commercial space chillers.

Another indicator of some classes of long lasting equipment still operating is the continuing presence of chlorofluorocarbons (CFCs) in the stream of waste refrigerant delivered for destruction (see *Section 8.7: End-of-life emissions and RRA data*). The importation and manufacture of CFCs was banned from 1996, and while some of the waste CFCs delivered for destruction may arrive in old 44 gallon drums (i.e. still in the bulk container that it was purchased in), some of it is certainly being recovered from equipment only now being decommissioned at end-of-life (or possibly even old equipment being refurbished and having the gas charge replaced).

What this illustrates is that some of the millions of pieces of RAC equipment introduced to the economy every year will continue to be operational for decades and that, even while global agreements are driving the industry towards the use of lower GWP refrigerants, older generations of refrigerants will still be either lost to the atmosphere or recovered for destruction for many years into the future.

Each of the four main classes of equipment is discussed in detail in the sections that follow.

⁷ Estimates of the average life of individual equipment categories are tabulated and explained in Table 38.

4.2 Stationary air conditioning

Stationary air conditioning equipment contains the largest portion of the bank of refrigerant, uses the largest portion of annual bulk refrigerant imports, and consumes more electricity than any of the other classes of equipment in the RAC industry.

Stationary air conditioning and heat pumps as a broad class of equipment includes all forms of stationary equipment that use the vapour compression cycle to provide human comfort in buildings of all sorts, and to provide close temperature control in data processing areas, medical facilities and scientific laboratories.

This class of equipment is a very broad group that includes equipment that can operate in reverse-cycle (heating and cooling) or cooling only, on single phase or three phase power and ranges in size from small 2 kW_r domestic portable air conditioners, with a refrigerant charge of less than 600 grams, to large 4,000 kW_r commercial space chillers containing more than a tonne of refrigerant in a single machine.

This class includes heat pumps used for other applications such as heating water, heating swimming pools and drying clothes. Evaporative air conditioning that does not use a vapour compression cycle is not included, although in recent years small and large indirect evaporative systems sometimes referred to as hybrid renewable technology have emerged as a viable technology to displace vapour compression technology in some instances.

The four major segments and eighteen product categories that make up this class account for approximately 61% of the bank of refrigerant in Australia, around 31,200 tonnes, in more than 14.4 million devices. Stationary air conditioning required an estimated 1,040 tonnes of HFC refrigerant for service, charging new equipment, retrofitting existing equipment, and use by original equipment manufacturers (OEMs) in 2016.

Table 2: Stationary air conditioning taxonomy.

STATIONARY AIR CONDITIONING				
Item no	Segment	Application	Category code	Product category
1	AC1: Small AC: Self-contained	Window/wall	AC1-1	Non-Ducted: Unitary 0-10 kW _r
2		Portable AC	AC1-2	Portable AC: 0-10 kW _r
3	AC2: Small AC: Split	Single split: non-ducted	AC2-1	Single split system: Non-ducted: 1-phase
4		Single split: non-ducted	AC2-2	Single split system: Non-ducted: 3-phase
5	AC3: Medium AC: Ducted & light commercial	Domestic & light commercial	AC3-1	Single split system: Ducted: 1-phase
6		Domestic & light commercial	AC3-2	Single split system: Ducted: 3-phase
7		Light commercial	AC3-3	RT Packaged systems
8		Domestic & light commercial	AC3-4	Multi split
9		Light commercial	AC3-5	VRV/VRF split systems

STATIONARY AIR CONDITIONING

Item no	Segment	Application	Category code	Product category
10	AC3: Medium AC: Ducted & light commercial	Light commercial	AC3-6	Close control
11		Light commercial	AC3-7	HW heat pump: commercial
12		Domestic & light commercial	AC3-8	Pool heat pump
13	AC4: Large AC: Chillers	Chillers	AC4-1	<350 kW _r
14		Chillers	AC4-2	>500 & <1000 kW _r
15		Chillers	AC4-3	>500 & <1000 kW _r
16		Chillers	AC4-4	>1000 kW _r
17	AC5: Other	HW Heat pump	AC5-1	HW heat pump: domestic
18		Heat pump clothes dryers	AC5-2	Heat pump clothes dryers

Notes:

1. New segments in the 2016 Taxonomy such as AC5-2 Heat pump clothes dryers are highlighted in blue.

Several of the product categories in this class capture a wide range of technology formats. The technology covered by each product category is expanded upon below.

- AC1-1: Packaged room air conditioning units intended to be inserted through a hole in a wall or through a window aperture of a home, shop or worksite demountable building. This is a declining and now predominately a replacement market and generally referred to as ‘window/wall’ units;
- AC1-2: Dehumidifiers and portable air conditioning for domestic use, and portable space coolers for spot cooling in commercial and industrial applications, or to provide temporary relief where normal air conditioning systems are inadequate or have broken down;
- AC2: Non-ducted split systems covering a broad class of equipment including an outdoor unit combined with single or multiple indoor units in a variety of styles such as wall hung, cassette, console and under ceiling units, all designed for different applications;
- AC3-1 and AC3-2: 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;
- AC3-3: Roof top packaged air conditioning systems, with generally larger capacities than the previous categories, and that use high static pressure fans which allow long duct runs. In recent times these systems have been redesigned with variable speed compressors (i.e. digital scroll), electric commutated plug fans and advanced controls to improve efficiency levels to compete with other technology platforms sold into commercial buildings;

- AC3-4 and AC3-5: Multi split systems and variable refrigerant volume/flow (VRV/F) split systems with multiple indoor units, which is emerging as the preferred technology for medium sized commercial buildings, schools and other multi-purpose buildings;
- AC3-6: Close control or precision air conditioning 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;
- AC3-7 and AC3-8: Hot water heat pumps for commercial applications and swimming pool heat pumps;⁸
- AC4-1 to AC4-4: Chillers for space cooling in large commercial buildings;
- AC5-1: Hot water heat pumps for domestic applications; and,
- AC5-2: Heat pump clothes dryers, a type of condenser dryer that use refrigeration technology to remove moisture from clothes and discharge the moisture as condensate to the drain.

The stock and the energy consumption estimates of equipment categories in this report are broadly consistent with the Australian Government regulatory impact statements for split systems, close control air conditioning, chillers and hot water heat pumps (E3 2017a). However, there are some deviations from sales inputs where pre-charged equipment data provided CHF3 with more accurate estimates for changes in the stock in 2014, 2015 and 2016. These changes lead to differences between CHF3 projections and projections published in the regulatory impact statements.

Table 3: Stationary air conditioning by category and stock numbers: 2012-2016.

STATIONARY AIR CONDITIONING					
Category code	Application	Product category	Total (Units) 2012	Total (Units) 2016	Change (%)
AC1-1	Window/wall	Non-Ducted: Unitary 0-10 kW _r	1,915,000	1,592,000	-17%
AC1-2	Portable AC	Portable AC: 0-10 kW _r	606,000	827,000	+36%
AC2-1	Single split: non-ducted	Single split system: Non-ducted: 1-phase	7,145,000	9,238,000	+29%
AC2-2	Single split: non-ducted	Single split system: Non-ducted: 3-phase			
AC3-1	Domestic & light commercial	Single split system: Ducted: 1-phase	1,304,000	1,900,000	+46%
AC3-2	Domestic & light commercial	Single split system: Ducted: 3-phase			
AC3-3	Light commercial	RT Packaged systems	70,000	126,000	+80%
AC3-4	Domestic & light commercial	Multi split	276,000	317,000	+47%

⁸ Hot water heat pumps for domestic and commercial applications, and swimming pools use refrigeration technology (i.e. vapour compression cycle) to remove the heat from the air to heat water.

STATIONARY AIR CONDITIONING

Category code	Application	Product category	Total (Units) 2012	Total (Units) 2016	Change (%)
AC3-5	Light commercial	VRV/VRF split systems		88,000	
AC3-6	Light commercial	Close control	11,500	21,000	+83%
AC3-7	Light commercial	HW heat pump: commercial	1,000	1,800	+80%
AC3-8	Domestic & light commercial	Pool heat pump	28,000	38,000	+36%
AC4-1	Chillers	<350 kW _r	20,200	8,200	-40%
AC4-2	Chillers	>350 & <500kW _r		3,900	
AC4-3	Chillers	>500 & <1000 kW _r	7,200	7,200	0%
AC4-4	Chillers	>1000 kW _r	1,100	3,300	200%
AC5-1	HW Heat pump	HW heat pump: domestic	170,000	206,000	21%
AC5-2	Heat pump clothes dryers	Heat pump clothes dryers	NA	64,000	NA

Note:

- Where two product categories in the table in 2012 are represented by only one stock number, and in 2016 has two stock numbers, the Taxonomy has been changed to break a 2012 category into two product categories in 2016.

Single split systems sales including wall hung, cassette, consoles and ducted systems have grown rapidly from 2012 to 2017 with annual sales reported of 833,000 in 2012; 887,000 in 2013; 934,000 in 2014; 1,000,000 in 2015; and 1,177,000 in 2016. This strong sales growth continued into 2017 when a record number of 1,356,000 single split systems were sold. The overwhelming majority of split systems are single split systems comprising one indoor unit attached to one outdoor unit.

Analysis of pre-charged equipment (PCE) imports in 2016 indicates that non-ducted single split systems made up about 84% by quantity (pieces of equipment) and about 54% by refrigerant volume⁹ of all stationary AC imported into Australia. There are no local manufacturers of Small AC: Self-contained equipment or Small AC: Split systems. A summary of the analysis of PCE imports with a charge greater than 800 grams and less than 2,600 grams is provided in *Table 4* below.

⁹ Based on actual refrigerant volume charge sizes.

Table 4: Impacts of pre-charged equipment numbers and tonnes of contained refrigerants with a charge greater than 800 and less than 2,600 grams reported in 'Domestic use air conditioning' category 2014-2016.

	2014		2015		2016	
	Units	Refrigerant (Tonnes)	Units	Refrigerant (Tonnes)	Units	Refrigerant (Tonnes)
HFC-410A	547,523	796	547,784	788	485,774	708
HFC-32	154,913	168	270,704	314	348,333	412
Total	702,436	964	818,488	1,102	834,107	1,120
Proportion HFC-32	22%	17%	33%	28%	42%	37%

Filtering out equipment from this data with charges less than 800 grams, and greater than 2,600 grams spotlights the very large majority of non-ducted split systems in the Small AC sales mix. The data filtering excludes the majority of portable AC and window wall units that are typically under 800 grams and the majority of ducted systems which generally have charges larger than 2,600 grams. These larger units are most likely to be charged with HFC-410A.

However, there are some exceptions of small AC that fall outside these bounds.

For example, the current model 2.0 kW_r Daikin wall hung split system (the smallest model they produce in this format) contains only 600 grams of HFC-32, whereas the 2.5 kW_r model contains 900 grams. In addition, the largest capacity HFC-32 product on the market is the Fujitsu AOTG54KBTA, delivering 13.0 kW cooling, and 16.0 kW heating from a ceiling mounted cassette unit with a charge of 2,700 grams.

This dataset does capture some smaller multi-split systems, for example the Fujitsu 2 or 3 head multi split systems (model AOTG24, 6.8 kW cool/8.0 kW heat) containing 2,200 grams of HFC-410A, whereas the 3 or 4 head multi split system (model AOTG30, 8.0 kW cool/9.6 kW heat) contains 2,800 grams.

There has been significant growth in single split ducted systems (included in above numbers) increasing from around 110,000 in 2012 to 197,000 in 2017. Some of the growth has come from compact bulk head units below 10 kW_r, comprising 32% of sales by quantity in 2017, versus 25% in 2012.

Multi head split system (excluding VRV/F) sales have grown, from around 23,000 in 2012 and 2013 to around 40,000 in 2017. The ratio of indoor units to outdoor units sold is slowly increasing from a ratio of 1.03 in 2012 to 1.06 in 2017 as the range of applications for multi-head units grows.

Australia is largely a 'technology taker' of air conditioning equipment, driven by product development from overseas manufacturers and international regulatory regimes. Trends in the international market are therefore reflected in changes in the Australian stock of equipment and bank of working gases.

In this class, Australia still has a declining stock of the older HCFC charged equipment, and a large and rapidly growing stock of relatively new HFC charged equipment. The main HFCs employed in stationary AC are HFC-410A, HFC-407C and HFC-134a. The recently commercialised HFC-32 is rapidly emerging as the fastest growing portion of the bank in the main small AC product categories.

Small AC transition from HFC-410A to HFC-32

Analysis was undertaken of PCE imports to assess the progress of the transition of Small AC from primarily using HFC-410A to using HFC-32. PCE imports for 2014, 2015 and 2016 reported under the 'Domestic use air conditioning' category in the Department of the Environment and Energy's import data, reveals that HFC-32 has been adopted very quickly in non-ducted split systems designed primarily for residential use.

Until as recently as 2013 air conditioning units charged with HFC-410A had been the fastest growing segment, with around 98% of small split systems, and medium and light commercial air conditioning sales

in that year being charged with HFC-410A. In just the last four years, HFC-32 has emerged as the preferred refrigerant employed by manufacturers with a rapidly growing share of the small AC market.

The split system market has experienced solid compound annual growth rates (CAGR) of around 5.5% from 2012 to 2016 with a significant increase in sales of HFC-32 charged systems of more than 30% in 2017 compared to 2016.

By the end of 2016 there had been 964,000 air conditioning units containing HFC-32 imported, mostly split systems, containing a total of 1,039 tonnes of the refrigerant. The count of HFC-32 charged systems exceeded one million pieces part way through the first quarter of 2017.

The average charge of HFC-410A models imported over the same period was 1,450 grams compared to the average charge of HFC-32 models of only 1,155 grams, equating to an average 20% reduction in charge size across these equipment segments. This reduction is consistent with an analysis of the relevant models of Daikin's product range, which showed an average 22% reduction in charge size between HFC-410A and HFC-32 charged equipment with the same refrigerating capacity. Combined with the much lower GWP of HFC-32 (GWP of 675 for HFC-32 as compared to a GWP of 2088 for HFC-410A) this equates to a 75% reduction in CO₂e of this portion of the refrigerant bank when taking both charge size and GWP into account.

This capacity of HFC-32 to provide equivalent cooling services, but with a smaller charge than some of the older generation of refrigerants, flows through to both the make-up of the bank, and the rate of growth of the bank. From the point of view of making projections of future sales mixes by refrigerant charge, the RAC Stock model uses a concept of 'equivalent charge', effectively factoring the volume of HFC-32 in new equipment by 1.26 (i.e. the average charge for small split systems with HFC-410A and HFC-32 are 1.45 and 1.15 kilograms respectively in 2016). This treatment of the HFC bank allows a visual depiction of the scale of the energy services delivered by HFC-32 to be illustrated, as compared to the bank of HFC-410A that would otherwise have been required.

If future projections of new equipment sales by refrigerant species were illustrated using just the raw mass of chemicals in the charge, because of the better performance of HFC-32 as a thermal media, and the smaller charge required to deliver the same cooling services, it would appear as if the overall market for small AC was declining, which is far from the case.

The equivalent refrigerant charge is a tool used in this report to help visually compare the work that the refrigerants carry out. This has assisted in illustrating how different product categories are transitioning to alternative refrigerants.

It does not ignore or replace the 'actual' charge; it is an alternative measure used to help represent the rate of transition of the number of devices, and the energy services they provide. For instance, when developing projections of changes to the bank from 2016 to 2030, the New Sales Mix for Small AC: Split by Refrigerant species in the RAC Stock model shows HFC-32 charged equipment making up 58% of new sales in 2016, as this was the adjusted equivalent volume of HFC-32 in the refrigerant mix.

This method of illustrating the growing share of energy services delivered by new refrigerants in the bank is also used when illustrating market shares of hydrocarbons (GWP of 3) and HFOs such as HFO-1234yf (GWP of 5 or 1^{AR5}). The equivalent refrigerant charge factor shows the rate of the changing market shares of the older, higher GWP refrigerants, being replaced by lower GWP alternatives.

The companies and brands that are transitioning non-ducted split systems to HFC-32 include Daikin, Fujitsu, Mitsubishi Electric, Panasonic, Beijer Refrigeration (Gree brand), Electrolux, Castel (Midea brand) and Teco. These products are predominantly imported from Japan, Thailand and China. Electrolux and Teco are major suppliers of window/wall units that have recently migrated their ranges to HFC-32.

Brands operating in Australia with all or the large majority of their 2016 imports or local manufactured systems still charged 100% with HFC-410A include Actron Air; AHI Carrier (Toshiba brand); Heatcraft (Lennox brand); Mitsubishi Heavy Industries; Seeley-Braemar; Teco; Haier; Sharp; Temperzone (Hitachi

brand); Hisense; Sanyo; and other private label imports. Many of these suppliers are expected to migrate to HFC-32 early in the projection period.¹⁰

The strong growth in HFC-32 charged systems has been facilitated by Daikin, a long time manufacturer of HFC-32, who chose in 2012 to 'open source' elements of its proprietary IP relating to HFC-32 charged equipment, in effect creating a new de-facto standard for inter-changeable common components used by all manufacturers. This had the effect of accelerating introduction of the technology to broader markets, created opportunities for Daikin to supply components to the assembly lines of competitors, increased overall volumes and thus drove down component prices, finished equipment costs and the cost of the global transition of small AC to HFC-32.

Small AC: Hydrocarbons

At the same time efforts to introduce HC charged small AC systems appear to have faded with the technology developing only limited manufacturing support, and still facing potential regulatory and work place limitations due to the greater flammability of the refrigerant charge.

Industry participants report that HC charged equipment has not achieved any significant market share in Australia in the last two years. Chinese manufacturers of HC charged equipment have not increased marketing efforts or been publicising recent case studies of installations or establishment of new distribution lines. The ongoing message is that systems are under development and available in some overseas markets (e.g. India and in small volumes in China) and are expected to emerge as technically and commercially feasible soon.

However, at present, there are only a few air conditioner models containing HC in Australia. As a result, it is concluded that HCs in residential AC, other than in very small charge portables in the Small AC category, are unlikely to achieve a significant market share in the foreseeable future, and may never establish a significant niche in Small and Medium AC.

Small AC: Self-contained

The majority of all equipment classified as 'Small AC: Self-contained' are Window/Wall units, many of which were installed in the 1990s and are charged with HCFCs. Of the approximately 1.6 million window/wall and 827,000 portable AC units estimated to be in operation in 2017, more than 1.2 million are charged with HCFCs, representing a bank of some 800 tonnes of mostly HCFC-22. This stock of HCFC charged equipment is declining steadily as the equipment reaches the end of its useful life and is predicted to be virtually non-existent by 2030. In 2012 it was estimated that there were more than 1.7 million HCFC charged window wall units.

Two major suppliers of window/wall units, Electrolux and Teco have migrated their product ranges to HFC-32, and the majority of the market is expected to follow within the next 2 to 3 years. The Small AC: Self-contained bank is estimated to be around 798 tonnes in 2030, comprising less than 2% of all HFCs in the total bank at that time.

A market for small portable and window wall AC units charged with less than 1 kg of HCs has been established during the last few years. For example, DeLonghi has been importing portable AC units in commercial volumes for more than 6 years with the total stock of HC charged portables now likely above ten thousand.

Hot water heat pumps

Just prior to 2012 hot water heat pump annual sales peaked at over 66,000 units per annum and have since steadily declined due to changes to the solar hot water rebate, which was a significant factor in early sales growth. Other historical factors dampening sales have been product reliability issues and customer perception

¹⁰ Assessment base on review of PCE, pprivate communications with industry informants and Expert Group market research into current product specifications.

issues (i.e. not delivering hot enough water in cooler climates). Since that time product reliability issues have been overcome and the market has stabilised at just under 20,000 pieces per annum.

In 2012 Rheem, DUX and Quantum, and a few others manufactured around 20,000 to 25,000 hot water heat pumps in Australia (requiring around 19 tonnes of HFC-134a). Subsequently as the market slid from its 2012 peak some suppliers have moved manufacturing operations off shore.

There are a number of suppliers of domestic hot water heat pump identified in PCE that have imported hot water heat pumps over the last three years including Chromagen, Quantum Energy Technologies, Stiebel Eltron, Siddons and smaller participants, Glen Dimplex and Solar Station Alpha. Over 2014, 2015 and 2016 there were at least 23,000 pieces imported containing 23.4 tonnes of HFC-134a or almost 7,600 pieces per annum. The charge sizes ranged from 300 to 2,600 grams with an average charge of 1,010 grams.

These import statistics do not include those units charged with hydrocarbon or CO₂. For example, heat pumps that use CO₂ only technology achieve very high efficiencies, with a coefficient of performance of 5.0, and are charged with ~650 grams of CO₂. The Clean Energy Regulator offers small-scale technology certificates (STCs) for solar water heater or air source heat pump systems which confirms these products are very efficient compared to their peers. CO₂ and HC are not controlled substances under the OPSGGM Act and import and manufacturing PCE containing these refrigerants do not need to be reported, therefore there is limited ability to analyse sales volumes of these types of units.

In CHF2 the 2012 stock of hot water heat pumps was estimated at 170,000, this figure has been revised down to 133,000 in 2012 and 206,000 in 2016 due to improved information. The Clean Energy Regulator¹¹ publishes small-scale renewable energy installation data for Air Source Heat Pumps. The total count of domestic scale hot water heat pumps registered with the Clean Energy Regulator at the end of 2016 was 210,649. The stock model assumes an average lifespan of 15 years and roughly aligns with the regulators reported stock, when taking into account equipment that would have retired.

The stock model assumes sales of domestic hot water heat pumps will continue at a typical annual sales volume of just under 20,000 pieces per annum until 2030.

Heat pump clothes dryers

A heat pump clothes dryer is a recently introduced product type of condenser dryer that is extraordinarily energy efficient, as they recycle heat in the process of extracting moisture, resulting in MEPS energy efficiency ratings of up to 6 stars (the best possible). Whilst they are more expensive than conventional clothes dryers, they deliver good electricity cost savings and have the added benefit of not pumping humid air into the laundry area as the condenser dryer extracts the dampness from the clothes and the condensate is discharged down the drain.

There are a number of premium appliance suppliers identified in PCE that have imported heat pump clothes dryers over the last three years including Asko Appliances, Miele, LG Electronics, Robert Bosch, Samsung Electronics and Whirlpool. Over the last three years there were at least 44,000 pieces imported or almost 15,000 pieces per annum. There are no local OEMs that manufacture heat pump clothes dryers in Australia.

All appliances were charged with HFC-134a containing from 300 to 480 grams and an average charge of 460 grams. The total charge of HFC-134a imported over the three year period in these appliances was around 20 tonnes.

Small AC: Split

The Small AC: Split segment of the taxonomy contains the largest numbers of units in operation, largest proportion of the bank and largest annual sales in the Stationary AC class. Small split systems, in the last two decades have become almost as common as domestic refrigerators.

¹¹ <http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations#Solar-water-heater-SWH-installations>

In many Australian houses in 2016 there may be several reverse cycle, wall hung split AC systems, that provide both heating and cooling. New homes and apartments built in the last two decades almost always have at least one wall hung split system as a standard inclusion.

In the 1990s when the cost of small split systems first started to fall, as the economics of mass production in Thailand, Korea and China began to drive prices down, these devices were universally charged with HCFC-22. As import volumes rose towards a million units a year in the early part of the century, manufacturers moved to the use of HFC-410A as the Montreal Protocol phase out of HCFCs progressed.

In 2006 HCFC-22 dominated the bank of working gas in Australia largely as a result of its use in stationary AC, in both the small and medium commercial categories, and those early years of rapid growth of small split system sales. In 2012 the portion of HCFC-22 was still estimated at 26% (11,227 tonnes) of the total bank. Small AC equipment pre-charged with HCFCs only stopped entering the country in 2010 (excluding some minor exemptions), although most major manufacturers had moved away from HCFC-22 before the 2010 pre-charged equipment import ban.

In 2016 HCFCs are still estimated to make up 17% of the bank, or 8,500 tonnes, the majority of which will be found in small and medium AC systems. HCFC-22 was the refrigerant of choice for most of the 90s and into the early years of this century in other applications as well, including larger chillers and some types of commercial refrigeration, however it is estimated that of the total of 8,500 tonnes of HCFCs still in the bank, more than 50% is still operating in some 2.7 million small AC and 780,000 medium AC.

The move to HFC-410A starting around 2005, occurred at the same time that small and medium AC sales passed more than 1 million units a year in Australia, a figure that has continued to climb to more than 1.3 million units in 2017. This has built a stock of more than 9.2 million HFC-410A charged pieces of equipment in the course of the last decade, containing a bank of 18,700 tonnes of HFC-410A, representing 37% of the total bank in tonnes.

Since 2014, with the introduction of HFC-32 as a more energy efficient and lower GWP refrigerant into small AC, the growth of HFC-410A in the bank has slowed. In just three years nearly a million HFC-32 charged systems have been imported into Australia and already this refrigerant makes up 2% of the total bank of refrigerant.

Overall, in the last two decades, the trend in small AC has been towards greater energy efficiency, driven by regulatory settings in developed economies, international standards¹², competition in the market place, and technical improvements, particularly the incorporation of highly efficient variable speed drives and the perfection of reverse cycle systems. Over the same period design improvements have led to the use of smaller refrigerant charges in designs that also exhibit better refrigerant containment. In 2006 the average charge in this product category was 1.7 kg, in 2012 it was 1.6 kg and in 2016 the average HFC-32 charge is 1.15 kg.

With the advent of HFC-32 this trend to smaller charges is set to accelerate as the reduced HFC-32 charges required to achieve the same cooling, allow designers more leeway in designing smaller devices with smaller compressors and thus lower electricity demand, to deliver the same cooling services.

¹² IEC 60335-2-40 Household and similar electrical appliances - Safety - Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers includes permissible A2L refrigerant charge sizes.

Medium AC

There was no HFC-32 reported in PCE import data categories, ‘Commercial use air conditioning’ or ‘Commercial or domestic use heat pumps’.

AS/NZS ISO 5149: 2016 Refrigerating systems and heat pumps-Safety and environmental requirements imposes refrigerant charge limits that restricts the use of HFC-32 in commercial equipment and domestic hot water heatpumps. However, manufacturers are exploring lower GWP alternatives for these product categories.

Analysis was undertaken of the PCE imports for 2014, 2015 and 2016 reported under the ‘Domestic use air conditioning’ and ‘Commercial use air conditioning’ categories dissected into three charge sizes including >2.6 kg and ≤10 kg; >10 kg and ≤ 60 kg and >60 kg. A summary of the results is provided in the table below.

Table 5: Pre-charged equipment imports reported with a charge greater than 2.6 kg in 2014-2016.

	2014		2015		2016	
	Units	Tonnes	Units	Tonnes	Units	Tonnes
>2.6 kg and ≤10 kg						
HFC-410A	187,137	661.3	195,161	730.0	199,596	773.5
HFC-407C	291	1.2	137	0.8	46	0.2
Sub-total	187,428	662.5	195,298	730.8	199,642	773.7
>10 kg and ≤ 60 kg						
HFC-410A	6,338	77.1	9,482	111.5	12,522	147.5
HFC-407C	132	3.4	91	2.4	72	2.0
Sub-total	6,470	80	9,573	114	12,594	149
> 60 kg						
HFC-410A	79	8.2	92	8.9	129	19.7
HFC-407C	30	3.9	19	2.0	33	7.7
Sub-total	109	12.2	111	10.9	162	27.4
>2.6 kg (includes all of the above categories)						
HFC-410A	193,554	746.6	204,735	850.5	212,247	940.7
HFC-407C	453	8.5	247	5.2	151	9.9
Total	194,007	755.2	204,982	855.6	212,398	950.6

Notes:

1. The large majority of imports in this category are medium AC with a charge less than 15 kg.
2. In 2016 there were 11,839 devices containing a total of 130 tonnes in the category >10 kg and < 15 kg.
3. In 2016 there were only 755 devices containing a total of 19.0 tonnes with a charge ≥ 15 kg and ≤ 60 kg, and only 176 devices containing a total of 6.5 tonnes with a charge ≥ 30 kg and ≤ 60 kg.
4. Industry sources suggest that large commercial equipment is increasingly being imported with a nitrogen charge or small holding charge. Importers are constantly weighing up the benefits of importing equipment pre-charged with refrigerant versus charging locally. The main considerations are the refrigerant cost in the country of manufacture versus Australia; the cost of labour to charge locally and potential additional transport fees or delays associated with transporting equipment with a larger refrigerant charge. Under the International Maritime Dangerous Goods Code equipment containing greater than 14 kg of refrigerant is classified as Dangerous Goods.

The PCE data shows there was an average of around 200,000 medium AC pieces of equipment imported per annum over the three-year period, containing an annual average of 846 tonnes of HFC-410A and 8 tonnes of HFC-407C per annum.

Total Australian medium AC sales includes these PCE imports plus local manufacturing by Actron Air, Temperzone and the recently acquired Brivis Climate Systems and Specialized Engineering, now divisions of Rinnai HVAC. All three companies locally produce single split ducted systems, as well as roof top packaged systems and collectively consume 187 tonnes of HFC-410A. Local manufacturing of hot water heat pumps is estimated to consume 2 to 3 tonnes of HFC-407C.

Unlike the large international air conditioning corporations who develop their own compressors, local air conditioning manufacturers are reliant on suppliers such as Copeland and Danfoss for supply of compressor technology, and thus are limited in their compressor and refrigerant choices.

There is negligible HFC-407C (0.1% based on sales and 0.4% based on refrigerant charge) in air conditioning equipment with charges >2.6 kg and ≤ 60 kg. However, in large capacity equipment with charges > 60 kg HFC-407C is more common (21.5% based on sales and 27.0% based on refrigerant charge). Many of these larger devices are likely to be chillers, some of which are used in process applications.

Recent changes to *IEC 60335-2-40: 2018 Particular requirements for electrical heat pumps, air conditioners and dehumidifiers*, regarding the refrigerant charge/floor area limitations for A2L (mildly flammable or lower flammability) refrigerants were published in the new edition in January 2018.¹³ The revised standard includes a new clause (cl 22.125) and definition to define an 'Enhanced Tightness Refrigeration System' as well as *Annex GG: Flammable Refrigerant Charge Limits* that specifies charge limits that can be applied where A2L refrigerants are used in Enhanced Tightness Refrigeration Systems. These changes potentially allow larger refrigerant charges if additional mitigation of fire risk (e.g. ventilation, sensors, enhanced tightness of design) is undertaken including natural or mechanical ventilation meeting specific requirements; safety shut-off valves meeting specific requirements; and/or safety alarm systems meeting specific requirements.¹⁴ If passed by the AU/NZ standards committee (EL-002), these changes increase the scope of medium AC products to use A2L refrigerants such as split ducted systems and VRV/F multi head systems. However, the question for air conditioning manufacturers is whether it would be cost effective, practical or acceptable to the end user to undertake the additional fire risk mitigation measures.

While low GWP HFOs were thought to be a real candidate for small and medium AC, current performance data on HFOs and on HFO/HFC blends in AC indicates that HFC-32 provides superior or equivalent energy efficiency and overall performance, and therefore best Total Environmental Warming Impact (TEWI). As such the rapid transition from HFC-410A to HFC-32 is expected to continue.

Anecdotally HFOs on the market in 2016 were priced at significant multiples of HFC-32 so in applications where HFC-32 exhibits clear technical advantages HFOs are unlikely to have a significant impact until the deterrent of the price differential is alleviated.

Large AC: Chillers

There are estimated to be 22,600 chillers operating in Australia in 2016, containing in total approximately 4,200 tonnes of refrigerant. This stock estimate has been revised down from the 28,500 published in CHF2 as a result of better market intelligence. This stock estimate is consistent with the findings of the Decision and Consultation Regulation Impact Statement for Air Conditioners, Chillers and Close Control Air Conditioners, prepared by the Equipment Energy Efficiency (E3) program (E3 2017a) which estimated a population of 20,600 chillers in Australia in 2016.

¹³ Refer Glossary for definitions on refrigerant classifications.

¹⁴ For specific requirements refer to *IEC 60335-2-40: 2018*. The AU/NZ committee (EL-002) will need to vote on accepting these changes as an AS/NZS Standard before they can be considered in Australia.

Higher resolution data has also allowed improvements in the categorisation of this segment in the taxonomy with the three CHF2 categories being expanded to four, with the addition of a new category for chillers <350 kW_r that had previously been aggregated with a category that included all devices <500 kW_r.

Smaller chillers (<350 kW_r) can contain HFC-410A and HFC-407C, with charges ranging from 40 kg to more than one tonne. The PCE import category '*Commercial use air-conditioning*' includes many other Medium AC product types with similar refrigerant charges including Variable Refrigerant Volume/Flow Split systems, larger ducted systems and close control AC.

Generally, chillers require larger refrigerant charges and the majority are charged with HFC-134a. PCE imports for 2013, 2014, 2015 and 2016 reported under the '*Commercial use air-conditioning*' category in the DoEE pre-charged equipment import data were analysed for HFC-134a equipment with a charge greater than 10 kg. Over the four-year period 1,686 units were imported with an average charge of 194 kg, equating to imports of 82 tonnes of HFC-134a on average per annum in these large devices. Over the same period there were 28 units imported containing HCFC-123 with an average charge of 825 kg, equating to almost 6 tonnes per annum¹⁵. The import of space chillers charged with HCFC-123 continued until the end of 2015.

There can be exceptions; for example, further analysis of PCE imports for 2013, 2014, 2015 and 2016 revealed there were 45 large chillers containing HFC-407C imported by companies providing off-shore services¹⁶ with charges ranging from 120 kg to 650 kg. In addition, there were chillers containing as much as 460 kg of HFC-410A. These chillers were most likely process chillers with particularly demanding operational requirements.

The remaining local manufacturer of chillers, Smardt Chillers, provided Expert Group with its manufacturing use of HFC-134a, which was used in the model to assess manufacturing and service use in this segment.

New chillers sales are expected grow at around 1% per annum or in line with construction activity in large commercial buildings.

All of the global manufacturers of space chillers (including local manufacturer Smardt Chillers) are offering equipment charged with HFOs or HFO/HFC blends. The refrigerant landscape in this segment is changing rapidly, primarily driven by experiences in the European Union where the HFC phasedown timetable is driving change.

The HFO refrigerant of choice for large centrifugal chillers is HFO-1233zd as there is a financial benefit delivered to the equipment owner due to significant energy efficiency gains. The non-flammable safety classification of the refrigerant (i.e. Class A1, non-flammable) also makes installation similar to HFC-134a charged equipment under the new technical standard *ISO 5149: 2016 Refrigerating systems and heat pumps - Safety and environmental requirements*. There were several large chillers installed in Australia in 2017 operating on HFO-1233zd.

Some suppliers are adopting a two-step approach, moving to a Class A1 HFO/HFC blend with around half the GWP of HFC-134a, such as HFC-513A (GWP of 632), while planning the transition to pure HFOs. One impediment to this transition, particularly to HFO-1234yf is the additional installation costs arising from its Class A2L mildly flammable classification.

¹⁵ While a general ban on the import of equipment pre-charged with HCFCs was introduced in 2010, exceptions allowed the import of HCFC-123 charged equipment until the end of 2015.

¹⁶ Some of these companies include Emas Offshore Services, FUGRO TSM, Farstad Shipping (Indian Pacific), Heerema Marine Contractors, MMA Offshore, Svitzer Australia, TS Marine, Tidewater Marine, Woodside Energy, Petroleum Geo-Services (PGS Australia), Quadrant Energy, and others.

Table 6: Stationary air conditioning main metrics: 2012 versus 2016.

Metric	2012	2016	Change
Share of refrigerant bank	63%	61%	-1%
Size of refrigerant bank	27,200 tonnes	31,200 tonnes	+15%
Annual usage to replace leaks (excl. OEM)	1,470 tonnes	1,004 tonnes	-31%
Gas in pre-charged equipment imports over last five years (excl. 2012)	970 to 1,285 tonnes per annum	1,100 to 1309 tonnes per annum	+2%
Estimated stock of equipment	> 11.5 million units	> 14.4 million units	+25%
Annual expenditure on new equipment	~\$3.35 Billion	~\$4.86 Billion	+45%
Annual electricity consumption	36,845 GWh	30,442 GWh	-17%
Share of HVAC&R Electricity consumption	62%	55%	-12%
Annual GHG indirect emissions	33.67 Mt CO ₂ e	30.44 Mt CO ₂ e	-10%
Share of HVAC&R indirect emissions	59%	52%	-12%
Annual GHG direct emissions (ODS) ⁽²⁾	1.18 Mt CO ₂ e	0.72 Mt CO ₂ e	NA ⁽³⁾
Annual GHG direct emissions (SGG)	1.14 Mt CO ₂ e	1.47 Mt CO ₂ e	NA ⁽³⁾
Share of HVAC&R direct emissions	44%	34%	NA ⁽³⁾
Share of HVAC&R total emissions (direct and indirect, not including EOL)	58%	50%	NA ⁽³⁾

Notes:

1. Change comparison of pre-charged refrigerant imports over last five years, compares the highest numbers over the period.
2. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol or United Nations Convention on Climate Change, as they managed through the Montreal Protocol.
3. The direct emissions in 2012 cannot be directly compared to 2016 as CHF2 is an assessment of a full bank and CHF3 is an assessment of a partially full bank.

4.3 Mobile air conditioning

Mobile air conditioning (MAC) includes air conditioning equipment found in passenger vehicles, light commercial vehicles, buses, trucks, and in unregistered and off-road applications including locomotives, passenger rail, mining equipment, harvesters, forklift trucks, road making vehicles, mobile and fixed cranes, military vehicles, earthmoving equipment, registered shipping, pleasure craft, and light aircraft.

The two segments and twelve product categories that make up this class contained approximately 21% of the bank of working refrigerants in Australia (CHF2, 21%), or around 10,800 actual and 11,400 equivalent tonnes (2012, 10,600 actual and 11,130 equivalent tonnes¹⁷) in more than 18 million vehicles of all sorts (CHF2, 16 million).

The RAC Stock model for CHF3 has simplified this class, reducing the previously four segments to just two, small MAC and large MAC. There have also been three product categories added to this class, buses >7 metres has been dissected into two categories (MAC2-1 and MAC2-2) based on gross vehicle mass (GVM) of less than or greater than 12 GVM to align with ABS registration data; MAC2-5, 'Vehicles: RV and caravan', to allow higher resolution tracking of a rapidly growing pool of registered recreational vehicles and caravans, and MAC2-7, 'Registered marine vessels and pleasure craft'.

Table 7: Mobile air conditioning taxonomy.

MOBILE AIR CONDITIONING				
Item no	Segment	Application	Category code	Product category
19	MAC1: Small Mobile AC	Registered vehicles <3.5t GVM	MAC1-1	Passenger vehicles
20		Registered vehicles <3.5t GVM	MAC1-2	Light commercial vehicles
21		Registered vehicles <3.5t GVM	MAC1-3	Rigid truck and other
22		Registered vehicles ≥3.5t GVM	MAC1-4	Truck: articulated
23		Registered vehicles ≥3.5t GVM	MAC1-5	Commuter buses
24	MAC2: Large Mobile AC	Registered vehicles ≥4.5t & <12t GVM	MAC2-1	Buses and coaches: Small
25		Registered vehicles ≥12t GVM	MAC2-2	Buses and coaches: Large
26		Rail	MAC2-3	Passenger rail
27		Rail	MAC2-4	Locomotive

¹⁷ This 2012 value has been revised upwards in the CHF3 RAC Stock model to 10,600 tonnes compared to the estimate of 9,100 tonnes published in CHF2. There are two main factors that influence this revision including larger charge sizes for older vehicles and CHF3 takes into account the partial charge of the bank that is discussed later in this section.

MOBILE AIR CONDITIONING

Item no	Segment	Application	Category code	Product category
28	MAC2: Large Mobile AC	Vehicles: RV and caravan	MAC2-5	RV and caravan
29		Un-registered	MAC2-6	Off-road, defence and other.
30		Marine	MAC2-7	Registered marine vessels and pleasure craft

Note:

1. New segments in this class in the 2016 Taxonomy, MAC2-1 Buses and coaches: Small; MAC 2-5 Vehicles: RV and caravan, and MAC2-7; Marine are highlighted in blue.

The majority of mobile air conditioning systems (95%) are found in passenger and light commercial vehicles. These systems now generally contain between 600 to 700 grams of refrigerant when fully charged. The average charge size of MAC has fallen significantly since the early 1990s, a time at which MAC started to become standard in most new vehicles.

Recording of the manufacturers' recommended refrigerant charges from more than 10,000 vehicles, conducted over several years by an industry participant has provided primary data on average charges of vehicles by year of make. What this data has shown is that in the early 1990s Small MAC was being manufactured with an average of 1,100 grams of refrigerant charge. By 2000 this average charge had reduced to about 800 grams and continued to decline to the current average charge of 620 grams. This data has been used to establish an average charge by year of make that is used in the RAC Stock model (see *Appendix A: Section 11.2.4 Small MAC refrigerant charges*).

The majority of the MAC bank is made up of HFC-134a (~94%). It is estimated that there are still more than 400,000 older vehicles in the fleet that were originally manufactured containing CFCs, the large majority of which are likely to have been converted to HFC-134a or hydrocarbons at some stage in the last two decades. Hydrocarbons, which are sometimes installed as an aftermarket option in MAC in Australia, are estimated to be used in about 4% of the fleet. Other refrigerants used in mobile air conditioning applications include HFC-407C and HFC-410A which are more likely to be used in large MAC including locomotive, passenger rail, recreational vehicles, caravans and off-road applications such as marine. The relatively rare HCFC-124 can be found in extreme ambient applications such as in mobile cranes.

While the taxonomy incorporates some vehicles that might be thought of as large vehicles, in the small MAC segment, and vice versa, the taxonomy is based on the size of the average charge in the MAC installed in the vehicle, not the size of the vehicle.

The size of the MAC system and its refrigerant charge does not always necessarily equate to the size of the vehicle, or its gross vehicle mass, but rather the use of the vehicle and the investment in equipment required for passenger and operator comfort.

Table 8: Mobile air conditioning by category and stock numbers: 2012 versus 2016.

MOBILE AIR CONDITIONING					
Category code	Application	Product category	Total (Units) 2012	Total (Units) 2016	Change (%)
MAC1-1	Registered vehicles <3.5t GVM	Passenger vehicles	12,079,000	13,938,000	15%
MAC1-2	Registered vehicles <3.5t GVM	Light commercial vehicles	2,487,000	3,049,000	23%
MAC1-3	Registered vehicles <3.5t GVM	Rigid truck and other	422,000	489,000	16%
MAC1-4	Registered vehicles ≥3.5t GVM	Truck: articulated	88,000	98,100	12%
MAC1-5	Registered vehicles ≥3.5t GVM	Commuter buses	68,600	55,000	NA
MAC2-1	Registered vehicles ≥4.5t & <12t GVM	Buses and coaches: Small	22,000	17,000	NA
MAC2-2	Registered vehicles ≥12t GVM	Buses and coaches: Large	NA	24,870	NA
MAC2-3	Rail	Passenger rail	6,800	5,450	NA
MAC2-4	Rail	Locomotive	1,900	2,050	8%
MAC2-5	Vehicles: RV and caravan	RV and caravan	NA	452,000	NA
MAC2-6	Un-registered	Off-road, defence and other	32,800	20,000	NA
MAC2-7	Marine	Registered marine vessels and pleasure craft	NA	6,000	NA
Total MAC			15,208,100	18,156,470	19%

(Sources: AB&C 2017, ABS 9309.0 2017, ABS 9314.0 2017, AMSA 2017, BITRE 2016, BIC 2017, CVIAA 2016, DoEE 2017, FCAI 2017 and industry informants)

There are several product categories where the rate of change since 2012 is noted in the table above as NA, and the new product categories (highlighted in blue) added to this segment are mostly as a result of having improved data since 2012. Better data from the Bus Industry Council caused the downward revision of the estimated fleet in MAC1-5: Commuter buses, and the disaggregating of coaches into MAC2-1 and MAC2-

2, Small and Large buses and coaches. In these last two categories, new data also caused a significant upward revision of the estimates of the fleet in these categories.

As a result of the changes to the taxonomy, and new data, there are several product categories in which there is no value in making comparisons directly between the 2012 stock and the 2016 stock. As such the change in the total stock of MAC from 2012, and 2016, noted as being 19%, is inflated by inclusion of stocks of air conditioned caravans, and should be regarded as a study reference only, identifying changes between CHF2 and CHF3, but not being an accurate measure of growth in stocks of equipment in the economy.

However, stock numbers in product categories MAC1-1 to MAC1-5 are very reliable, based on registration data. The RAC Stock model uses both sales (ABS 9314.0 2017) and registration data (ABS 93090.0 2017) from the Australian Bureau of Statistics to calculate the current fleet of small MAC in passenger and light commercial vehicles; rigid trucks; articulated trucks; non-freight trucks; and small buses with a GVM less than 4.5 tonnes. In these categories CHF3 assumes 100% of vehicles manufactured after 2000 contain air conditioning.

As those categories make up the bulk of all stock it should be noted that the increase in total stock in those four categories between 2012 and 2016 was a sizeable gain from a total of 15.1 million vehicles with MAC to more than 17.6 million vehicles with MAC, or a nearly 17% increase in the period.

New vehicle sales in the small MAC segment have grown at 2.8% per annum for the past 20 years from around 650,000 per annum in 1996 to 1,178,100 in 2016 (ABS 9314.0 2017).

The vast majority of MAC enters the stock of equipment pre-charged with HFC-134a in imported vehicles. While individual charges are small, with more than 1.1 million new vehicles fitted with MAC systems entering the economy annually for the past five years, the addition to the total bank of refrigerant from MAC is quite substantial, even after subtracting the number of vehicles reaching end-of-life each year. *Table 9* below shows total new vehicle sales in Australia annually from 2010, and the number of vehicles manufactured in Australia.

Table 9: New vehicles sales and local manufacture from 2010 to 2016.

	2010	2011	2012	2013	2014	2015	2016
Vehicle sales	1,035,574	1,008,437	1,112,032	1,136,227	1,113,230	1,155,408	1,178,133
Vehicles locally manufactured	243,031	146,176	221,073	210,538	174,986	167,538	155,000 ⁽¹⁾

Notes:

1. Calculated estimate from VFACT 2017 data.

Imported vehicles fitted with MAC that contain a HFC refrigerant are reported as pre-charged equipment at point of entry into Australia. The chart below illustrates the scale of this source of input to the bank, an average of nearly 600 tonnes per annum between 2012 and 2016.

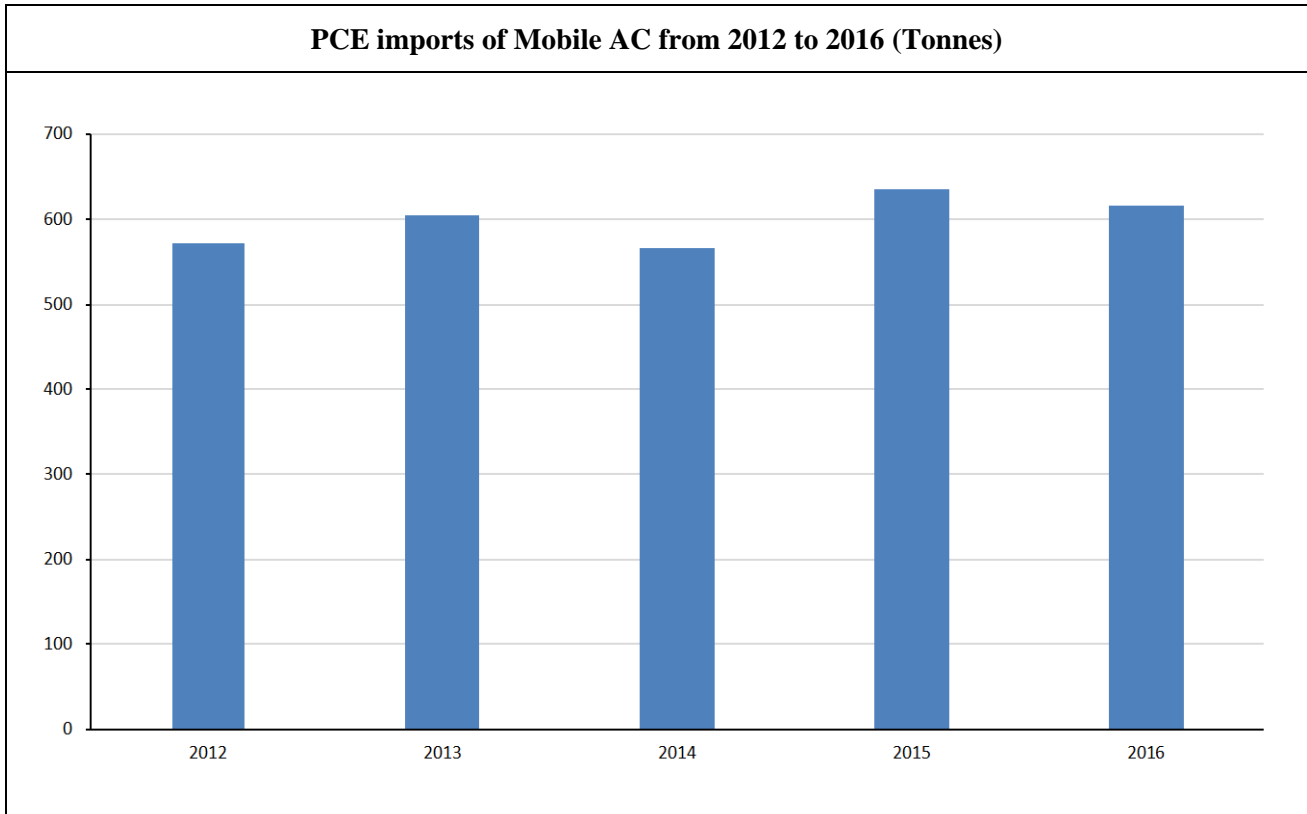


Figure 1: Pre-charged equipment imports of mobile AC from 2012 to 2016 in tonnes.

(Sources: DoEE 2017)

Changes to the MAC bank and service rates

An important result of the new data and changes to the methodology underlying the model (as compared to that employed in CHF2) has been a significant upward revision of the estimate of the 2012 MAC bank.

CHF3 now calculates that the bank of refrigerant in MAC in 2012 was 10,600 tonnes, as opposed to the original estimate of the bank in 2012 of 9,100 tonnes. This is a 16% upward revision of the estimated MAC bank in 2012, with increases in volumes of both HCFCs and HFCs. The reason for this significant revision of the small MAC bank flows from an improvement to the RAC Stock model, whereby equipment can be modelled in cohorts based on year of manufacture, resulting in the ability to adjust MAC charge sizes for every year of vehicle production going back to the 1960s. As earlier model vehicles had larger charge sizes, the changes in aggregate produced the larger estimate of the 2012 bank.

Market intelligence, data on sales of bulk refrigerant and sales of MAC components into this segment suggests that, at least in private vehicles, there is a considerable degree of underservicing of small MAC, with possibly less than half of the refrigerant lost to air being replaced in any one year. As a result, the RAC Stock model now calculates a significant reduction in refrigerant used for servicing in MAC in 2016, as compared to the estimates in CHF2.

Estimates of bulk refrigerant use by vehicle manufacturers and for servicing the vehicle fleet in 2016 is 668 tonnes, or an estimated 19% of all bulk HCFCs and HFCs used in Australia in 2016. This refrigerant was used to either replace leaked refrigerant in that year, or in the manufacture of new vehicles produced by car makers who were still in operation at that time. CHF2 estimated total vehicle manufacturer and service use to be ~1,048 tonnes, or 33% of all bulk imports in 2012.

The large majority of the 2016 bulk refrigerant sold into this segment, 570 tonnes, was used servicing air conditioning systems in existing vehicles. This estimate of 2016 service refrigerant is a very robust value and is based on three consecutive years of surveying of market participants who supply more than 95% of this market. The survey results are summarised in the table below which do not take into account any aftermarket recovery and reuse.

Table 10: Volumes of HFC-134a sold by calendar year (kilograms) based on aftermarket supplier survey.

2014	2015	2016
557,429	563,655	569,996

Notes:

1. Excludes volumes supplied to major OEMs (i.e. Toyota, Holden, Ford) for the manufacture of vehicles.
2. HFC-134a including all variants such as R134a UV plus.
3. Survey participants includes Ashdown-Ingram, Cooldrive, Burson, Repco, JAS Oceania, Highgate, BOC, Heatcraft, Actrol and an allowance of 10 tonnes for Ready Gas, and miscellaneous independent wholesalers.
4. The above volumes do not account for refrigerant recovery and re-use that may occur in workshops.

CHF2 reported 'leak rates' of 11.8% for MAC across the entire fleet compared to the globally accepted default rate of 15% per annum (IPCC 2006 Vol 3 Table 7.9). 'Leaks' from MAC include an allowance for handling losses in the refrigerant supply line, losses while servicing vehicles, losses during operation of the vehicles, catastrophic losses from equipment failure, and a 1.5% annual allowance for losses as the result of collisions.

Applying that 'leak rate' to the estimated MAC bank in 2012 (9,100 tonnes) indicated annual fleet wide losses at 1,073 tonnes. This reconciled quite closely with the proportion of bulk imports that were thought to be sold into the MAC supply lines in Australia in 2012, even allowing for the 140 tonnes used in manufacturing in that year.

On the basis of 933 tonnes of bulk imports in 2012 having been used in servicing existing vehicles, that implied a service rate of more than 85% (i.e. more than 85% of refrigerant lost to leaks in the year were replaced).

With the now increased MAC bank estimated for 2012 to have been 10,600 tonnes, applying the leak rate of 11.8% suggests losses to air of approximately 1,250 tonnes for that year. The volume of bulk imports at the time that were identified as servicing the MAC fleet (933 tonnes), suggests that the 'service rate' of MAC in 2012 was actually closer to 74% (i.e. 74% of refrigerant lost from MAC in that year was replaced). Which means something like 317 tonnes of refrigerants lost from MAC in that year (around 3% of the MAC bank in 2012) was not replaced. It is also possible that the leak rate applied to MAC in 2012 was simply too high. This possibility is explored further below.

There is other evidence to suggest that underservicing of a MAC fleet is not uncommon. A 2017 study of the HFC economy conducted in New Zealand (MfE 2017), where most of the population live in a mild to cool climate, and most of the vehicles are imported second hand, found evidence that underservicing of MAC was widespread.

Assuming that servicing of the Australian fleet of MAC is consistently replacing around 75% of the annual losses, then the actual bank of working gases across the entire stock of MAC is about 93% of the fully charged capacity of that stock of equipment.

Since completing CHF2 the authors were also involved in conducting a study that involved assessing the volume of refrigerant gas found in small MAC in Australia at the point of vehicle retirement (DoEE 2015b). It concluded that, on average, MAC in retiring vehicles was likely to have around 67% of the original charge. This study was not just measuring reduced charges in MAC in very old cars. Some of the end-of-life vehicles

(ELVs) assessed were new or relatively new vehicles as there are a great many relatively new vehicles taken off the road as the result of collisions that do not destroy the MAC.

The partial charge found in MAC in ELVs does suggest widespread underservicing of the fleet. However, the residual gas charge in ELVs, combined with aftermarket usage volumes, also suggested that the leak rate used in CHF2 was too high.

The mobile AC aftermarket study that collected data for the last three years indicates that, with a 2016 refrigerant bank of 10,800 tonnes, the refrigerant used for servicing MAC in 2016 was equivalent to just 5% of the bank. However, if leak rates on average were 11.8%, service usage equal to 5% of the bank implies less than 50% of annual losses are being replaced. With an average life of 18 years, and a service rate replacing less than 50% of annual losses, then vehicles at the end of their service life should have none of the original refrigerant charge left.

There is evidence from service companies to suggest that refrigerant leak rates have improved in newer car models. And noting average charges in ELVs of 67%, then it appears that the generally held assumption of an 11.8% annual leak rate from MAC in 2012 was too high.

Assuming an average vehicle life of 18.6 years, and a service rate replacing about 70% of the annual losses achieves an average of a 67% residual charge in end-of-life vehicles. This implies a leak rate across the fleet of MAC of just 6.8%, significantly lower than the rate used in 2012 of 11.8%, a value that at the time was an internationally accepted average leak rate for MAC. In the absence of any better data on residual charges in MAC in ELVs, this study has applied an average leak rate across the MAC fleet of 6.8%.

This new understanding about MAC leak rates in Australia, the degree of underservicing of the fleet, and new data sets revealing previously hidden product categories, has resulted in far higher resolution of the mass flows of refrigerant into this major end use segment.

Vehicle manufacturing usage

Passenger vehicle manufacturing declined from 221,073 vehicles in 2012 (including light commercial vehicles) to 155,691 (FAI 2017) in 2016. All significant passenger vehicle manufacturing in Australia ceased on October 20, 2017 with the closure of the Holden manufacturing plant in Adelaide after nearly 100 years of operation in that city. Toyota's Altona factory in Melbourne, which in its nearly 55 years of operation produced more than 3.3 million vehicles, closed only days prior on October 3, 2017.

The decline in vehicle production reduced demand for HFC-134a for vehicle manufacturing from around 140 tonnes in 2012 to around 97 tonnes in 2016. The effect of the end of all significant vehicle manufacturing in 2017 means that since the year 2000 more than 300 tonnes of annual bulk HFC demand has been removed from the Australian economy.

Along with this decline in manufacturing, the amount of refrigerant imported in MAC in passenger vehicles continues to rise as HFC charged vehicle imports replace lost local manufacturing.

While there is evidence of some vehicles charged with HFOs being imported, the great majority of vehicles imported since 2012 were charged with HFC 134a.

HFOs

The new generation of low GWP refrigerants, hydro-olefins, known as HFOs, developed with MAC in mind, (HFO-1234yf AR5-100 GWP of 1), have been entering use in international vehicle markets since 2013, initially in Europe despite some initial resistance from a number of European manufacturers. EU regulations required all new car model releases, or 'new platforms' manufactured with MAC to have a refrigerant with a GWP of less than 150 from January 2011, and all new vehicles with MAC were to meet these requirements by January 2017.

Several leading manufacturers in 2012 refused to agree to change over their production lines on the basis of perceived safety risks of the mildly flammable HFO-1234yf. By the end of 2013 with leading international car makers such as Toyota deciding to charge cars bound for the EU market with HFOs, resistance from

European car makers eased. As a result of the initial opposition, in 2017, Mercedes has been ordered to recall more than 160,000 cars manufactured in the first 6 months of 2013 with MAC charged with HFC-134a and rebuild their air conditioning systems charged with a refrigerant with a GWP<150.

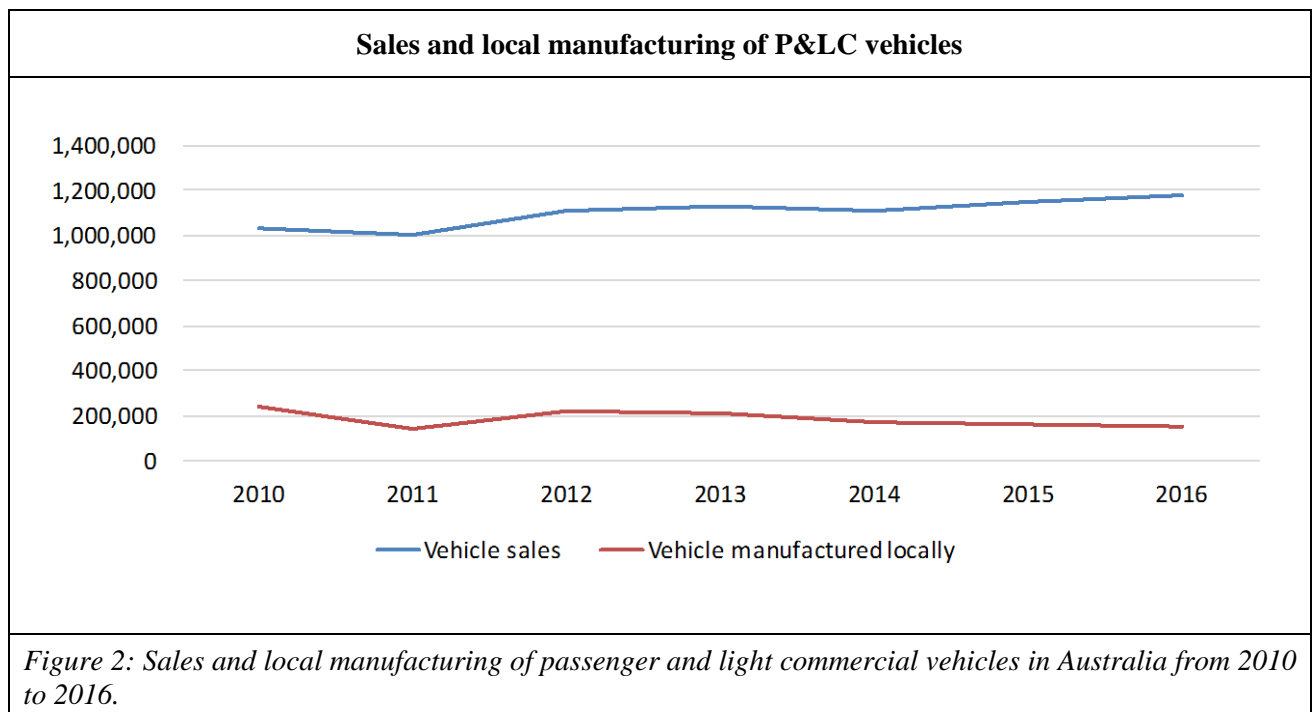
With the international agreement to the Kigali Amendment to the Montreal Protocol, and a clear timeline for an international HFC phase down, it is expected that new vehicles from most leading manufacturers will be charged with HFO-1234yf by the mid-2020s, and only a small portion (<0.5%) charged with CO₂.

HFO use is now supported by regulations in the majority of major economies. Japan’s Act on the Rational Use and Proper Management of Fluorocarbons, for instance, mandates a maximum GWP of 150 for refrigerants in air conditioners of all new passenger cars, effective from 1 January 2023. The Expert Group model assumes that 90% of vehicles manufactured in Japan from this point will contain HFO-1234yf, and 100% in 2030. Japanese industry sources suggest there are no plans to manufacture vehicles with air conditioners charged with CO₂.

The US Environmental Protection Agency (EPA) and the Department of Transportation’s National Highway Traffic Safety Administration (NHTSA) have set standards to reduce Greenhouse Gases and Improve Fuel Economy for Cars and Light Trucks manufactured in 2017 to 2025. These emission standards are driving a rapid transition of mobile air conditioning technology to HFO-1234yf in new vehicles sold in the US.

Despite the international momentum, HFOs and other alternatives are yet to make any significant impact on the MAC bank in Australia. Vehicle manufacturing in Australia ceased in 2017 without any move to different refrigerant types. As such the last 150,000 vehicles manufactured in Australia in 2016 and 2017 were all charged with HFC-134a. Interviews with industry representatives indicate that in 2016 and in 2017 Australia saw an insignificant number of vehicles charged with HFOs being imported, and none containing CO₂.

A comparison between PCE imports, plus local manufacturing less exports, versus new vehicle sales, found a statistical difference of around 2% over the last 5 years to be unchanged and confirmed reports from industry that there is no statistically significant decline in reported PCE charged with HFCs, as a result of substitution of HFC-134a with alternatives.



(Sources: ABS 9314.0 2017, FCAI 2017, FAPM 2014)

Suppliers are however gearing up for HFOs with at least one vehicle distributor securing the specialised HFO servicing equipment and a supply of refrigerant for every one of its Australia wide service centres.

While the RAC Stock model predicts that there may be around 23.7 million vehicles with small MAC on Australian roads in 2030, it is expected that around 41% of those vehicles, or around 9.8 million vehicles will, by that time, be charged with a refrigerant with a GWP less than 10, with the large majority of those (~99%) containing HFO-1234yf. Refer to *Appendix B2: New equipment sales mix by segment*, for new sales mix predictions to 2030.

Hydrocarbons in MAC

Hydrocarbon use in the MAC market is exclusively in aftermarket servicing of second-hand vehicles and is estimated to account for around 4.2% of the passenger and light commercial vehicle fleet (*CHF2 8%*).

This estimate is clearly much smaller than the 2012 estimate published in *CHF2*. However greater insight into the supply lines for hydrocarbons provided by the aftermarket surveys that have been conducted for the past three years and including an audit of the books of one of the largest aftermarket suppliers of hydrocarbon services in Australia, has led to a better understanding of the volumes of hydrocarbons being traded in this market, and the number of retrofits¹⁸ being completed.

As a result, the original estimate of the portion of the fleet containing hydrocarbons in 2012 has been revised down to 3.8%. The 2016 estimate of 4.2% of the small MAC fleet being charged with hydrocarbons equates to around 743,000 vehicles. This is significantly lower than the *CHF2* estimate of there being nearly 1.2 million hydrocarbon charged MAC in vehicles in Australia. HC charged MAC is expected to remain at around 4% of the fleet. Refer to *Appendix A: Section 11.2.5: Proportion of hydrocarbon in small MAC* for details on the calculation methodology and assumptions.

Trucks

A fleet of more than 587,000 registered rigid body and articulated trucks on the road in Australia in 2016 is estimated to have air conditioning installed. The RAC Stock model assumes 5% of the smaller rigid body and non-freight vehicles do not have MAC installed. These are likely to be older vehicles, tipper trucks and flat beds used for short hauls on farms, in other rural environments and possibly only in part time use.

Most new truck prime movers sold in Australia are imported, and in most instances, if they have MAC on board, they will come pre-charged. More than 30,000 new trucks are sold every year in Australia and the majority have had some kind of final customising or work completed in Australia, including the incorporation of locally manufactured components, to make them finally fit for purpose. There are also a number of truck manufacturers operating in Australia that assemble almost the entire prime mover and truck body in Australia including:

- Volvo Group Australia manufacturing Volvo and Mack brand trucks at Wacol, Queensland;
- PACCAR Australia manufacturing Kenworth trucks at Bayswater, Victoria; and,
- IVECO Trucks Australia manufacturing IVECO trucks at Dandenong, Victoria.

Market intelligence from MAC component suppliers suggest that in total these manufacturers between them are purchasing components for about 2,600 new MAC systems a year.

Large MAC

This segment comprises large buses and coaches dissected into two sizes, >12t GVM and >4.5t and <12t GVM; Passenger rail; Locomotive; Un-registered vehicles including off-road, defence and other (marine, etc.), and the rapidly growing category recreational vehicles (RVs) and caravans. RVs are defined by the

¹⁸A HC retrofit typically involves charging the MAC with HC without changing components unless it is a repair and retrofit. For further details refer to manufacturers installation guidelines.

ABS as self-propelled motor vehicles containing an area primarily used for accommodation, which includes motor homes and powered caravans.

Bus air conditioning

The fleet of buses and coaches with air conditioning is more than 41,000 with 24,870 buses with a GVM greater than 12 tonnes, and 17,000 buses greater than 4.5 tonnes GVM and less than 12 tonnes GVM. The RAC Stock model assumes bus air conditioning systems have an average lifespan of 20 years as most contracts for purchasing new buses set a maximum lifespan of 25 years (BITRE 2016a). Given the longevity of a passenger bus working life it would be fair to expect the air conditioning system in a bus would be completely refurbished at least once during its typical lifespan.

The main bus manufacturers are Iveco, Scania and Volvo. Australasian Bus & Coach (AB&C) publishes a comprehensive analysis of bus and coach deliveries nation-wide from 1998 to the present day that includes detailed specifications down to the supplier of the air conditioner. Bus and coach air conditioning OEM sales have grown from 466 in 1998 to an average of 1,345 per annum from 2012 to 2016 (AB&C 2017).

The main bus air conditioning suppliers are Thermo King, CoachAir, Denso and Carrier, however over the last decade there have been many new suppliers enter the market including Cooltek, Daewoo, Fainsa, Higher Air, Hispacold, Kingtech, Konvekta; KT, Lou Air, MCC, Spheros, Suttrak, Tracs, and Yutong.

Bus and coach air conditioning systems are generally charged in Australia with around 65% containing HFC-134a and the balance HFC-407C.

Better data on bus manufacturing and the air conditioning systems employed has resulted in the average charge employed in the RAC Stock model being revised down from 9.0 kg in 2012 to 5.5 kg in 2016.

Rail air conditioning

The air conditioned rail fleet in Australia comprises 2,050 locomotives and 5,430 passenger rail cars. Not all passenger rail cars are air conditioned, for instance in 2016 there were 1,619 passenger rail cars in Sydney of which 1,427 were air conditioned.

All locomotives on Australian railway networks are air conditioned for the comfort and security of drivers, and typically contain 3 to 4 kg of HFC-134a. Locomotive air conditioning systems use HFC-134a and are generally specified to cope with higher ambient temperatures as they may have to endure temperatures up to 50°C on various sections of the trans-Australia network.

Passenger railcar air conditioning units are generally much larger than those required for locomotive drivers' cabins and at 40 kW capacity will typically contain much larger charges of around 15 kg of HFC-407C.

Rail air conditioning units are imported to Australia as pre-charged equipment typically as part of a complete train set. Replacement MAC units are imported separately.

While Adelaide has introduced a new light rail/tram network to the city in the last decade, of all the State capitals only Melbourne has a significant tram network. There are 216 trams in Melbourne that have no air conditioning other than in the driver's cabin. Many of the operating trams are now decades old and will not be retrofitted with MAC because of the high cost. Instead the network operator, Yarra Trams is gradually rolling out a new supersized E-Class tram, replacing the oldest trams in its fleet as it does, and redeploying air conditioned trams across the longer routes on its network.

The key market participants in the service of MAC in locomotives, rail and trams include Sigma Coachair Group (subsidiary of Knorr Brams); Mitsubishi Electric (Transportation & Heavy Engineering Division); Faiveley Transport, and to a lesser extent Noska Kieser.

Recreational vehicles and caravans

Since 2012 the rapid growth in caravan manufacturers in Australia has received a great deal of press, although in 2012 it had not yet been widely noted, and research for CHF2 missed this growing product category and active market.

New investment has flowed into this now significant Australian manufacturing sector with the Caravan Industry Association of Australia, and Tourism Australia, reporting the fastest rise in caravan and camping trips in 2016 since data began to be collected, with sales value of Australian made caravans and RVs topping \$1.8 billion in 2016.

As a result, a new product category, 'MAC2-4: RV and caravan' has been added to the MAC class in the RAC Stock model. Caravan manufacturing in Australia has been one of the rapid growth manufacturing businesses driven by innovation in manufacturing, and economic and demographic changes that has seen larger numbers of Australians and international visitors caravanning around the country, some for long periods of the year.

The Caravan Industry Association of Australia¹⁹ reports that caravan registrations have soared by more than 30% since 2011 to more than 554,000. Campervan registrations climbed 20% in the same period reaching nearly 61,000 by January 2016. Of the more than 30,000 new registrations of both caravans and campervans in the previous year, more than 21,000 were manufactured in Australia. Anecdotal reports from manufacturers point to new caravan buyers generally being older, and having a preference for higher end vehicles, which will include air conditioning.

The RAC Stock model assumes that 100% of RVs and two thirds of caravans have air conditioning equating to a fleet of some 452,000 RVs and caravans with an average charge of 750 grams. The assumptions on the proportion of air conditioning was based on a survey conducted on the Hume Highway in Victoria over a 5 hour period that counted 12 RVs and 53 caravans followed by a review of second hand vehicles for sale.

Analysis of pre-charged imports of sealed units destined for caravan manufacturers in Australia shows the main refrigerant employed is HFC-407C (~90%) and some HFC-410A (DoEE 2017).

Table 11: Mobile air conditioning main metrics: 2012 versus 2016.

Metric	2012	2016	Change
Share of refrigerant bank	21%	21%	0%
Size of refrigerant bank	9,100 tonnes	10,800 tonnes	+19%
Annual usage to replace leaks (excl. OEM)	1,048 tonnes	636 tonnes	-39%
Refrigerant in pre-charged equipment imports over previous four years (excl. 2012)	Vehicles with gross vehicle mass (GVM) < 3.5 tonnes = 396 to 558 tonnes	All vehicles 925 to 996 tonnes with an average of 957 tonnes ⁽²⁾	+89%
Estimated stock of equipment	> 16.0 million units	> 18.2 million units	+14%
Annual expenditure on new equipment	~\$560 Million	~\$977 Million	+74%

¹⁹ *The Caravan and Campervan Data Report 2016 prepared by the Caravan Industry Association of Australia Ltd is a compilation of data from the ABS Motor Vehicle Census and Australian Demographic Statistics. (CVIAA 2016 and ABS 93090.0 2017).*

Metric	2012	2016	Change
Annual GHG indirect emissions	3.03 Mt CO ₂ e	2.96 Mt CO ₂ e	-2%
Share of HVAC&R indirect emissions	5%	5%	0%
Annual GHG direct emissions (ODS)	0.01 Mt CO ₂ e	0.01 Mt CO ₂ e	NA ⁽³⁾
Annual GHG direct emissions (SGG)	1.36 Mt CO ₂ e	1.24 Mt CO ₂ e ⁽³⁾	NA ⁽³⁾
Share of HVAC&R direct emissions	25%	20%	NA ⁽³⁾
Share of HVAC&R total emissions (direct and indirect, not inc. EOL)	7%	6%	NA ⁽³⁾

(Sources: AB&C 2017, ABS 9309.0 2017, ABS 9314.0 2017, AIP 2017, AMSA 2017, BITRE 2016, BIC 2017, CVIAA 2016, DoEE 2017, FCAI 2017 and industry informants)

Notes:

1. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol or United Nations Convention on Climate Change, as they managed through the Montreal Protocol.
2. Pre-charged equipment is for all DoEE mobile AC categories including motor vehicle, watercraft or aircraft air-conditioning. Therefore, this is not an exact comparison however the very large majority of these imports are vehicles with gross vehicle mass (GVM) < 3.5 tonnes.
3. The direct emissions in 2012 cannot be directly compared to 2016 as CHF2 is an assessment of a full bank and CHF3 is an assessment of a partially full bank.

4.4 Refrigerated cold food chain

Introduction

More than any other segment of the RAC industry, the refrigerated cold food chain (RCFC) is essential to the maintenance of our modern way of life. The RCFC is an essential piece of infrastructure without which it would be impossible to supply cities with the millions of tonnes of fresh food that are needed to sustain them. Without a highly reliable and extensive cold food chain, modern cities simply could not exist.

Food production and consumption, and all the associated activity and employment, also makes up a considerable part of the Australian economy.

In Australia, total household food expenditure (which includes eating out) was \$92 billion in 2015-16.²⁰ More than half of this reported household expenditure is on food that requires at least some, if not full-time refrigeration. At least 44% of average household food expenditure (not including eating out) is on food that generally has to be refrigerated including meat, fish and seafood (15% of average expenditure), dairy products (7%), fruit and vegetables (13%), and non-alcoholic beverages (8%).

The balance of household expenditure on food includes meals out and fast foods (31%), condiments, confectionery, food additives and prepared meals (11%), bakery products, flour and cereals (10%). It would be safe to assume that at least half of the food purchased during eating out, in fast food purchases and in prepared meals will have been refrigerated at some point. As such we can conclude that as much as 60% of total household food expenditure is on foods that have been delivered via the cold food chain, or more than

²⁰ *Food Demand in Australia; Trends and Security Issues*, Lindsay Hogan, ABARES June 2017.

\$55 billion worth of annual food expenditures. This is a figure that will grow closely aligned to population growth.

With perishable refrigerated food exports now delivering a significant and growing proportion of national export income, Australia's reliance on the cold food chain extends to its national economic well-being. In March 2017 UBS reported that farm production contributed more to GDP in the previous 12 months than the housing sector did.

Delivering the keynote address to the Global Food Forum²¹ only a week after the UBS analysis was released, Anthony Pratt, the US-based billionaire Australian and owner of global packaging giant, Visy, told the audience that Australian food exports had risen 60% between 2012 and 2016 to be worth more than \$44 billion. The Global Food Forum, that was started in Australia in 2013, has declared a target of \$100 billion in annual food exports from Australia.

For a lot of perishable produce, such as soft berries, most fruits and a large proportion of vegetable crops, the cold food chain starts inside the farm gate with refrigeration commencing as soon as possible after picking. Similarly, with fish and crustaceans immediate refrigeration at the correct temperatures corresponds directly to shelf life and thus economic viability of the wild or farmed harvest.

In recent years 'climate control' systems using permanent structures and, at this point, primarily passive ventilation, has extended right over the field with advanced farming mega-structures being installed over vegetable and fruit production in Queensland and Tasmania²². It is unlikely to be long before these examples of intensive agriculture bring some forms of refrigeration right into the growing process to manage the risk of damaging higher temperatures and control humidity. Given the pace at which these systems for 'farming under cover' are proliferating and proving to be highly economically viable at certain scales, it is almost inevitable that this will lead to controlled climate, and controlled atmosphere, horticulture for optimal yields, pest and fungal controls and management of pollination and ripening processes and timing.

Total farm gate production of food in Australia was estimated to be worth some \$63 billion in 2016 (*CHF2 \$49 billion*) more than 75% of that, worth more than \$48 billion (*CHF2 75% and \$38 billion*) was exported, contributing directly to the diets and wellbeing of tens of millions of people over and above the Australian population of 25 million (ABS August 2018).

Total production of perishable foods that require an unbroken chain of refrigeration from the point of production to the point of consumption, such as dairy products, seafood, meat and much fruit and vegetable production, was worth more than an estimated \$38 billion at the farm gate (*CHF2 \$28 billion*). Approximately \$18.8 billion was earned from export of perishable foods in 2016 (*CHF2 \$11 billion*). At the same time Australian's dined out on more than \$17 billion worth of total food imports in 2016, (*CHF2 \$11 billion*) at least 40% of which was likely to be refrigerated.

While being one of the smaller classes in terms of the portion of the bank employed and being the smallest in terms of the individual pieces of stock of equipment, the refrigerated cold food chain is thought to be the largest generator of direct and indirect employment associated with the RAC industry, including the people employed in the refrigerated transport task.

Refrigerated preservation of food is the original purpose for which the underlying technology of vapour compression refrigeration was developed and, as a result, refrigerating systems for maintaining food have been in constant technological development for more than 150 years.

As such it is no surprise that, while the refrigerated cold food chain is not numerically the largest class of equipment employed, it is characterised by having more variety of formats and mechanical styles for delivery of cooling services than any of the other classes.

Starting inside the 'farm gate' and extending into every aspect of food retail and hospitality, the cold food chain is built on several distinct technology segments including:

²¹ <http://www.theaustralian.com.au/business/in-depth/global-food-forum/global-food-forum-visy-executive-chairman-anthony-pratts-keynote-address/news-story/b8ebb588148e3ba7d2b84f9d0d9647a3>

²² <http://www.abc.net.au/news/2017-03-04/farmers-grow-crops-in-greenhouses-prevent-climate-change-effects/8321720>

- Cool rooms alongside the packing sheds in egg, meat, fruit and vegetable production;
- Dairy refrigeration including milk vats, jacketed tanks and processing systems;
- Blast freezers and chillers in the fishing fleet and dockside in fishing ports;
- Large cold storage facilities at distribution centres, including at port facilities and rail heads;
- Refrigerated display cabinets (RDCs) in retail outlets and refrigerated storage cabinets (RSCs) behind the scenes in commercial kitchens, hotels, restaurants and takeaway outlets;
- Large centralised supermarket refrigeration systems; and,
- Refrigerated transport involving vehicle engine driven refrigeration systems on trucks and vans of many sizes plus refrigerated shipping containers ('reefers') and some refrigerated rail cars that connect every step in the food production and delivery process with the final point of retail sale or processing.

Part of the reason for this diversity is the wide range of application temperatures required, ranging from water coolers dispensing water at around 10°C, to blast freezers operating below -35°C. However, the wide variety of tasks performed, and products moved along the cold food chain has also shaped the diverse formats employed, from small cool rooms and freezers in farm sheds and on fishing boats, to the dozens of types of refrigerated retail merchandisers used in retail outlets, restaurants and food halls.

End user requirements have also shaped both formats and sizes. While some formats have 'standardised' to an extent over the years, for instance beer cooling systems for hotels selling beer on tap from a keg, the majority of larger equipment formats in retail and hospitality are often able to be customised to some extent to suit the demands of the physical site, the unique aspects of the business and the budgets of equipment buyers.

This requirement for a large degree of flexibility in design and installation has meant that building and supplying larger commercial refrigeration equipment supports a significant domestic industry. This flexibility is exemplified by the local manufacturers of refrigerated cabinets who invite enquiries from potential customers, asking them on their websites to 'design your own product', selecting from a palette of options for size, capacity, temperature range, and physical format.

While local manufacturers continue to report tough trading conditions, and many standard components such as compressors are imported, as is some partially assembled equipment (e.g. refrigeration circuit sub-assemblies), some equipment in the RCFC is still manufactured in Australia²³, making this supply chain one of the few sectors in Australia in which manufacturing has been maintained during the last two decades. Even where equipment is imported largely ready to install, most still requires custom installation, charging with refrigerant and commissioning by skilled local technicians.

Using the product category codes in *Table 12* below it is estimated that:

- Less than 15% of equipment in RCFC1-1 is manufactured, or assembled and charged with refrigerant in Australia, the balance being imported as pre-charged equipment;
- Less than 15% of equipment in RCFC1-5 is manufactured, or assembled and charged with refrigerant in Australia;
- All equipment in categories RCFC1-8 and RCFC2-1 to RCFC2-8 is charged with refrigerant in Australia;
- While supermarkets employ a range of equipment including some smaller pieces that are likely imported as PCE, the great majority of equipment in categories in RCFC3-1 to RCFC3-3 is manufactured, or assembled and charged with refrigerant, in Australia;
- Around one third of equipment in categories RCFC4-1 and RCFC4-3 is manufactured, or assembled and charged in the field with refrigerant in Australia; and

²³ *Williams Refrigeration in Dandenong in Melbourne and Stoddard Manufacturing are significant local manufacturers of refrigeration display cases. Advanced Refrigeration Technology on the Sunshine Coast is a small producer of highly energy efficient refrigerated display cabinets.*

- All of the equipment in categories RCFC4-4, RCFC5-1 and RCFC5-2 is manufactured, or assembled and charged with refrigerant in Australia.

The direct employment in manufacturing, installing, charging and commissioning this large stock of complex electro-mechanical equipment is discussed further in *Section 10: Economics and employment*.

Improved visibility into the complex equipment supply chain in this class of equipment has led to some changes in the equipment taxonomy. Product categories that have changed since 2012 are highlighted in *Table 12* below.

Table 12: Refrigerated cold food chain taxonomy.

REFRIGERATED COLD FOOD CHAIN				
Item no	Segment	Application	Category code	Product category
31	RCFC1: Small Commercial Refrigeration	Self-contained	RCFC1-1	Refrigeration cabinets: self-contained
32		Self-contained	RCFC1-2	Refrigeration beverage vending machines
33		Self-contained	RCFC1-3	Beverage cooling (post mix)
34		Self-contained	RCFC1-4	Ice makers
35		Self-contained	RCFC1-5	Water dispensers (incl. bottle)
36		Self-contained	RCFC1-6	Other self-contained refrigeration equipment
37		Self-contained	RCFC1-7	Walk-in cool rooms: small: Slid-in/Drop-in
38		Remote	RCFC1-8	Walk-in cool rooms: small: remote
39		RCFC2: Medium Commercial Refrigeration	Remote	RCFC2-1
40	Remote		RCFC2-2	Walk-in cool rooms: large
41	Remote		RCFC2-3	Refrigeration cabinets: remote
42	Remote		RCFC2-4	Beverage cooling (beer)
43	Remote		RCFC2-5	Milk vat refrigeration (direct expansion)
44	Remote		RCFC2-6	Packaged liquid chillers (incl. milk vat)
45	Remote		RCFC2-7	Process, and mfg. refrigeration (<40 kW _r)

REFRIGERATED COLD FOOD CHAIN				
Item no	Segment	Application	Category code	Product category
46		Remote	RCFC2-8	Other remote equipment
47	RCFC3: Supermarket	Supermarkets	RCFC3-1	Supermarket refrigeration: small
48		Supermarkets	RCFC3-2	Supermarket refrigeration: medium
49		Supermarkets	RCFC3-3	Supermarket refrigeration: large
50	RCFC4: Transport refrigeration	Transport refrigeration	RCFC4-1	Mobile refrigeration: road: trailer - inter-modal
51		Transport refrigeration	RCFC4-2	Mobile refrigeration: road: diesel drive
52		Transport refrigeration	RCFC4-3	Mobile refrigeration: road: off engine
53		Transport refrigeration	RCFC4-4	Mobile refrigeration: marine
54	RCFC5: Process and industrial refrigeration	Industrial refrigeration	RCFC5-1	Cold storage and distribution
55		Industrial refrigeration	RCFC5-2	Process and mfg. (≥ 40 kW _r)

Notes:

1. Differences between CHF2 taxonomy and CHF3 taxonomy in this class are highlighted. Product categories highlighted in yellow indicate that the product has been renumbered since CHF2. Product categories that are highlighted in blue are either new additions to the list or have some definitional change to the category.

Overall confidence in the data relating to this broad class of equipment has improved substantially for a number of reasons. Insight into activity in each of the five equipment segments, small commercial refrigeration; medium commercial refrigeration; supermarkets; transport refrigeration; and, process and industrial refrigeration has improved through a mix of new research plus greater supply line transparency.

Partly as a result of conducting the research for CHF2, and undertaking subsequent research tasks, the authors have been involved in the routine quarterly production of a confidential market intelligence report for sections of the wholesale equipment supply line. The process involves a commercial-in-confidence arrangement among suppliers of various components who provide sales data on a quarterly basis, and in return, receive an aggregated report of the entire market on which they are providing data, with all identifying information stripped out.

This market intelligence gathering process is reasonably common in a number of industries and is very useful to all participants who can compare and track their own company's activity against the total market activity. The market intelligence reports managed by the authors of this report collect information from participants who in aggregate supply more than 90% of the markets being analysed.

From the point of view of CHF3 this process has greatly improved confidence in the majority of stock numbers reported, improved field data on leak rates in most categories, and revealed some parts of the market that were effectively hidden from the researchers in 2012.

Since CHF 2 was published there has also been a detailed Regulatory Impact Statement on Refrigerated Display and Storage Cabinets, formats that make up the majority of the extensive stock of the Small Commercial Refrigeration segment.

Stocks of the various product categories in this class of equipment are listed in *Table 13*. It should be noted that the 2016 RAC Stock model has been significantly revised and updated during the intervening years, and as a result some of the 2012 stock numbers in the current stock model have been revised to reflect new data. Any 2012 values in the RAC Stock model that have changed since the publication of CHF2 are noted in the table and discussed in notes below the table.

Table 13: Refrigerated cold food chain by category and stock numbers: 2012 versus 2016.

REFRIGERATED COLD FOOD CHAIN						
Category code	Application	Product category	Total (Units) 2012		Total (Units) 2016	Change (%)
			CHF2 Published	CHF3 ⁽²⁾ Updated		
RCFC1-1	Self-contained	Refrigeration cabinets: self-contained	447,000	578,000	670,000	+16%
RCFC1-2	Self-contained	Refrigeration beverage vending machines	134,000	134,000	136,000	+1.5%
RCFC1-3	Self-contained	Beverage cooling (post mix)	37,000	37,000	50,000	+35%
RCFC1-4	Self-contained	Ice makers	66,000	66,000	71,000	+8%
RCFC1-5	Self-contained	Water dispensers (incl. bottle)	235,000	235,000	239,000	+2%
RCFC1-6	Self-contained	Other self-contained refrigeration equipment	5,000	74,000	99,000	+34%
RCFC1-7	Self-contained	Walk-in cool rooms: small: Slid-in/Drop-in	65,700	8,300	9,000	+7%
RCFC1-8	Remote	Walk-in cool rooms: small: remote		199,700	210,000	+5%
RCFC2-1	Remote	Walk-in cool rooms: medium	20,200 ⁽⁵⁾	17,600	19,600	+11%
RCFC2-2	Remote	Walk-in cool rooms: large (incl. warehouse)	12,200 ⁽⁶⁾	16,500	19,650	+19%
RCFC2-3	Remote	Refrigeration cabinets: remote	-	13,600 ⁽⁷⁾	13,500	-1%
RCFC2-4	Remote	Beverage cooling (beer)	12,200	12,200	10,200	-18%
RCFC2-5	Remote	Milk vat refrigeration (direct expansion)	6,800	6,800	5,600	-18%
RCFC2-6	Remote	Packaged liquid chillers (incl. milk vat)	10,000 ⁽⁸⁾	10,500	12,000	+14%
RCFC2-7	Remote	Process, and mfg. refrigeration (<40 kW _r)	-	9,200	10,200	+11%

REFRIGERATED COLD FOOD CHAIN						
Category code	Application	Product category	Total (Units) 2012		Total (Units) 2016	Change (%)
			CHF2 Published	CHF3 ⁽²⁾ Updated		
RCFC2-8	Remote	Other remote equipment	-	33,500	37,500	+12%
RCFC3-1	Supermarkets	Supermarket refrigeration: small	2,048	2,048	2,355	+15%
RCFC3-2	Supermarkets	Supermarket refrigeration: medium	985	985	1278	+30%
RCFC3-3	Supermarkets	Supermarket refrigeration: large	333	333	460	+38%
RCFC4-1	Transport refrigeration	Mobile refrigeration: road: trailer - inter-modal	6,300	6,300	9,900	+57%
RCFC4-2	Transport refrigeration	Mobile refrigeration: road: diesel drive	5,000	5,000	7,200	+44%
RCFC4-3	Transport refrigeration	Mobile refrigeration: road: off engine	17,600	17,600	20,800	+18%
RCFC4-4	Transport refrigeration	Mobile refrigeration: marine	420	420	410	-2%
RCFC5-1	Industrial refrigeration	Cold storage and distribution	13.05 Million m ³	13.05 Million m ³	15 Million m ³	+13%
Total RCFC			1.08 ⁽¹⁰⁾ Million	1.49 Million	1.65 Million	+11%

(Sources: A2EP 2017, AACS 2015, AMSA 2017, DoEE 2017a, DoEE 2013, MC 2017, WF 2017a, WF 2017b, WOW 2017a, WOW 2017b, and industry informants)

Notes

1. Stock values are rounded to the nearest hundred.
2. In many instances the CHF2 2012 stock value has been revised based on improved information. For example, the stock of self-contained refrigeration display cabinets reported in CHF2 was estimated as 447,000. Improved data from the Regulatory Impact Statement on Refrigerated Display and Storage Cabinets increased the stock value to 578,000. This revised value is listed under the CHF3 2012 column.
3. The change per cent compares the CHF3 2012 revised value with the CHF3 2016 estimate.
4. Data on walk-in cool rooms of all sizes has improved significantly since 2012 with both new self-contained mini and small formats being identified and some shifting of stock between the medium and large categories. This is further discussed in the section below.
5. Total numbers of stock in the cold food chain includes the count of supermarkets which accounts for the centralised systems and the remote display cases connected to the system. Some of the stock of smaller classes of equipment such as self-contained merchandisers are counted separately in RCFC1-1.

Main metrics

The five segments and twenty five product categories that make up this class contained approximately 14% of the bank of refrigerant in Australia, or around 6,900 tonnes (*CHF2 11%, 5,000 tonnes*). The refrigerated cold food chain has more than 1.6 million installations and pieces of equipment that used an estimated 35% (1,250 tonnes) of all HCFCs and HFCs used in 2016 to charge new equipment and replace leaked refrigerant (*CHF2 19%, 614 tonnes*).

There have been several notable developments in this class since 2012 including;

- Rapid growth of HC refrigerants in smaller self-contained equipment (~20,000 devices imported in 2016) and increasing sales of CO₂ charged equipment in some small equipment categories (although rising from a very low base);
- Reductions in leak rates from larger equipment and supermarkets, and a concerted move to natural and lower GWP refrigerants among the leaders in the supermarket segments;
- An increase in the number of cool rooms identified in the market place; and,
- A rapid increase in small refrigerated transport units in operation as home delivery of fresh foods, food services and catering businesses and prepared meals delivery business expands.

Leak rates slashed in supermarkets

The disproportionately high level of bulk refrigerant use, compared to the portion of the bank employed in this class is, to some extent, due to the nature of the task. Machinery in the cold food chain is generally very hard working and operates the majority of the day, if not 24 hours a day. Generally, much lower temperatures need to be attained and maintained than in any air conditioning applications.

At the time of CHF1 in 2006 the larger players in the industry were acknowledging that leak rates were high in this sector and some work had commenced. However by 2011 with the imminent imposition of the equivalent carbon tax, all of the large participants in the cold food chain had launched wide ranging programs focussed on a transition to alternative systems and refrigerants, and refrigerant containment, generally involving both leak prevention, through proactive maintenance programs and system redesign, and installation of automatic leak detection systems.

In some instances, the results have been outstanding with annual leak rates dropping from as high as 25% a decade ago to around 6% per annum in 2016 (e.g. Coles).

Much larger stocks of cool rooms identified

Greater transparency into the supply lines for components that go into construction of cool rooms has led to an increase in the stock of walk-in cool rooms and walk-in freezers in the RAC Stock model.

The term walk-in cool room (WICFs) is used to describe an enclosed storage space that is refrigerated, either to temperatures above zero degrees Celsius or to zero degrees Celsius and below (also referred to as walk-in freezers).

WICFs comprise a structure formed by an insulated enclosure of walls and ceiling, and refrigeration equipment to refrigerate the space. The majority use remote condensing units and smaller WICFs can use self-contained equipment commonly referred to as “drop-in or slide-in” units. New technology is just starting to emerge in this sector where it uses brushless DC compressor technology, monitors refrigerant superheat and optimises the co-efficient of performance to achieve flat line temperature control. Best practice equipment can save energy consumption of around 25% to 30% over conventional equipment and this is not taking into account the structure, operation and maintenance improvement opportunities. AIRAH in association with Expert Group is currently drafting a discussion paper and potentially a Good Practice Guideline for WICFs that is expected to be released by the end of 2018.

Improved market intelligence revealed much larger sales during the last five years of condensers and evaporators in capacity ranges that are commonly used in WICFs, particularly in ‘small cool rooms’.

Annual sales of equipment required for small cool room refrigeration are now estimated at around 17,400 units and total stocks of small cool rooms are estimated at more than 219,000 in 2016 (*CHF2 65,700 revised to 219,000*). There is an estimated stock of 39,000 medium and large WICFs in 2016.

The size of the stock of equipment in this category makes sense if one considers the numbers of food retail outlets, such as fast food franchises, small cafes and restaurants operating in Australian towns and cities, most of which are likely to have at least one small cool room.

The RAC Stock model estimates that almost 90% of sales of remote condensing units are for equipment being used in WICFs. However, the growth in the stock of small WICFs is considerably less than annual equipment sales might suggest. This is because this hard-working equipment has a relatively short useful life of only 12 years, and as such some of the equipment sales are being used to either replace the refrigeration equipment servicing cool rooms, or to refurbish one or more of the components, such as replacing compressors in the condensing unit, or replacing the evaporators sited inside the cool rooms. Evaporators particularly are subject to corrosion due to exposure to breakdown products from fruit and vegetables, such as ethylene, and of course in small cool rooms, they are potentially subject to impact damage from cartons and pallets of food.

The tripling of this stock of equipment in the RAC Stock model flows through to increases in the estimates of energy used and of the size of the bank of refrigerant in this category which are discussed in the relevant sections later in this report.

The second realisation was the growth in what are referred to as “drop-in/slide-in” self-contained systems that are used in the construction of very small cool rooms. While the numbers of these sales are not huge, at an estimated 500 a year, the total number of units in this category is now estimated to be slightly more than 9,000. These devices are generally being sold into small hospitality venues, restaurants and takeaways. Changes to the taxonomy to accommodate this equipment category are discussed in the Small commercial refrigeration section below.

4.4.1 Small commercial refrigeration

Most of the equipment categories in the small commercial refrigeration segment are referred to in the trade as ‘self-contained refrigeration’. These units are stand-alone refrigeration systems in many different formats.

A huge amount of engineering effort has been invested in these devices over the decades to produce the wide range of reliable equipment that consumers purchase food and beverages from.

Self-contained commercial refrigeration equipment typically contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system employing relatively small refrigerant charges, ranging from as little as 40 grams in a small water cooler, to up to three kilograms in a larger refrigerated display case.

These equipment categories are employed in large numbers in both the front of store and back rooms of supermarkets of all sizes, local grocery and butcher stores, cafes, restaurants, takeaways, hotels and clubs and other food retail outlets. Generally front-of-store equipment is referred to as ‘refrigerated display cabinets’ and is fitted with either glass doors, transparent lids (in the case of tub displays) or are open (at least during trading hours) as is the case with many of the long upright fresh food, dairy and drinks display cases.

Small commercial refrigeration formats used in the service areas of restaurants, hotels, takeaways and in the back rooms of other food retail outlets are referred to as ‘service or storage cabinets’, and are generally upright formats, often multi-door but with solid doors (reducing heat gain).

The main product categories include:

- RCFC1-1: Includes both service cabinets and the more varied refrigerated display cabinets, sometimes referred to as ‘self-contained merchandisers’ covering plug-in-type food retail and supermarket cabinets, including; sandwich-pizza preparation and display counters; kitchen and service storage and preparation equipment found extensively behind the scenes in takeaways, restaurants and hotels; glass door merchandisers and upright cabinets; chest cabinets commonly used for ice cream display; wine, drink and glass chilling cabinets for bars, restaurants and hotels. RCFC1-1 also picks up a small number of specialised cabinets for pharmaceutical applications;
- RCFC1-2: 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.;
- RCFC1-3: (*CHF2 RCFC1-7*) 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 clubs, hotels, large restaurants with bars and entertainment venues;
- RCFC1-4: (*CHF2 RCFC 1-3*) 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;

- RCFC1-5: (*CHF2 RCFC 1-9*) Bottle water coolers and water dispensers found in offices, factories, gymnasiums, etc.;
- RCFC 1-6: Other self-contained small commercial refrigeration including some portable refrigeration systems for commercial applications;
- RCFC1-7: (*CHF2 RCFC 1-4*) Drop-in and slide-in packaged refrigeration units used in walk-in cool rooms and extensively used throughout the food chain to refrigerate fresh, chilled and frozen produce; and
- RCFC 1-8: (*CHF2 RCFC 1-4*) Small scale walk-in cool rooms, but with a remote condensing unit. These very small walk-in cool rooms are the only category in the RCFC1 segment that use a remote condensing unit.

In CHF2, categories RCFC1-7 and RCFC1-8 listed above were treated as one category of equipment, however new market intelligence has demonstrated that not only are these small systems far more numerous than previously realised, but also that high quality data can be identified to quite accurately estimate stock numbers and changes over time. As such these two categories have been separated and re-coded in the taxonomy of CHF3. Self-contained equipment has lower leak rates and smaller refrigerant charges than remote condensing unit systems which may provide potential for these WICFs to transition to HC charges depending on future charge restrictions defined by technical standards.

The refrigerant employed in commercial refrigeration is often selected based on the two main temperature ranges used for the conservation or freezing of fresh food and beverages. These are referred to in the industry as either; medium temperature (where produce is refrigerated to temperatures above zero degrees Celsius), and low temperature, (where food is refrigerated to zero degrees Celsius and below).

The majority of the existing stock of self-contained commercial refrigeration contains HFC-134a which is the refrigerant of choice for medium temperature applications.

A smaller portion of the stock of equipment operates on HFC-404A, mostly in low temperature applications or when greater refrigerating intensity is required.

Natural refrigerants taking market share in self-contained equipment categories

The use of hydrocarbons (HC-600a and HC-290), a trend that had barely started in 2012, is now firmly established as an option for buyers of new small commercial equipment in Australia with around 2% of the total bank in this segment now being hydrocarbon and expected to grow rapidly.

Smaller self-contained retail equipment is the leader in this trend with sales of new HC charged equipment in this category increasing more than 30 times (up 3,000%) since 2012, to nearly 20,000 units out of almost 140,000 total sales of self-contained units (including beverage vending machines, post mix drink vending machines, ice makers and water coolers) in 2016. This is compared to just a little over 600 HC charged units in 2012. Equipment being sold using hydrocarbon refrigerants with a charge less than or equal to 150 grams includes upright and horizontal freezer cabinets, refrigerated display cabinets, wine coolers and ice cream merchandisers.

Given the relative energy efficiency of devices charged with HCs and CO₂ as compared to the older equipment charged with HFC-404A and, now more commonly with HFC-134a, the trend of increasing sales of small self-contained commercial refrigeration using natural refrigerants is expected to continue.

Other categories of small self-contained equipment expected to migrate to natural refrigerants (in particular HC) include RCFC1-2, Beverage vending machines, RCFC1-3, Beverage cooling (post mix), and RCFC1-4 Ice makers.

A range of small self-contained refrigeration display cabinets (RDCs) charged with CO₂ were introduced to the market in recent years. Possibly as many as 1,000 sales were made of RDCs charged with CO₂ in the RCFC1-1 category in 2016. However, it is thought to be unlikely that CO₂ charged equipment in this category will grow significantly as the HC technology is proving to be highly energy efficient and competitively priced.

At present there is a refrigerant charge threshold imposed by safety standards in Australia (*AS/NZS ISO 5149: 2016*) of 150 grams for class A3 refrigerants (i.e. highly flammable) such as hydrocarbon²⁴. Increasing this charge size in general, or by specific application, would have a significant impact on the future penetration of hydrocarbon in small to medium commercial refrigeration applications.

Opportunities would particularly open up in those types of self-contained equipment and smaller remote equipment such as small walk in cool rooms, that do not already use HCs. An increase of the allowable HC charge size to 300 grams would for instance see the relatively high energy using freezers, up to 3 x 3 meters by 2.5 meters high, that presently employ a charge of up to 1 kg of HFC, being able to operate on HCs. As the engineering standards develop and the operational safety of HCs in larger charges is demonstrated, it is thought likely that regulatory controls will change to allow larger HC charges in these equipment segments.

In 2016 Australia adopted *AS/NZS ISO 5149: 2016 Refrigerating systems and heat pumps - Safety and environmental requirements*, a revised version of a similar standard, EN 5149 already in place in the EU.

More recently, the two officially recognised European Standardization Organisations: the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC) has taken the first steps to act on a request from the European Commission to review the limits and barriers on flammable refrigerants. The request requires CEN-CENELEC to analyse European standards for the use of flammable refrigerants, the relationship of risk, increased charge and risk mitigation requirements and identify mitigation options to enable consideration of wider use of flammable substances in refrigeration and air-conditioning equipment.

Partly driven by these developments in standards both here and overseas, and corporate commitments in the Australian supermarket sector to employ natural refrigerants (as seen for instance at both Coles and Woolworths), and supported by equipment manufacturers ready to roll-out product charged with natural refrigerants, HCs and CO₂ are expected to make up more than 41% of the bank in this segment by 2030. Projections of the changing sales mix by species of refrigerant employed are illustrated and discussed in *Appendix B2: New equipment sales mix by segment*.

The main local manufacturers of self-contained equipment include Williams Refrigeration, Advanced Refrigeration Technologies, Zip Industries, and Stoddart Manufacturing.

4.4.2 RCFC2 Medium commercial refrigeration

Much of the medium sized equipment in the refrigerated cold food chain is built using ‘remote condensing units’. For the average consumer, while they may not realise it, many are actually familiar with a ‘remote condensing’ equipment format, although in an air conditioning application. The majority of householders in Australia will be aware that wall hung split air conditioning systems have a component inside the house, and a component, connected by piping, outside the house. This is in effect a remote condensing unit with the heat carried from inside the house rejected by the condensing unit outside.

In medium commercial refrigeration most of the equipment categories are designed around a similar system, with a component (evaporator) inside the space being refrigerated, and the condensing unit connected by piping in some other location where the heat can be rejected to atmosphere and the refrigerant condensed for pumping around the system again.

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

²⁴ Refer *AS/NZS ISO 5149: 2016 Refrigerating systems and heat pumps. - Safety and environmental requirements for further details on refrigerant charge limits*.

Refrigeration systems with remote condensing units are used in a variety of applications including in large refrigerated display cabinets such as the rear loading wine and beer refrigerators, walk-in cool rooms, beverage cooling (e.g. beer and soft drinks), milk vat refrigeration on dairy farms and chilling and freezing applications in industry.

As data about commercial refrigeration equipment has improved, and the understanding of the supply lines and market requirements for equipment developed, it became apparent that the taxonomic classification of commercial refrigeration equipment in CHF2 could be improved in this edition. One of the changes in the RCFC class has been to move nearly all equipment using a remote condensing format into the RCFC2 segment, medium commercial refrigeration. Equipment employing remote condensing formats are generally much larger pieces of equipment, with larger refrigerant charges, than the suite of stand-alone, self-contained formats found in RCFC1.

The equipment categories in this segment include:

- RCFC2-1 and RCFC2-2: (*CHF 2 RCFC 1-5 and RCFC 1-6*) medium and large walk-in cool rooms;
- RCFC 2-3: Refrigeration cabinets with remote condensers (new category split out from CHF2);
- RCFC 2-4: (*CHF2 – RCFC 1-8*) Beverage cooling systems for beer in which beer from kegs is circulated through an ice bank cooler to serve beer from taps in all sorts of hospitality venues including clubs, hotels, large restaurants with bars and entertainment venues;
- RCFC 2-5: (*CHF2 – RCFC 1-11*) Milk vats used exclusively in the dairy industry for rapid chilling of fresh milk;
- RCFC 2-6: (*CHF2 – RCFC 1-10*) Packaged liquid chillers; and,
- RCFC 2-7: Process and Manufacturing <40kW_r (new category split out from CHF2).

The categories of commercial refrigeration equipment cover a wide range refrigeration capacity from >1 kW_r, up to packaged liquid chillers <40 kW_r used in process refrigeration applications in industry, and centralised systems for large cold storage facilities.

Some older walk-in cool rooms, beer coolers and milk vats are still charged with HCFC-22 with an estimated bank in this segment of some 260 tonnes of HCFCs in 2016 (*CHF2 450 tonnes*), although this is expected to fall to less than 5 tonnes by 2030.

HFC-404A, which has been the refrigerant of choice for most of this segment, particularly in walk-in cool rooms and freezers for more than a decade, maintains its dominance of the bank in RCFC2 with nearly 2,700 tonnes in 2016. This is essentially unchanged since 2012, with HFC-134a being the alternative refrigerant employed in the segment, increasing from around 600 tonnes in 2012 to over 800 tonnes in 2016, particularly among the smaller walk-in cool rooms. HFC-134a is expected to grow steadily in these applications to around 950 tonnes in 2030 as HFC-404A declines over the same period to around 1,180 tonnes.

The growth of HFC-134a has also capped growth of HFC-410A and HFC-407C, collectively, at around 130 tonnes, and both are expected to stabilise around that level for the next few years before declining towards the end of next decade as older equipment is retired.

HC charged systems have started to appear in the market for this segment with the entry of HC charged packaged liquid chillers. HCs are projected to grow from a relatively few units containing an estimated (1 tonne) in 2016, to an estimated 68 tonnes in 2030, however representing just 1.7% of the bank in this segment at that time. CO₂ systems are expected to achieve greater penetration in this segment, achieving around 8% of the remote condenser bank by 2030.

Illustrations showing projected new sales mix of equipment by refrigerant species are included in *Appendix B2: New equipment sales mix by segment*.

Walk-in cool rooms are prone to refrigerant leakage with an estimated annual average leak rate of around 15% per annum. Cool rooms of all sizes are often working in very difficult conditions, with remote units connected by refrigerant lines often in exposed, high traffic areas as, by the very nature of the systems, they

are generally associated with high frequency movements of goods and in areas with forklift and vehicle traffic.

Beverage cooling systems employ approximately 400 tonnes of refrigerant, (*CHF2 470 tonnes*) due to the large refrigerant charge required for beer chilling applications. An average installation can have 40 kilograms of refrigerant.

Milk vat refrigeration units are used by dairy farmers to rapidly chill fresh milk from 34°C to 4°C prior to pick up by bulk tankers. There are two common milk cooling methods used on dairy farms, ‘direct expansion’ cooling and ‘indirect cooling’ systems. Indirect cooling uses packaged liquid chillers to produce chilled water.

The rapid consolidation of the dairy industry that was reported up to 2012 has slowed considerably with reports of new equipment purchases increasing in this segment. Larger dairies that have survived the period of consolidation are upgrading to more efficient packaged liquid chillers. Subsequently refrigerant leak rates and energy consumption in this segment is also decreasing relative to earlier years.

4.4.3 RCFC3 Supermarkets

Supermarkets are divided into three sub-categories by trading floor area:

1. Large Supermarkets with a floor area greater than or equal to 2,750 m²;
2. Medium Supermarkets with floor areas between 1,500 m² and 2,750 m²; and,
3. Small Supermarkets with floor areas between 400 m² and 1,500 m².

Mini-marts, convenience stores and liquor outlets with floor areas smaller than 400 m² are categorised as ‘Extra small’ but, unlike the first three categories of supermarkets, do not have a code of their own in the taxonomy as the refrigeration equipment in these very small outlets will all be either self-contained equipment and remote condensing units (i.e. walk in cool rooms) which is captured in other categories of equipment. *Table 14* shows the dissection of large, medium and small supermarkets as well as mini-marts by brand.

Table 14: Supermarket fleet by brand and size.

Brand	Stores	Av. Trading floor (m ²)	Trading floor (m ²)			
			Large	Medium	Small	Extra small
			≥ 2,750	≥1,500 & < 2,750	< 1,500 & ≥400	< 400
Coles	801	2,298	200	401	200	0
Woolworths (Safeway) ⁽¹⁾	1,002	2,605	251	501	251	0
Aldi ⁽²⁾	490	1,060	0	0	482	0
IGA	1,683	~800	0	337	1,178	168
Foodworks	530		0	39	197	294
Costco	9	~5,000	9	0	0	0

Brand	Stores	Av. Trading floor (m ²)	Trading floor (m ²)			
			Large	Medium	Small	Extra small
			≥ 2,750	≥1,500 & < 2,750	< 1,500 & ≥400	< 400
SPAR	135	-	0	0	27	108
	4,642		460	1,278	2,335	570⁽³⁾

(Sources: WF 2017a, WOW 2017a, MC 2017 and industry sources)

Notes:

1. Woolworths has 544 stores with attached liquor.
2. Aldi had 482 stores in August 2017.
3. There are a further 6,080 to 6,100 convenience and petrol stores including 7 Eleven, AA Holdings, Apco, BP Coco, BP Regional, Caltex All Star (excluding WW co-branded sites), Coles Express, Freedom Fuels, Independents, New Sunrise, Night Owl, On The Run (Peregrine), Puma Energy, UCB, United (incl. distributors), and Woolworths Petrol (AACS 2015 extrapolated to FY 2016/7).

The major supermarket chains are leading the trends that are expected to dominate the supermarket sector until 2030, demonstrating new technologies and practices to the rest of the commercial refrigeration sector.

Supermarkets generally contain a variety of refrigeration equipment that can include:

- Large central plant (rack system) providing refrigeration to large volumes of glass fronted and open display cases with varying temperature requirements for dairy, meat and grocery food stuffs; large volume freezers for frozen goods; and, other refrigerated retail display formats;
- Remote condensing units servicing refrigerated display cases and walk-in cool rooms; and,
- Self-contained merchandisers in a wide variety of formats located throughout the store such as single, double or even triple door glass fronted display cabinets for selling drinks, icecream, dairy or other medium and low temperature products.

A centralised plant supermarket refrigeration system typically includes 8 to 12 compressors, ranging in capacity from 7.5 to 22.5 kW_r, serving both low, medium and high refrigeration temperatures, built onto a rack system located in a dedicated refrigeration plant room. It is these centralised refrigeration systems that are increasingly being operated with a low GWP refrigerant, reducing the GWP of the bank in this segment, and delivering significant improvements in energy efficiency from more advanced refrigeration systems.

Historical data indicates that large supermarkets have employed centralised equipment requiring refrigerant charges from 900 to 1,300 kg; with medium supermarkets generally requiring between 600 to 900 kg and small supermarkets employing 160 to 300 kg of refrigerant on average.

The charge sizes are changing as modern supermarket systems evolve from conventional direct expansion rack systems, to more advanced refrigeration systems, such as cascade systems with secondary chilling loops that can encompass air conditioning loads and other refrigeration loads such as attached liquor outlets.

In aggregate, large, medium and small supermarkets in Australia have a combined trading floor of around 7 million m² and consume more than 5,700 GWh of electricity per annum of which at least 50% to 60%, or around 3,200 GWh per annum is for running refrigeration systems.

Mini-marts, convenience stores, liquor outlets and some small supermarkets generally operate with remote condensing units connected to display cases, cool rooms and freezers with total aggregate charges on average of only 40 to 80 kg. Depending on the type of retailer and location these smaller food retail and liquor outlets will also employ a variety of self-contained equipment such as self-contained refrigeration display cabinets, vending machines and frozen drink makers.

There are at least 4,070 supermarkets (trading floor >400 m²) which together contain around 1,950 tonnes of high GWP HFCs and 160 tonnes of HCFCs, or about 4% of the bank (*CHF2 3,200 tonnes and 7%*). This estimate of the share of the bank employed in supermarkets *excludes* refrigerant in self-contained devices which are analysed separately in Sections 4.4.1 *RCFC, Self-contained commercial refrigeration*.

In 2012 the large majority (85 to 90%) of refrigerant in supermarkets was the very high GWP HFC-404A (GWP 3,922). Most of the rest of the refrigerant employed at that time was HFC-134a or HCFC-22.

As the share of the total bank attributed to supermarkets has fallen since 2012 from approximately 7% to approximately 4% of the larger 2016 bank, so has the relative share of direct emissions from supermarkets fallen to an estimated 11% in 2016.

This has been achieved by one of the most notable trends in supermarkets, the dedicated programs by supermarket managers to eliminate direct emissions from equipment leaks and the risk of catastrophic losses of refrigerant. These increasingly common programs of improved refrigerant containment are generally accompanied by, or part of, overarching energy efficiency programs, which have also been producing tremendously positive results for supermarket owners.

In the mid-2000s some major supermarkets were reporting annual direct emissions of as much as 25% of their refrigerant charge. Since that time all of the major supermarket chains have increased focus on maintenance and engineering efforts to reduce refrigerant losses.

For instance, a dedicated program of maintenance and leak reduction across the Coles fleet of equipment, coupled with automatic leak detection systems at all Coles supermarkets, has seen annual use of high GWP refrigerants reduced by more than 50% since 2012, from more than 120 tonnes to less than 60 tonnes in 2016. Programs of leak reduction across the entire supermarket fleet have resulted in average leak rates now estimated at less than 10%.

An emerging trend in refrigerant retrofitting, that was first reported in CHF2, has also persisted. In 2012 it was noted that the supermarket industry and other medium temperature refrigeration applications were beginning to switch from HFC-404A to HFC-134a (GWP 1430), partly because of the lower GWP of the HFC-134a refrigerant which, as a result of the equivalent carbon tax on imports of HFCs at the time, made HFC-134a significantly less expensive than HFC-404A.

Some retrofitting of HFC-404A systems with HFC-407F (GWP of 1825) was also reported at the time. CHF2 estimated that as much as 40 tonnes of HFC-404A was replaced with HFC-407F in 2012. However, this trend did not develop significantly in the supermarket industry post-2012. The major industry player who initiated the retrofitting in 2012 encountered operational issues with compressors and the repeal of the equivalent carbon tax removed the financial driver for migrating to HFC-407F.

Wholesaler reports indicate that in the last five years only 136 tonnes of HFC-407F has been sold into the cold food chain. One reliable estimate is that about 56 tonnes of HFC-407F is employed in supermarkets in total, which suggests about another 80 tonnes is employed elsewhere in the cold food chain.

Emerging lower GWP blends are now being assessed by some supermarket operators as alternatives to HFC-404A and HFC-134a. Some supermarket operators are trialling and considering retrofit programs that replace HFC-404A with recently commercialised and approved²⁵ reduced GWP blends, HFC-448A (GWP of 1387^{AR4}) or HFC-449A (GWP of 1397^{AR4}).²⁶

HFC-513A, also referred to as XP10, (GWP of 573) is also being considered as a retrofit refrigerant to replace HFC-134a.

²⁵ ASHRAE Approve refrigerants and assign refrigerant numbers in accordance with ANSI/ASHRAE 34-2016, *Designation and Safety Classification of Refrigerants*.

²⁶ The AR4 GWP-100 value for blends such as HFC-448A and HFC-449A uses a GWP of 5 for HFO-1234yf and HFO-1234ze whereas the AR5 calculation uses a GWP value of 1.

While retrofitting older systems with reduced GWP refrigerant and new blends is being considered and trialled, investment trends in new equipment demonstrate that the large and medium supermarket segments in Australia are rapidly adopting refrigeration systems that need much smaller HFC charges overall.

This is being achieved with the active adoption of ‘cascade’ refrigeration systems that employ a smaller charge of high GWP HFC in the primary cooling loop, and a charge of CO₂ in a secondary refrigerant circuit (i.e. a large store with 1,000 kg refrigerant charge comprising 2/3 HFC-134a and 1/3 CO₂). Cascade systems are now regularly being specified for newly built large supermarkets.

The first HFC/CO₂ cascade refrigeration system was installed in Australia in 2005 by Coles and other varieties were trialled including an ammonia/CO₂ cascade system. There are now more than 800 of these advanced refrigeration systems in operation in Australian supermarkets.

The technology formats and charge sizes in cascade systems vary significantly, however the primary refrigerant of choice is HFC-134a comprising around two thirds of the total charge, and CO₂ as the secondary refrigerant with CO₂ charges ranging from more than 400 kg to as little as 25 kg of CO₂. This format means there will be scope to replace the HFC-134a charged phase with lower GWP blends at some time in the future as effective replacements are proven and released to the market.

A great deal has been learned about the variables that drive energy consumption in supermarket refrigeration technology over the last 5 years. Leaders in the supermarket industry have been working hard to deliver reliable, robust, cost effective low GWP refrigerant options that can be replicated at any site, and establishing baseline performance for new systems that can be used to benchmark improvements at successive installations. The long-term objective of the work has been to establish a technology mix that can be used as the foundation for industry transformation as the supermarket industry adapts to 21st century demands for hyper energy efficiency in operations, and minimal to zero emissions.

In the delivery of mission critical refrigeration this goal has been achieved with cascade HFC-134a/CO₂ systems that are typically one third more efficient than older HFC-404a parallel rack systems when comparing systems of similar capacity and in the same climatic conditions²⁷.

For some time, efficient operation of trans-critical CO₂ systems has been restricted in warmer climatic zones due to the low critical temperature of CO₂ refrigerant (e.g. critical temperature of CO₂ is 31.1°C versus 101°C for HFC-134a). This characteristic of CO₂ refrigerants has been a technical barrier for use of trans-critical CO₂ systems in higher ambient regions in Australia, with the early CO₂ trans-critical systems only found to perform efficiently in BCA climate zones 6 and 7. Early designs for trans-critical CO₂ systems incurred an energy penalty in the hotter months in warmer climate zones, as compared to HFC charged systems.

However, a new generation of CO₂ trans-critical technology is rapidly evolving with a mix of technology enhancement add-ons including booster systems, parallel compression groups, ejectors, adiabatic coolers, evaporative pre-cooling, indirect evaporative/dew point coolers and mechanical sub-cooling. Many of these innovations seek to manage the system gas cooler outlet temperature to offset the limitations of the low critical temperature of CO₂.

These systems are now well established in major supermarket groups and are starting to be employed by smaller independent supermarket operators. Leading supermarket contractor AJ Baker has installed CO₂ trans-critical systems across 14 sites with seven in Perth, one in Brisbane, two in Sydney and 4 others in climate zones 5 and 6 as of March 2018.²⁸ The key lessons have been that system gas cooler outlet temperature control is imperative for energy efficient operation in higher ambient temperatures zones, and that adiabatic coolers can deliver energy savings not previously possible in hotter months.

²⁷ AIRAH Refrigeration Conference 2018: Energy performance benchmarking of an Australian trans critical CO₂ supermarket, Dario Ferlin, Woolworths Ltd.

²⁸ AIRAH Refrigeration Conference 2018: Trans critical CO₂ in Australian supermarkets – continued success, Mike Baker, AJ Baker & Sons Pty Ltd.

A combination of the focus on alternative refrigerants, dedicated efforts to reduce losses of refrigerant, the shift to cascade systems with much smaller HFC charges, and the adoption of some CO₂-only trans-critical systems, have all contributed to reduce demand for bulk refrigerant in supermarkets.

As a result of these trends, and particularly the surge in investment in cascade and CO₂-only trans-critical systems, the RAC Stock model predicts that a significant portion of high GWP refrigerants will be removed from the supermarket sector by 2030, with around 35% of systems operating entirely or in part on CO₂. The model predicts around 35% of refrigeration systems in supermarkets will still be operating on high GWPs however this could be a conservative estimate if prices of high GWP refrigerant significantly increase compared to alternatives and lower GWP HFC blends. The balance of refrigerants comprises lower GWP blends and HFOs with a smaller footprint of HC (<1%) in 2030.

While these predictions may appear too conservative, this large fleet of hard working equipment, migrating from very nearly 100% high GWP HFC and HCFC charges in 2012, to low (i.e. CO₂) or reduced GWP charges in a period of less than two decades is a significant challenge.

The two retailers who presently control the majority of food retail in Australia (estimated at around 65% of the trading floor), Coles and Woolworths have both made public commitments to deliver HFC free refrigeration in their supermarket fleet in the course of the next decade, by 2026-27 (WOW 2017b, WF 2017a).

These declarations of intent and the corporate strategies underpinning them are worthy of note. Their central role in the RAC industry in Australia means that the plans by these industry leaders to transform the technology employed in the cold food chain will have far reaching impacts on the performance and characteristics of the refrigerated cold food chain, and on RAC supply chains.

While the major supermarket operators have essentially declared the same intention of achieving HFC free refrigeration services, they are taking different approaches to achieving their aims.

Coles initiatives

Coles supermarket stores are serviced by central plantrooms. Since the launch of its first 'green' supermarket in Gisborne in 2005 Coles has remained at the forefront of development in supermarket refrigeration.

Starting from just one cascade system at its Gisborne, Victoria, store in 2005, trials of CO₂ cascade refrigeration systems soon followed at a number of stores.

Coles now has around 150 large integrated cascade refrigeration systems (HFC-134a/CO₂) that provide combined cooling services to the refrigeration equipment in the store, attached liquor store equipment and air conditioning. Coles have another 10 cascade refrigeration systems providing just refrigeration services.

Coles Hallam, east of Melbourne, was the company's first store to feature a combined CO₂ cascade refrigeration and air conditioning plant, replacing the traditional approach of separate refrigeration and air conditioning plants – leading to a 20% reduction in energy consumption and the store becoming the first Green Star-rated supermarket in Australia. The Coles Coburg North supermarket in Melbourne's inner north has recently established a new advanced refrigeration system benchmark, with a combined cooling plant utilising CO₂ as the only refrigerant commissioned in early 2017 (Source: AIRAH 2017a and WF 2017b).

This so called 'critical control point' (CCP) system at Coburg North is a three-stage trans-critical CO₂ only system and was the first one implemented by any enterprise in Australia. Coles planned to have up to four further CO₂ only trans-critical systems in operation early in 2018.

Alongside this upgrading of the existing fleet and commitment to adoption of state of the art new technology where the business case supports new investment, Coles in partnership with City Holdings has developed a centralised fleet monitoring centre in Melbourne. The 'Contact Centre' at Mulgrave in Melbourne, provides 24/7 real time monitoring of environmental conditions, equipment operating status and refrigerant leaks across more than 2,500 Wesfarmers Group sites that includes Coles, Target, liquor outlets, hotels and convenience stores. The Contact Centre team now manage refrigeration services from planning through to

commissioning and then ongoing monitoring and management²⁹. This integrated approach with dedicated teams of refrigeration technicians and tradespeople has delivered energy savings in the order of 20 to 25% since 2012, and leak rates across the supermarket fleet estimated at around 6% per annum in 2017 as compared to more than 20% in the middle of the last decade.

Woolworths initiatives

When Woolworths laid out its sustainability strategy in 2006, seeking to maintain total CO₂e emissions at 2006 levels by 2015, it identified refrigeration as the source of 48% of the corporation's CO₂e emissions.

The target of maintaining group emissions at 2006 levels by 2015 translated as a 40% reduction from the company's projected BAU emissions growth. Given this ambitious target and the central role of refrigeration in the business and in the emissions profile of the organisation, it is no surprise that a great deal of the engineering focus has been on refrigeration systems.

In 2006 Woolworths took its first step away from the common use of HFC-404a refrigeration systems with the commissioning of their first HFC-134a/ CO₂ cascade system, proving to itself that both the installed and the operating costs of the cascade system were lower than the previous generation of equipment.

Woolworths now has nearly 250 cascade systems operating and piloted its first CO₂ only trans-critical system in May 2017. Representatives of the company state that it was the use of CO₂ as a refrigerant that allowed them to achieve their 2015 target with the CO₂ charged systems contributing directly to a reduction in the environmental impact of the corporation's refrigerant emissions, as well as reducing energy use across their stores and thus reducing energy related emissions.

In early 2017 Woolworths released its sustainability plans out to 2020 which target a further 15% reduction in direct refrigerant emissions and reducing overall CO₂ emissions by 10% below 2015 levels. Among the main planks of this plan is a commitment to innovate in the use of natural refrigerants, and in effect, declaring that the days of using HFCs are numbered. As a result, the company's engineers are now exploring every opportunity for lower HFC charged systems, or completely HFC free systems.

In 2017 Woolworths installed its first two trans-critical CO₂ only systems in Greenway Village mall in Colebee, New South Wales, and in March 2017 it commissioned a pilot water loop system in Collins Square in Melbourne (AIRAH 2017a). Water loop systems still use HFCs, but quite small quantities in a central plant as compared to older water chiller systems. As the name suggests they then circulate chilled water to supply refrigeration services. Water loop systems have potential for both higher energy efficiency and even lower HFC charges than even advanced cascade systems.

As part of its commitment to maximise its use of natural refrigerants during the course of the next decade, Woolworths has also developed a wide-ranging strategy of engagement with the wider refrigeration industry to ensure the professional skills and creative capacity for this generational change is available in the market.

Aldi initiatives

The more recent market entrant into this highly competitive and capital-intensive industry, Aldi, has established a fleet of new stores, almost all of which have been built using the latest refrigeration systems.

The majority of Aldi's 490 stores have a smaller trading floor of around 1,000 m² and a different technology platform from the other major retailers. Aldi stores are commonly equipped with a selection of self-contained freezers (up to 28 per store) that operate on hydrocarbons, with charges ranging from 110 to 150 grams. Therefore, they only require 4 kg of a natural refrigerant in total to operate freezers storewide versus 50 to 100 kg of HFCs on a conventional rack system.

The larger central plant they employ is generally a small cascade refrigeration system connected to around 40 metres of multi-deck chillers and back of house cool rooms that are serviced from a central plantroom or packaged system. At the time of writing more than 270 Aldi stores incorporate small cascade refrigeration systems.

²⁹ <http://www.cityholdings.com.au/about-city-services.html>

Independents

In the fleet of approximately 1,750 independent supermarkets there are at least 200 cascade refrigeration systems and around nine CO₂ only trans-critical systems currently in operation with several others under construction and planned.

Among others, A.J. Baker has been demonstrating novel approaches to adapting cascade refrigeration systems to higher ambient temperature environments, for instance with installations in Perth using evaporative cooling processes to assist waste heat transfer rates.

With both cascade and CO₂ only charged refrigeration systems demonstrating strong economic returns (via energy cost savings, lower refrigerant losses and reduced refrigerant replacement costs and lower maintenance costs) as compared to the previous generation of equipment, it is thought most significant investments in supermarket systems in Australia will employ cascade and CO₂ only charged systems in the future. As such the tenure of HFCs in the supermarket segment of the cold food chain is limited to the rate of refurbishment and replacement of the equipment stock in the older portion of the supermarket fleet.

Suppliers

The suppliers to the supermarket sector are compressor and refrigeration rack system manufacturer Bitzer; wholesalers such as Heatcraft, and supermarket contractors McAlpine Hussmann (a subsidiary of Panasonic); City Holdings (partners with Coles); Retail FM (subsidiary of Woolworths); AJ Baker & Sons; and smaller regional contracting businesses such as CA Group Services, MB Refrigeration and others.

4.4.4 RCFC4 transport refrigeration

The transport refrigeration segment has also seen significant improvements in available data since CHF2.

Refrigerated transport systems on road, rail and in intermodal containers are all referred to as 'transport refrigeration'. Refrigeration systems on fishing vessels and coastal shipping are simply called 'marine'. The majority of marine systems are on fishing vessels.

The transport refrigeration bank is estimated to employ 245 tonnes of refrigerant comprising less than 0.5 % of the refrigerant bank (*CHF2 0.4% and ~170 tonnes*). Annual leakage of refrigerants is relatively high as a result of high vibration and hard operating conditions of this equipment, compared to the small portion of the bank this segment employs.

Transport refrigeration is estimated to use approximately 1.6% or around 55 to 60 tonnes (*CHF2 1%, ~50 tonnes*) of annual HFC and HCFC refrigerant bulk imports, the majority is used servicing systems and for replenishment following system failures. Some is also used charging new equipment manufactured in Australia, or that is imported without a refrigerant charge.

Transport refrigeration technology is made up of:

- The transport refrigeration units (TRUs) 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.

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 failures would most likely result in the total loss of refrigerant charge. Compressor replacement would typically involve recovery and reuse of the refrigerant.

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.

The existing stock is prone to high leak rates estimated at around 20% per annum, however attention in new 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.

Refrigeration systems for trucks, trailers and intermodal refrigerated containers are predominantly charged with HFC-404A. In 2012 the typical charges were reported to be between 7 and 10 kilograms. The charges of new systems are now typically 4 to 6.5 kg of HFC-404A, and some brands are expected to migrate to a HFC/HFO blend in the next 2 to 3 years.

Significant growth in the refrigerated transport fleet across all categories RCFC4-1, 4-2 and 4-3 has been reported. Almost certainly some of the growth is directly tied to increased exports of fresh food flowing from new investment in horticulture and agriculture. However, there are also major increases in the fleet as a result of changes in the domestic market.

Both Woolworths and Coles for instance now provide home delivered groceries that can be ordered on line and scheduled for delivery to your door. Both of these grocery market majors now have fleets of more than 500 home delivery trucks and vans each.

At the same time there has been strong growth in sales of smaller off-engine-devices that are suitable for small delivery vans. These sales are thought to be tied to the growth of 'food services' businesses that are delivering increasing volumes of pre-made meals for either sale through other retail outlets, such as cafés and corner stores, or for quick home cooking.

While there have been some improvements in design of systems to reduce leaks of refrigerant, transport refrigeration systems in general operate in very high vibration and difficult conditions and design flaws of older designs (i.e. shaft seal and vibra-sorber) result in higher than normal leak rates.

At present the refrigerant of choice is HFC-404A on larger systems and HFC-134a on smaller systems with HFC-452A (GWP of 2141) as an option that has not been taken up in Australia.

Countering the high leak rates in this product category some suppliers are now offering sealed technology without shaft seals and vibra-sorbas. Trials were undertaken with CO₂ open loop systems which have not proven to be viable, and now closed loop vector technology is under review in Europe that may provide an alternative in the next five to ten years.

The next generation of road transport equipment is expected to have HFC-452A (includes 30% HFO-1234yf) as the refrigerant of choice and the older refrigerants as an option.

An unknown number (certainly in the tens of thousands) of refrigerated shipping containers commonly known as "reefers" enter and leave Australian ports every year, primarily carrying perishable foods. Most of the refrigerant use in manufacturing and service of reefers occurs overseas.

Mobile refrigeration: Marine

RCFC 4-4 (*CHF2 RCFC 2-4*) is a category that essentially captures refrigeration systems used in the commercial fishing fleet and are simply called 'marine' in the trade. While there are a small number of Australian registered coastal shipping vessels that have galley kitchens and on-board refrigeration, the majority of the engineering and investment is in the very large refrigerating capacity on commercial fishing vessels.

The majority of marine systems are found on fishing vessels. Marine refrigeration that is examined as part of the refrigerated cold food chain for this report are systems on fishing vessels that contain specialised chilling and often very high capacity blast freezing equipment.

Generally, only registered commercial fishing vessels of greater than 15 meters in length are likely to have a substantial refrigeration system.

These larger fishing vessels can stay at sea for two weeks or more before returning to dock or offloading to a 'mother ship'.

Smaller vessels, which might only spend a few days at sea, are more likely to either collect bulk ice at the wharf, and/or have portable refrigeration systems.

Interviews with industry stakeholders indicate that only about 20%, or between 400 and 450, of the more than 2,000 commercial fishing vessels registered with the Australian Maritime Safety Authority are regularly active.

The average refrigerant charge used in the CHF data base for these marine systems is 130 kg. However, at the larger end of the fleet refrigerant charges can be much greater.

For instance, the handful of the largest vessels in the fleet that sail to Antarctic waters for Patagonian tooth fish can have charges of up to 500 kg of refrigerant for snap freezing.

The 52 long distance vessels of between 17 to 28 metres that operate in the Northern Prawn Fishery in the Arafura Sea, and along the remote north coast of Australia, have an average charge of 260 kg. These specialised vessels contain more than 25% of the refrigerant bank used in the fishing fleet.

Tuna fishing vessels in Port Lincoln have smaller refrigeration charges as they do not freeze the produce and mostly operate brine tanks, whereas the vessels used to catch pilchards, which is the baitfish for the tuna fishery, have flooded refrigeration systems with larger charges up to 200 kg for rapid freezing.

There are many vessels around 15 meters in length that operate in coastal waters with a single compressor and a refrigerant charge of 100 to 130 kg. Shallow draught, smaller reef fishing boats only have small blast freezers with a charge of 10 to 12 kg.

In aggregate marine refrigeration is estimated to comprise around 0.1% (~55 tonnes) (*CHF2 0.1%, also 55 tonnes*) of the refrigerant bank. The leak rates have reduced from between 25% and 30% per annum³⁰ in 2012 to around 15% per annum in 2016, however industry usage is similar due to an increase in upgrades and retrofits equating to 0.4% of total usage (~15 tonnes) (*CHF2 2%, 16 tonnes*).

Leak rates of this magnitude are, to some extent, the result of the operating environment for these generally low temperature refrigeration systems. Fishing vessel systems are very hard working systems in difficult environments, often installed in very limited space with poor access for maintenance and repairs, operating in common plant rooms with the main engine, and under heavy load due to the need to rapidly chill or freeze tonnes of temperature sensitive product at a time. The normal machine vibration is greatly exacerbated by the high vibration and sometimes relatively violent movement of the vessel itself. Combined with operating in very high humidity plus dealing with the corrosive effects of salt from sea spray and sea water, these conditions would be demanding for most electro-mechanical systems.

Despite having relatively limited options due to the demanding requirements for snap freezers and refrigeration systems on fishing vessels, the refrigerants being used in the fleet are changing.

In 2012 more than 95% of the Northern Prawn Fleet for instance was using HCFC-22, with just a few employing HFC-404A. At that time HCFC-22 was on the verge of a price increase from around \$20/kg to more than \$100/kg, a price that has since stabilised at around \$100/kg as recovery and recycling in the market has increased.

A study in 2014 of options for refrigeration systems to transition away from the use of HCFCs had identified fishing vessels as an application for which very few economically attractive options were available. The Fisheries Research and Development Corporation provided funding for a more detailed investigation and ultimately, in 2015 invested \$675,000 in the Gulf Bounty Project, an engineering demonstration project run by the Expert Group on behalf of the Northern Prawn Fishery in which a NPF vessel was refitted with an

³⁰ Industry source: Austral Fisheries, leak rates greater than 30% per annum can be experienced on old open drive equipment.

advanced system design using HFC-404a. This system demonstrated improved energy efficiency compared to the previous equipment that is typically more than 25 years old, much higher levels of refrigerant containment, and greater refrigerating and blast freeze capacity (six tonnes of prawns per day versus 3 tonnes per day).

This project was a wakeup call to fishing vessel owners, demonstrating a viable and cost effective path to migrate their systems to more readily available HFC refrigerant.

Largely as a result of this initiative, today less than 25% of the Northern Prawn Fleet is still operating on HCFC-22, with more than 40% operating on HFC-404A, and the balance, around one third, now operating on HFC-438A (a HCFC drop-in replacement). The use of HFC-438A is considered a transition refrigerant, because it allows the continued operation of the older systems originally designed for HCFC-22, giving vessel owners more time to plan for and finance the work of moving to a new system charged with HFC-404A.

Interviews with participants in the refrigeration industry servicing the fishing fleet report that a new vessel being built in South Australia for a New Zealand fleet has been specified with HFC-404A. With the advent of the HFC phase-down under the Kigali Amendment to the Montreal Protocol fishing industry participants are now planning for a world with limited HFC supplies. Austral Fisheries for instance is building a large 35 metre boat in Mauritius that has a separate plant room presently designed to use HFC-404A. However, the vessel configuration allows for a future transition to an ammonia charged system.

Industry sources report that, where the plant room of smaller vessels allows, most of them have been moving to systems charged with HFC-404A. For instance, all of the boats owned by Kessels in Darwin are now charged with HFC-404A.

4.4.5 RCFC5 Cold storage, distribution, industrial refrigeration and large process chilling

Industrial refrigeration (RCFC5), or process refrigeration, are terms commonly used to describe refrigeration applications in large manufacturing processes, and those using a heat exchanger and secondary refrigerant such as water, brine or glycol to create the refrigerating effect.

Cold storage facilities and food manufacturers with in-house engineering expertise generally use industrial refrigeration systems with screw compressors or large reciprocating compressors operating on anhydrous ammonia (R717). There are a few industrial systems charged with HFC-404A, and some older HCFC-22 charged systems in operation, however these are now rare. Ammonia charged systems dominate this equipment category with around 99% of applications, based on total refrigerant bank in the category, using ammonia. There are some instances where cold storage facilities with equipment operating on HCFC-22 with steel pipes have been converted to ammonia and notable facilities with large HCFC-22 refrigerant charges (~6 tonnes) converted to cascade systems with ammonia as the primary refrigerant.

Small packaged liquid chillers (RCFC1-10) are used in process applications in laboratories, some food and drinks processing, and in other applications in manufacturing and research laboratories in a variety of industry sectors. They can have refrigerating capacities ranging from 10 kW_r to more than 1,000 kW_r. Refrigerant types used in these rare and specialised packaged liquid chillers vary significantly depending on the temperature range, size, application and design. Refrigerants used include HFC-134a, HFC-404A, HFC-407C, HFC-410A and HCFC-22.

Ammonia

The main applications where ammonia³¹ systems are found include cold storage facilities (typically 5,000 to 250,000 m³), large chilling, freezing and ice making systems in the primary and secondary stages of the cold food chain, and some chemical processes and mining air conditioning applications.

In 2016 there was an estimated 15 million m³ of cold storage space operating in Australia (*CHF2 9.5 million m³*) and the very large majority of these facilities (>99%) operate on ammonia systems. Assuming a benchmark obtained from industry sources of 29 kg per 1,000 m³ of storage space, this equates to around 430 tonnes of ammonia in cold stores.³²

Other applications where large charges of ammonia can be found in single installations are in high volume blast freezing applications that are extremely refrigeration intensive, requiring snap freezing of large masses of perishable goods such as in meat processing, poultry processing and other primary and secondary processes in the refrigerated cold food chain (i.e. snap frozen vegetables).

Some individual meat processing facilities are known to contain up to 150 tonnes of ammonia. There are almost 200 meat/poultry processing facilities in Australia that employ more than 20 people.³³ The meat and poultry industries have seen growth of around 16% since with production of around 3.03 million tonnes in 2012 to 3.50 million tonnes in 2016 (ABARES 2017).³⁴

A survey of suppliers of bulk ammonia estimated 577 tonnes were delivered to customers in 2016. A recent survey confirms an increase in supply with an average of 709 tonnes per annum over the three year period from 2014 to 2016. The supply of ammonia can vary depending on capital equipment works in that year, for example a new abattoir and meat processing plant may require between 10 and 20 tonnes of ammonia as a first fill.

Based on the research undertaken on existing facilities the present estimate of the ammonia bank is 4,800 tonnes in total, however the proportion of ammonia used on new plant, versus servicing and optimising existing plant is still largely unknown but is estimated to be around 50% new equipment and 50% existing equipment.

³¹Ammonia used in refrigeration systems is anhydrous ammonia meaning it does not contain water, the chemical symbol is NH₃ and the ASHRAE refrigerant number is R717.

³² Industry sources: Gabor Hilton and Michael Nolan, *Refrigerated Warehouse and Transport Association*.

³³ ABS 8165.0 *Counts of Australian Businesses, as of June 2017 and includes codes 1111 Meat Processing and 1112 Poultry Processing*. There were 62 business with more than 200 employees and 137 businesses with more than 20 and less than 200 employees. There were a further 1,057 businesses that were classified as non-employing or with less than 20 employees that are unlikely to have sufficient scale for an ammonia plant.

³⁴ ABARES, *Agricultural commodity statistics 2017 provides for production from 2010 to 2016*. The comparison values are three year averages from 2010, 2011 and 2012 versus 2014, 2015 and 2016. Actual production in 2016 was 3.2 million tonnes comprising beef and veal 2,125 million tonnes, pig and chicken meat 386 million tonnes and lamb and mutton 686 million tonnes. These production values exclude live exports.

Table 15: Refrigerated cold food chain main metrics: 2012 versus 2016.

Metric	2012	2016	Change
Share of refrigerant bank	11%	14%	+23%
Size of refrigerant bank	5,000 tonnes	6,900 tonnes	+37%
Annual use to replace leaks (excl. OEM and charging new equipment)	614 tonnes per annum	577 tonnes per annum	-6% ⁽²⁾
Estimated stock of equipment ⁽⁴⁾	1.48 million devices	1.65 million devices	+11%
Annual expenditure on new equipment	~\$0.782 Billion	~\$0.926 Billion	+18%
Annual electricity consumption:	14,657 GWh	18,994 GWh	+30%
Share of HVAC&R electrical consumption	25%	31%	+24%
Annual GHG indirect emissions	13.6 Mt CO ₂ e	17.53 Mt CO ₂ e	+29%
Share of HVAC&R indirect emissions	24%	30%	+25%
Annual GHG direct emissions (ODS) ⁽¹⁾	0.12 Mt CO ₂ e	0.12 Mt CO ₂ e	NA ⁽³⁾
Annual GHG direct emissions (SGG)	1.59 Mt CO ₂ e	2.79 Mt CO ₂ e	NA ⁽³⁾
Share of HVAC&R direct emissions	24%	46%	NA ⁽³⁾
Share of HVAC&R total emissions (direct and indirect, not including EOL)	24%	31%	NA ⁽³⁾

(Sources: A2EP 2017, AACS 2015, AMSA 2017, DoEE 2017a, DoEE 2013, MC 2017, WF 2017a, WF 2017b, WOW 2017a, WOW 2017b, and industry informants)

Notes:

1. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol or United Nations Convention on Climate Change, as they managed through the Montreal Protocol.
2. The average over the last three years was 709 tonnes, therefore the trend versus 2012 is more likely +15%.
3. The direct emissions in 2012 cannot be directly compared to 2016 as CHF2 is an assessment of a full bank and CHF3 is an assessment of a partially full bank.
4. In many instances the CHF2 2012 stock value has been revised based on improved information. For example, the stock of self-contained refrigeration display cabinets reported in CHF2 was estimated as 447,000. Improved data from the Regulatory Impact Statement on Refrigerated Display and Storage Cabinets increased the stock value to 578,000. This revised value is listed under the CHF3 2012 column. The change per cent compares the CHF3 2012 revised value with the CHF3 2016 estimate.

4.5 Domestic refrigeration

Modern domestic refrigeration and freezers are highly refined designs, benefitting from decades of engineering and operational data, are very reliable and generally very efficient devices that are the necessary end point of the cold food chain.

This class of equipment includes both larger refrigerators and freezers found in every kitchen, plus a growing number of portable and vehicle refrigeration systems that are used in caravans, trucks, and as camping systems that can run on low voltage automotive power feeds.

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, as are the number of machines with beverage dispensing capability, although these more expensive devices still only represent a relatively small fraction of existing stock.

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 200 grams³⁵, and charges around 40% less if charged with hydrocarbons. 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.

Table 16: Domestic refrigeration taxonomy.

DOMESTIC REFRIGERATION				
Item no	Segment	Application	Category code	Product category
56	DR1: Domestic refrig & freezers	Refrigerators and freezers	DR1-1	Domestic refrigerators
57		Refrigerators and freezers	DR1-2	Domestic freezers
58	DR2: Portable refrigerators	Portable and vehicle refrigeration	DR2-1	Portable refrigeration
59		Portable and vehicle refrigeration	DR2-2	Vehicle refrigeration

As the end point of the refrigerated cold food chain, domestic refrigeration and freezers provide labour saving and economic benefit for consumers. It has often been observed that when communities first get electricity one of the most prized possessions is a refrigerator, no matter how small. Refrigeration delivers the immediate benefit of being able to preserve both fresh and cooked food, saving enormous amounts of time and labour when several days food for the household can be gathered, purchased or cooked in one effort, and then stored for consumption on later days.

While the entire class of self-contained, non-display, refrigeration and freezers are categorised as ‘domestic’ appliances in the CHF3 RAC Stock model, there are of course large numbers of these appliances used in hotel rooms, office buildings, staff kitchens, behind the scenes in the commercial kitchens of restaurants and takeaways and in other non-residential situations.

After decades of steady improvements in the energy efficiency of domestic appliances, a phenomenon driven almost entirely by international and Australian regulatory requirements, it is possible that in developed

³⁵ The average charge of a domestic refrigerator is 140 grams of HFC-134a and 55 grams of HC.

economies overall energy efficiency in the newest models is plateauing. ‘Features’ such as ‘ice dispensers’ and chilled water or beverage dispensers have become more common. Many top end models now incorporate external touch screen display controls and connectivity with the internet, requiring Wi-Fi connections, which all adds to increased energy use, while not contributing directly to the essential cooling services.

Domestic refrigeration in Australia (including domestic freezers and small portable refrigerators) is estimated to contain approximately 1,900 tonnes of HFC-134a and 380 tonnes of HC refrigerant, equal to approximately 4% of the total refrigerant bank (*CHF2 5.4%, 2,200 tonnes*) in a total stock of greater than 19.2 million devices³⁶ (*CHF2, 17.1 million*).

Domestic refrigeration in Australia was estimated to have consumed 8,534 GWh of electricity in 2016 (*CHF2, 7,374 GWh*), including electricity in portable appliances, although these devices are generally ‘off-grid’.

New sales of all types of domestic refrigerators and freezers in 2015 (the latest year for which data is available) amounted to slightly more than 1.1 million devices, consistent with the average new sales of 1.1 million devices that have been sold every year for the past decade.

With an estimated 900,000 domestic devices reaching the end of their useful life in 2016, this stock of equipment is expected to continue to grow at around 1.5% per annum.

Leak rates are very low for the majority of these tightly engineered and completely self-contained systems. The decades of product development and the huge volumes of these appliances that are manufactured have produced a class of equipment that is so reliable that most people never have to get one repaired.

This vast population of equipment, each with an average charge of around 140 grams of HFC-134a refrigerant (55 grams of HC), is estimated to have lost slightly less than 34 tonnes of refrigerant in 2016 from leaks (*CHF2 0.7%, ~22 tonnes*), or approximately 1% of all direct emissions of high GWP refrigerant in 2016.

The large majority of the bank of refrigerant in the stock of domestic equipment is still HFC-134a, more than 83%, (*CHF 2 ~93%*), however this dominance of HFC-134a in the bank of refrigerant in domestic devices is declining rapidly. Some very old products manufactured prior to the mid-1990s contain CFC-12³⁷, and while these units are still occasionally found, it is expected that those numbers are becoming rapidly smaller, containing less than a few tens of tonnes of CFCs in aggregate.

Growth of hydrocarbon charged domestic refrigerators

The growth of hydrocarbon charged domestic refrigerators and freezers in the stock has accelerated dramatically since 2012, with nearly 4.7 million devices (~25% of devices) containing hydrocarbon HC-600a in 2016 (*CHF2, 1.1 million, ~7%*).

The migration of large format domestic appliances to hydrocarbon refrigerants has seen the number of domestic refrigerators and freezers imported that are pre-charged with HFCs fall from around 605,000 units in 2012 to just 255,000 units in 2016 of which 141,000 mostly portable refrigerators with a charge of less than or equal to 65 grams of HFC-134a (DoEE 2017a).

In April 2016 the Electrolux Appliances factory in Orange, NSW, was closed. This was Australia’s last refrigerator manufacturing plant that produced around 12 million refrigerators in its lifetime. As a result, all new sales of domestic refrigerators and freezers are imported as pre-charged equipment.

³⁶ *Deducting from this population of 19.2 million devices an estimated 888,000 portable and vehicle refrigerators, and an estimated 5% of devices that the CHF3 Model includes, but that are assumed to be used in business premises, such as restaurants and takeaway shops, and in office kitchens. The CHF3 RAC Stock model predicts an installed base of 17.41 million domestic refrigerators and freezers in residential buildings in Australia a value that aligns very well with the results of the Residential Baseline Study 2015 that estimated an installed base of 17.68 million refrigerators and freezers in Australian homes in 2016.*

³⁷ *This older stock of equipment is just one of the sources of the 30 to 40 tonnes of CFCs still being returned every year to the RRA destruction program, the refrigerant most likely being recovered from fridges being repaired by dealers of second hand white goods.*

There was barely 20 tonnes of high GWP HFC refrigerant imported in pre-charged domestic refrigerators in 2016 (*CHF2 94 tonnes*), including all portable and automotive style refrigerators imported in that year, further underlining the shift of the global manufacturing base of domestic equipment to the use of HCs.

Figure 3 below illustrates the dramatic decline in tonnes of HFCs contained in pre-charged domestic refrigerator imports over the course of the last decade. The growing portion of smaller portable refrigerators is apparent in this chart.

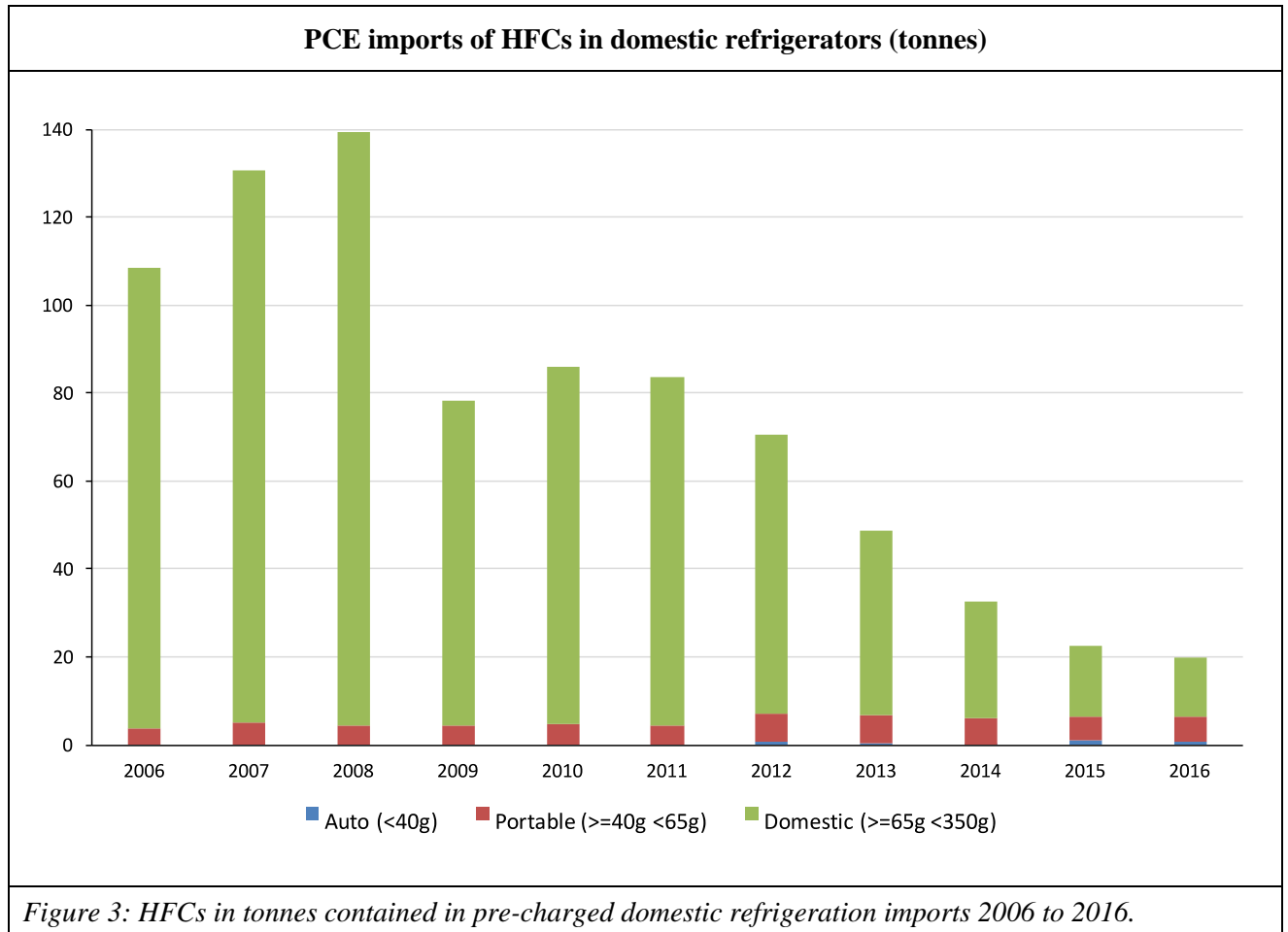


Figure 3: HFCs in tonnes contained in pre-charged domestic refrigeration imports 2006 to 2016.

(Sources: DoEE 2017a)

A retail survey of domestic refrigeration and freezer stock on the floor of a leading retailer conducted in July 2017 found just 6 models out of 123 inspected (<5%) charged with HFC 134a.

This strong trend, first noted in CHF2, is expected to see the migration of new sales of domestic equipment to HC charges to approach >95% during 2018. It is expected that HFC pre-charged imports of domestic refrigerators and freezers will effectively reach zero around 2022 to 2023.

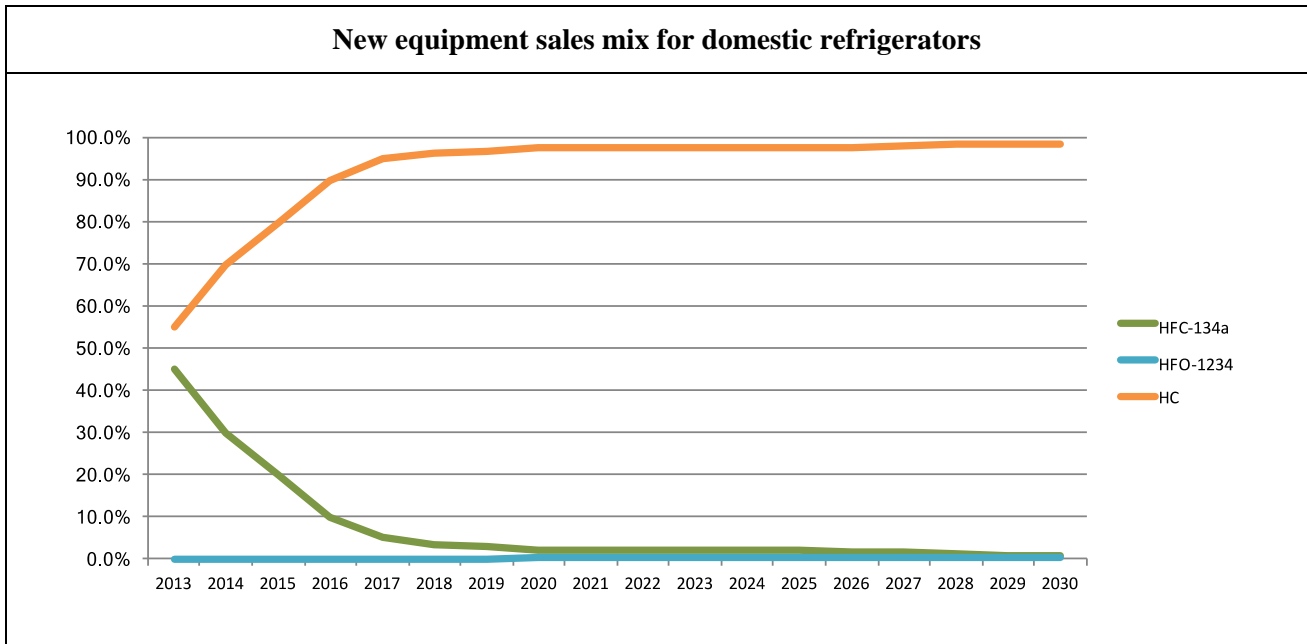


Figure 4: New equipment sales mix for domestic refrigeration from 2013 to 2030.

(Source: RAC Stock model, DoEE 2017, Retail surveys)

As a result of the comprehensive shift of domestic refrigerators and freezers to HC refrigerant, the contained bank of high GWP refrigerants in the domestic stock is projected to decline steadily.

While the trend in the larger formats is obvious, the smaller portable and automotive devices are still universally being imported with HFC charges. These smaller format devices have charges of less than 65 grams of HFC-134a. Approximately 135,000 portable and passenger vehicle refrigerators have been imported each year on average between 2012 and 2016; major suppliers include Dometic Group (Waeco brand) and Engel Australia. Evercool, Norcoast and OzeFridge manufacture small quantities of portable 12V refrigerators in Australia.

The estimated 900,000 domestic and portable devices that reached the end of their useful life during 2016 are expected to contain as much as 125 tonnes of HFC-134a. That quantity of HFCs is the equivalent of 178,750 tonnes of CO₂e.

The main metrics of the stock of domestic equipment are provided below in *Table 17*.

Table 17: Domestic refrigeration main metrics: 2012 versus 2016.

Metric	2012	2016	Change
Share of refrigerant bank	5%	4%	-25%
Size of high GWP refrigerant bank	2,200 tonnes	1,900 tonnes	-13%
Annual leaks of high GWP refrigerants	22 tonnes per annum	34 tonnes per annum	NA ⁽³⁾
High GWP refrigerants in pre-charged equipment imports over previous five years (excl. 2012)	142 tonnes reducing down to 85 tonnes	71 tonnes reducing down to 20 tonnes	-77%
Estimated stock of equipment	17.1 million appliances	19.2 million appliances ⁽¹⁾	+12%
Proportion stock HFC charged	93%	84%	-10%
Proportion stock HC charged	7%	16%	+129%
Annual expenditure on new equipment	< \$1.2 billion	\$1.4 billion ⁽²⁾	+17%
Annual electricity consumption	7,474 GWh	8,534 GWh	+14%
Share of HVAC&R electrical consumption	13%	14%	+7%
Annual GHG indirect emissions	6.83 Mt CO ₂ e	7.77 Mt CO ₂ e	+14%
Annual GHG (SGG) direct emissions	0.03 Mt CO ₂ e	0.05 Mt CO ₂ e	NA ⁽³⁾
Share of HVAC&R direct emissions	0.50%	0.8%	NA ⁽³⁾
Share of HVAC&R total emissions (direct and indirect, not incl. EOL)	11%	12%	NA ⁽³⁾

(Sources: DoEE 2017a, E3 2015 and E3 2008d and industry informants)

Notes:

1. Some of this increase is due to new data suggesting that CHF2 underestimated the number of pieces of portable and vehicle refrigeration in 2012. CHF2 estimates portable and vehicle refrigeration of only 100,000 pieces, as compared to CHF3 estimate of ~900,000 pieces. Further discussion about this market is included in the domestic refrigeration section above.
2. Including purchase of portable and automotive refrigeration.
3. The direct emissions in 2012 cannot be directly compared to 2016 as CHF2 is an assessment of a full bank and CHF3 is an assessment of a partially full bank.

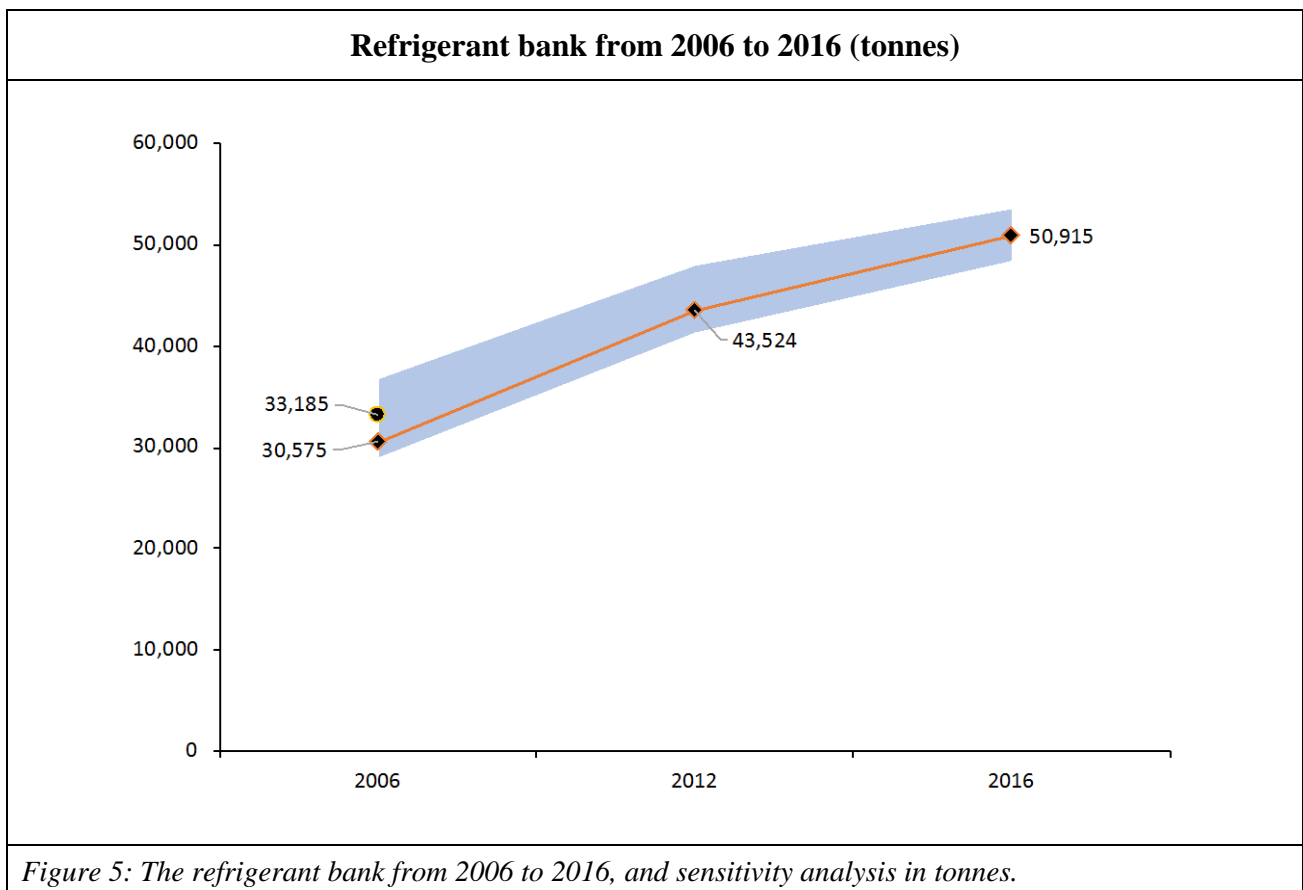
5 The refrigerant bank

The common denominator of all vapour compression air conditioning and refrigeration, in all of its forms and applications, is that it all employs a thermal media; the working refrigerants that are the medium for transferring heat. The sum of all refrigerant contained in RAC equipment is referred to as ‘the bank’ of working refrigerants.

Over the past century as the RAC industry and technology has developed and expanded to become one of the cornerstone technologies of modern society, the nature of the bank has also changed and evolved, and grown enormously. Originally starting with common compounds, some of which are toxic, such as ammonia, sulphur dioxide and methyl chloride, the bank today is populated by dozens of synthetic and natural refrigerants, all with varying properties and attributes suitable for different applications.

The stock of equipment is hugely varied as is the size of the refrigerant charges in them, from tiny benchtop drink merchandisers with less than 30 grams of HCs to huge chillers with 1,500 kilograms of HFCs cooling enormous structures like airport terminals.

Having successfully engineered an international phase out of the use of ozone depleting refrigerants, a process that is now well advanced, international governments and the refrigerants industry have now commenced a phase down of HFC refrigerants to further minimise the impact of emissions of refrigerants on overall greenhouse emissions. This is resulting in increasing diversity in the types of refrigerants employed in equipment as a fourth generation of refrigerants is developed and tested, and existing natural refrigerants find wider applications.



(Sources: CHF1, CHF2 and CHF3 RAC Stock model)

Notes:

1. The band provides sensitivity analysis with the 2006 value (+20%, -5%), 2012 plus (+10%, -5%) and 2016 value (+5%, -5%). In CHF2 the authors concluded that the 2006 bank was likely to have been underestimated by no more than 10%, the value of 33,185 tonnes represents higher estimate.

The total refrigerant bank in Australia in 2016 is estimated at approximately 51,000 tonnes of HCFCs and HFCs (CHF2, 43,500 tonnes). This is an increase of nearly 15% as compared to the bank in 2012, and greater than a 50% increase over the decade from 2006 to 2016.

Australia has seen such strong overall growth in the refrigerant bank, largely, but not entirely, as a result of at least 15 years of continuing strong sales of small and medium domestic and commercial air conditioning systems (< 30 kW), and the roll out of air conditioning across most types of public and community buildings and in retail and industrial environments. The near comprehensive adoption of mobile AC in all types of vehicles and 30% growth in the passenger and light commercial vehicle fleet over the last decade has also been a notable contributor to growth of the bank.

Overall demand for air conditioning increased at a rate much faster than the economy with imports of pre-charged air conditioning equipment averaging more than a million new air conditioning units each year in Australia for most of the past decade. This compares with average imports of only a couple of hundred thousand units per annum during most of the 90s.

In a first phase of small and medium AC driven growth in the 6 years between 2006 and 2012 the bank expanded by more than 45%, from an estimated 30,169 tonnes in 2006 to a total bank of 43,500 tonnes in 2012. At least 40% of the total growth in the bank in those 6 years was contributed by refrigerants in small and medium AC.

Subsequently in the years from 2013 to 2016 the bank has continued to grow strongly, increasing by more than 17% to approximately 52,000 tonnes, led by the small AC stock of equipment. Refrigerant in small and medium AC is estimated to have made up more than 37% of the growth in that period.

A growing community-wide dependency on AC in almost every type of building is being reinforced by changing climatic conditions that have seen five of the hottest years ever recorded in the last seven. It is reasonable to expect that longer periods of hotter daytime and night time temperatures will continue to make air conditioning a desirable, and in many cases, an essential, standard item in the majority of buildings of all sorts.

While the growing market for small and medium AC has driven much of the growth in the bank, during the same period rapidly growing middle classes in India, China and in other areas of Asia, and Australia's increasing food exports to those markets, have driven greater investments in refrigeration systems in agriculture and an expansion of the cold food chain in Australia. This is a sector that is also directly affected by hotter temperatures.

Contributions to the growth of the bank by refrigerants contained in mobile AC during the past decade have been in line with growth in the overall economy, but also driven by the near universal acceptance of air conditioning as standard, with nearly all new vehicle sales incorporating MAC as a standard feature. Refrigerant in mobile AC accounted for 26% of the overall growth of the bank between 2013 and 2016.

Uncertainty in the Bank

As noted in CHF2, the original baseline figure for the bank in 2006 may have been underestimated for some stocks of equipment, particularly the total stock of walk-in cool rooms and freezers, and some categories of commercial refrigeration equipment.

The 2012 model also included more accurate assumptions about retirement rates of certain equipment categories that had the effect of increasing the estimated average life of some equipment categories, therefore increasing the number of pieces of equipment in certain categories. This change increased the bank of gas working in those categories.

Even with the improved data and assumptions available in 2012, upon reviewing the underlying data used in CHF1 the authors concluded that the 2006 bank was likely to have been underestimated by no more than 10%. If we assume that is the worst case, and the 2006 bank may have been larger than the originally estimated 30,675 tonnes, but was closer to 33,600 tonnes, then the bank still grew by some 30% in the period 2006 to 2012.

The 2006 starting point does not have a significant impact on the observable trends in the composition of the much expanded bank in 2012, and subsequently in 2016. The rate of growth in the bank, while still substantial, appears to have slowed slightly between 2012 and 2016 as compared to the growth from 2006 to 2012.

Setting aside the apparent softening in growth in the most recent period, using the higher value starting point of 33,740 tonnes in 2006, the bank has grown in total by more than 51% in the decade between 2006 and 2016, equivalent to a compound annual growth rate (CAGR) of 4.2% over the 11 year period or a CAGR of 5.2% per annum from the 30,575 tonnes estimate.

5.1 Constituents of the bank, GWP and CO₂e

The main species of refrigerants in use today, described below in order of proportion of the bank they comprise, are:

- HFCs (hydrofluorocarbons) (42,000 tonnes or 81% of the bank) are now the most common refrigerants. HFCs were rolled out from the early 1990s to replace the earlier generation refrigerants, HCFCs and CFCs discovered to be destroying the protective ozone layer, and that in many cases had extremely high GWPs. While having no effect on the ozone layer, HFCs in common use have GWP values ranging from 675 for HFC-32 to 3922 for HFC-404A. HFCs are now subject to an international agreement to phase down their production and import gradually from 2019 towards a 2036 target of 15% of recent levels of use;
- HCFCs (hydrochlorofluorocarbons) and CFC (chlorofluorocarbons) (8,500 tonnes or 17% of the bank) were once the most common species of refrigerant in use and are potent ozone depleting substances. CFCs have been and HCFCs are being phased out of use under the Montreal Protocol, an agreement established in 1987. However significant volumes, particularly of HCFCs, are still employed in the stock of equipment and, due to the long life of some types of equipment, are expected to persist in the economy and the environment well towards the end of the projection period used in this study;
- Natural refrigerants are a group of refrigerants including ammonia, hydrocarbons and CO₂, that have very low or zero GWP, but that may have other properties, such as flammability, toxicity or requirements for high operating pressures, that limit their use in some applications³⁸. The bank of natural refrigerants that have displaced HFCs and HCFCs in commercial refrigeration and mobile applications between 2013 and 2016 is estimated at 740 tonnes or 1.5% of the bank. There is a further estimated 4,800 tonnes of ammonia in use in the cold food chain, the vast majority of which is in large chilling, blast freezing and ice making systems in the primary and secondary stages of the cold food chain, and large cold storage distribution centres.
- HFOs (hydrofluoro-olefins) are the newest generation of synthetic refrigerants that, in most cases, are mildly flammable, but exhibit many of the properties of thermal stability, non-toxicity and long life that HFCs provided, while also having very low GWPs (GWP of HFO-1234yf and HFO-1234ze is 5 or 1^{AR5}). HFOs are just beginning to enter into service internationally, initially in new motor vehicles, and chiller manufacturers are also offering some models that employ HFOs. In 2016 there was no significant volume of HFOs³⁹ in use in equipment in Australia although they are expected to grow their share of the bank quite rapidly.

³⁸ For further clarification on refrigerant properties, classifications and potential for replacement refer to 'AS/NZS ISO 817: 2016 Refrigerants - Designation and safety classification'; 'AS/NZS: 2016 (ISO 5149-1:2014, MOD) Refrigerating systems and heat pumps - Safety and environmental requirements'; and 'IEC 60335-2-89, Household and similar electrical appliances - Safety'.

³⁹ HFOs are not defined as controlled substances under the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, and therefore are not reportable in the same way that HFCs and HCFCs are required to be reported at the point of importation. Future data on HFOs in the bank may not be available with the same accuracy that the Customs data on imports of HFCs and HCFCs currently allows (i.e. pre-charged equipment data).

The effects of regulation, the introduction of new generations of gases, changing consumer demand and industry trends have all contributed to the make-up of the refrigerant bank in terms of the ways in which it is employed in the economy, and the refrigerant species it contains.

The Cold Hard Facts series allows comparisons of the composition of the bank in 2006, 2012, and 2016, as illustrated in *Figure 6* below. Comparing the composition of the bank across these benchmark years reveals important changes.

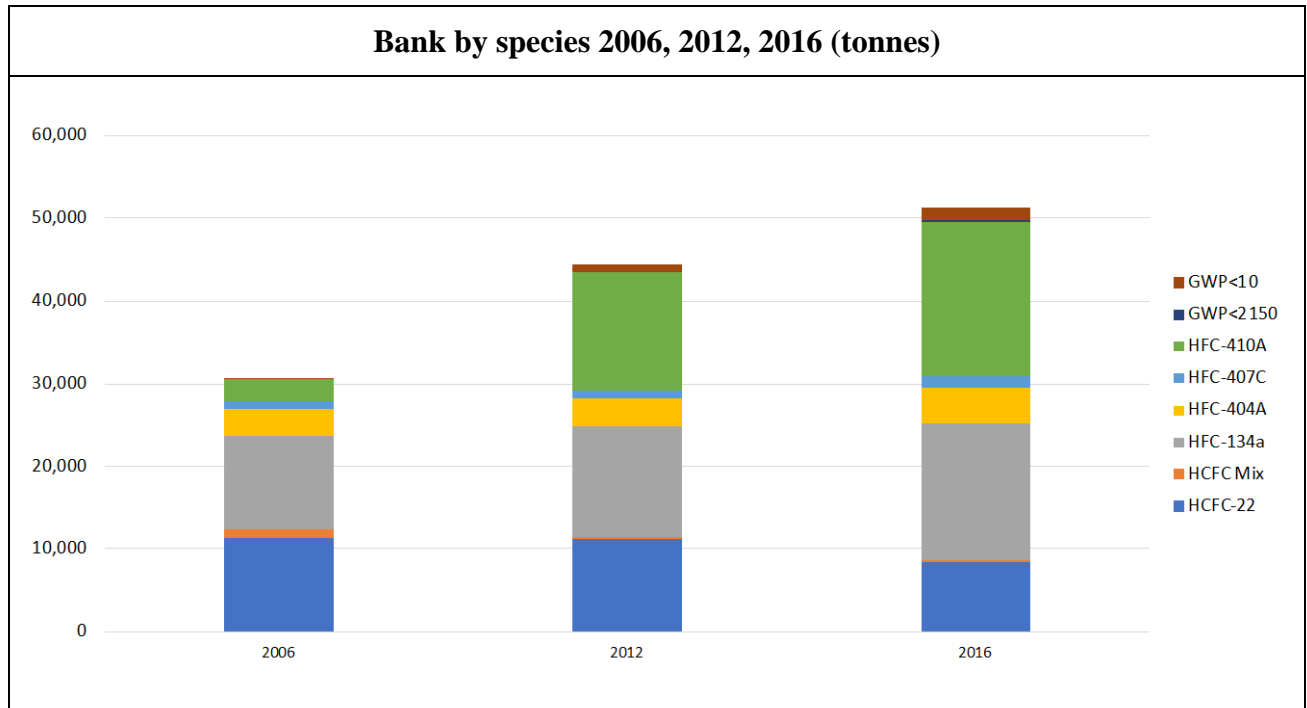


Figure 6: Refrigerant bank by species 2006, 2012, 2016 in tonnes.

(Sources: CHF1, CHF2 and CHF3 RAC Stock model)

The effect of the continuing boom in adoption of small and medium AC, and the shift away from HCFCs, can be seen in the slow decline of HCFC-22 and the rapid growth of HFC-410A.

Trends identified in CHF2 have continued with all of the main HFC species continuing to grow their share of the bank as HFC pre-charged equipment imports replace HCFC pre-charged imports and underpin increased service demand for HFCs overall.

The move from HCFC-22 to HFC-410A, as the predominant refrigerant charge in small and medium stationary AC, started around 2005, at the time that small and medium AC sales first passed more than one million units a year in Australia, a figure that has continued to climb to top more than 1.3 million units in 2017. This has built a stock of more than 9 million HFC-410A charged pieces of equipment in the course of the last decade, containing a bank of 18,400 tonnes of HFC-410A, representing 36% of the entire bank.

This 670% growth in HFC-410A from just 9% of the bank (2,782 tonnes) in 2006 to nearly 36% of the bank in 2016 is the stand out trend. The result is that HFC-410A is now the largest single component of the bank, surpassing HFC-134a. HFC-410A volumes are now more than double the declining bank of HCFC-22 that it was introduced to replace in many applications.

The expansion of the HFC-410A portion of the bank has been met with corresponding decline in the proportion of HCFC-22 in the bank, from 37% in 2006 to 16% in 2016.

Previously HCFC-22 was the refrigerant of choice in air conditioning applications. Its use peaked in 2010 when it was estimated that more than 12,800 tonnes of HCFCs made up just over 30% of the bank in that year. In what is quite a sharp fall, the bank of HCFCs has reduced by nearly 4,300 tonnes from that high point, or more than 33%, in the last 6 years.

This was a predictable outcome of the accelerated phase out of HCFC-22 adopted by Australia in the mid-1990s under its commitment to the Montreal Protocol which, in 2014, saw the import cap step down from 40 ODP tonnes to 10 ODP tonnes (equivalent to around 45 metric tonnes of HCFC-22 per annum), and then to 2.5 ODP tonnes from 2016 before the final phase out of HCFCs in 2030. This phase down of bulk imports was coupled with a ban on all imports of HCFC-22 pre-charged equipment that commenced in July 2010.

The sharp drop in the HCFC bank since 2010 should continue as a result of the large numbers of HCFC charged air conditioning units that were installed between 10 and 20 years ago, reaching the end of their useful life and being retired.

Despite the ban on import and manufacture of HCFC RAC equipment, small quantities of HCFC pre-charged equipment are still being imported under special exemptions, mainly as replacement parts for condensing units to match evaporators of air conditioning units already installed. The import of space chillers charged with HCFC-123 continued until the end of 2015. This small amount of equipment, building on the large numbers of HCFC pre-charged equipment imported up until as recently as 2009-10, indicates that the long tail of HCFC-22 bulk imports will not be sufficient to meet the expected demand to service and repair the remaining installed HCFC charged equipment without recycling.

Additional bulk HCFCs will be required for service and maintenance until at least 2025. In the case of HCFC-123, which is employed in long lasting, large, and expensive chillers, the service requirement is likely to continue until possibly 2036. As such it is expected that more of the HCFCs recovered from EOL equipment will be recycled or stockpiled for reuse.

The rate of change in trends for HCFCs provides insight into the change in trend that should emerge with HFCs overall, as the timetable agreed for a phase down of HFCs under the Kigali Amendment to the Montreal Protocol progresses towards the 2036 end date. Where suitable technical alternatives are available and affordable, they were readily adopted. Where no suitable alternative was immediately available, decreasing supply and increasing prices have created an active recycling industry to supply reconditioned HCFC-22 and give equipment owners an option to get the longest possible operating life out of their equipment.

Predicting the future rate of change in the bank of HCFCs is complicated by the amount of HCFC-22 reuse, the cost of maintaining older equipment and prices for recycled HCFC-22.

HFC-134a is the second most abundant refrigerant in the 2016 bank, growing steadily at around 3% per annum, and now accounts for 32% of the bank (*CHF2 31%*).

HFC-404A has seen some growth in overall tonnes between 2012 and 2016, increasing by more than 1,100 tonnes, or 25%, to reach 9% of the total bank, up from 7.5% in 2012, however has declined from 11% of the smaller bank in 2006. Much of the stock where HFC-404A can be found has been redefined in the taxonomy so the important message is the HFC-404A bank is still growing and accounts for 9% of the bank.

HFC-407C has also grown in volume by more than 25% since 2012, reaching some 1,289 tonnes in 2016, having grown steadily from around 700 tonnes in 2006 and has increased its proportion to 2.5% of the bank, mostly as a result of having similar refrigeration characteristics as HCFC-22 which it is sometimes used to replace.

The table below contains the data from which *Figure 6* above was produced. The tabulated data of the bank by species notably shows the 2016 emergence of HFC-32 as a component of the overall bank. HFC-32 with a GWP of 675, as compared to HFC-410A with a GWP of 2088, is expected to cap the GWP intensity of the refrigerant bank in the extensive stock of small AC.

Table 18: Refrigerant bank 2006, 2012 and 2016 by mass in tonnes and share in percent.

	2006	2012	2016
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	Tonnes	Share (%)	Tonnes	Share (%)	Tonnes	Share (%)
HCFC-22	11,280	37%	11,227	25%	8,283	16%
HCFC Mix	1,000	3%	201	0%	217	0.4%
HFC-134a	11,389	37%	13,432	30%	16,343	32%
HFC-404A	3,412	11%	3,306 ⁽⁴⁾	7%	4,547	9%
HFC-407C	711	2%	1,017	2%	1,336	3%
HFC-410A	2,783	9%	14,341	32%	18,660	36%
HFC-32	0	0%	0	0%	1,035	2%
GWP<2150	0	0%	0	0%	336	0.7%
GWP<10	100	0%	799	2%	737	1%
Total	30,675	100%	44,323	100%	51,493	100%

Notes:

1. The 2006 values in the table are estimates from “*ODS and SGGs in Australia: A study of end uses, emissions and opportunities for reclamation*”, prepared by Peter Brodribb and Michael McCann, 2008.
2. Some CFCs are still present in the bank, in some very old domestic refrigerators for example, however are not included in the above table in their own right. Total CFCs in the bank are now estimated to be less than 50 tonnes, are rapidly declining and have been included in the estimate of HCFC-22. Some relatively small quantities of HCFC blends used in air conditioning applications are also counted as HCFC-22.
3. The category GWP less than 2150 comprises a variety of blends including HFC-407F, a variety of HCFC-22 replacements, and emerging HFO blends such as HFC-448a and HFC-449a which are starting to be used for low temperature commercial refrigeration applications.
4. Based on CHF3 methodology the bank of HFC-404A in 2012 would be higher. The number of walk in cool rooms has been revised upward and this value is the published CHF2 bank of HFC-404A. The stock and bank value has been revised based on improved information. For example, the stock of self-contained refrigeration display cabinets and walk-in cool rooms where revised upward.

Strong sales of small AC are expected to continue, however the rate of growth of HFC-410A in the bank should moderate as HFC-32 takes market share from HFC-410A charged equipment.

Figure 7 below illustrates the proportions of the main refrigerants in the bank, underlining the current dominance of HFC-410A (in blue).

HFC-134a (in green) makes up the second largest portion of the bank, and is the primary refrigerant found in the majority of MAC systems.

While the largest part of the HFC-134a portion of the bank is contained in the estimated 18 million MAC systems in vehicles of all sizes, this refrigerant is also found in large commercial chillers for space cooling, a generation of domestic refrigerators produced between the late 1990s and early 2010s, and medium temperature commercial refrigeration.

2016 Bank by species (% by mass)

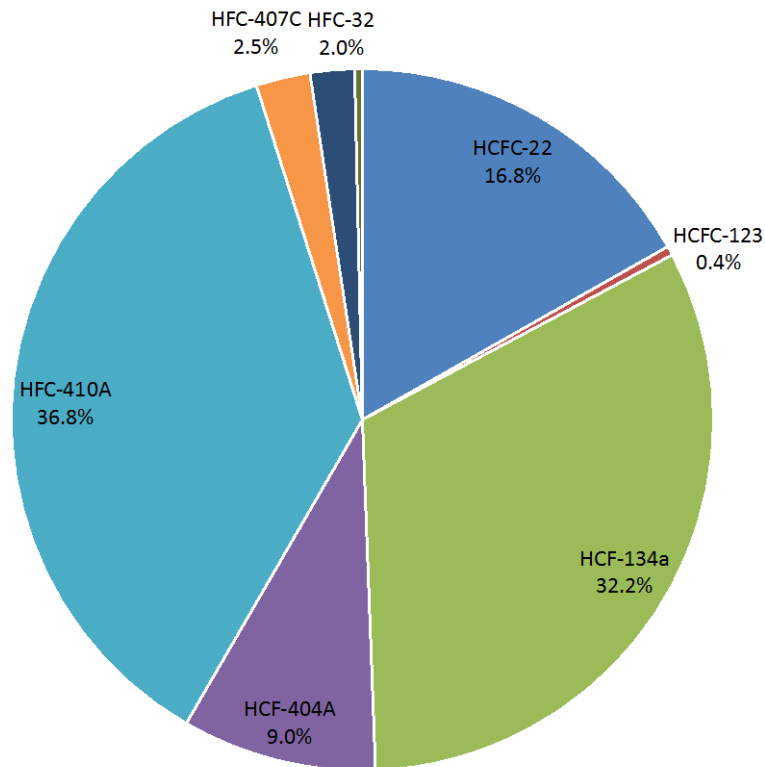


Figure 7: 2016 Refrigerant bank by species in per cent by mass.

(Sources: CHF3 RAC Stock model)

The third largest component of the refrigerant bank in 2016, HCFC-22 (in blue), has started to decline from its previously dominant position due to the progressive phase-out of HCFC bulk imports, and the ban on pre-charged equipment imports containing HCFCs. These changes initiated a decline in the stock of equipment charged with this refrigerant. The larger part of the HCFC bank is still found in small and medium AC.

None of the HCFC and HFC refrigerants in the bank are manufactured in Australia. The replacement cost of this bank for the end users is roughly estimated to be \$2.9 billion based on current market prices to the end user (*CHF2, \$5.8 billion*).

From one view point the bank can be broadly characterised by its global warming potential. A large portion of the bank is comprised of HCFCs and HFCs with GWPs above 1400. A small but growing portion of the bank of HFCs such as HFC-32 with a medium or reduced GWP of 675. There are a number of emerging HFO/HFC blends joining this reduced GWP group that are being developed as replacements for very high GWP substances such as HFC-404A. And there is a bank of natural refrigerants with very low or zero GWP that will soon also include HFOs.

These three segments of the bank, Low or zero GWP, Medium or reduced GWP and High GWP are defined as follows:

- Low or zero GWP refrigerants with a $GWP < 10$;
- Medium or reduced GWP refrigerants⁴⁰ with a $GWP \geq 10$ and < 1400 , where the most common substance is HFC-32, and emerging HFO/HFC blends; and,
- High GWP refrigerants with a $GWP \geq 1,400$, presently making up the large majority of the bank.

If we include the 4,800 tonnes of ammonia not counted as the HCFC and HFC bank, around 10% of the bank (incl. ammonia) is made up of substances with $GWP < 10$, and the rest is refrigerants with $GWP > 10$. Refer to *Appendix A: Section 11.2.16 GWPs and refrigerant compositions* for a list of the GWPs of the common refrigerants employed in the bank in Australia.

This national bank of refrigerant in 2016, as calculated by the CHF3 RAC Stock model, was equivalent to more than 98 million tonnes of CO₂ (including ODS, CHF₂, 71.4 Mt CO₂e) and was estimated to emit a total of about 6.4 million tonnes of CO₂e to the atmosphere in 2016 (CHF₂ – 5.4 million tonnes).

The 2016 emissions were as a result of direct losses of some 3,300 metric tonnes of refrigerant from operating equipment and the supply lines that service that equipment, the equivalent of 6.4 million tonnes of CO₂. A further 1,900 metric tonnes of refrigerant, the equivalent of 3.6 million tonnes of CO₂ (CHF₂ – 2.8 million tonnes) is lost to air or recovered from equipment at the end of its service life. Of the refrigerant recovered, 210 metric tonnes of HCFC-22, the equivalent of 0.38 million tonnes of CO₂ was reclaimed to AHRI 700 standard and resold in 2016. A further 350 metric tonnes of CFCs, HCFCs and HFCs, the equivalent of 0.75 million tonnes of CO₂ was sent for destruction by Refrigerant Reclaim Australia in 2016.⁴¹

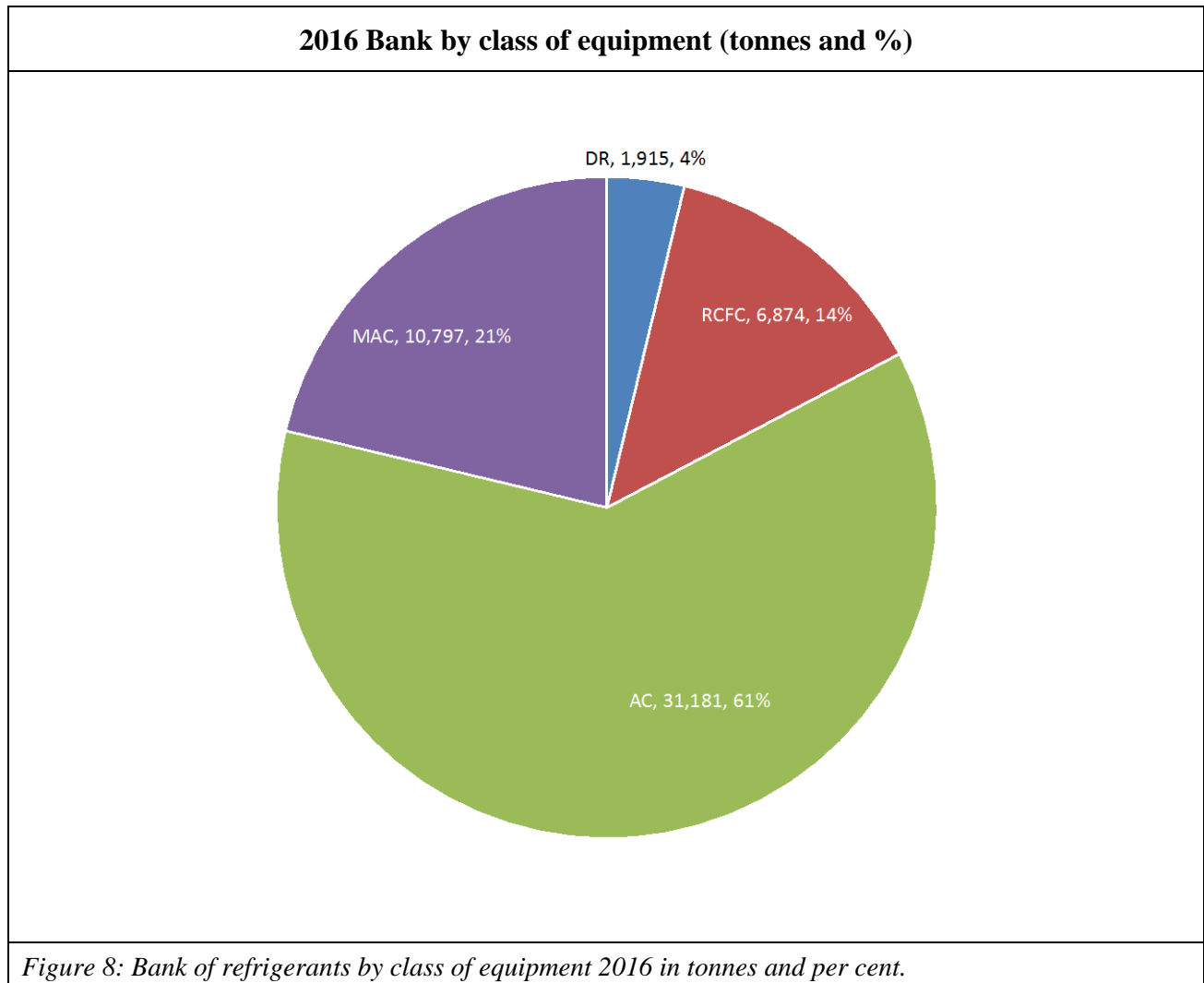
Greenhouse gas emissions of the refrigerants employed in the stock of equipment are equal to only about 10.8% of the total energy-related emissions created by the stock of equipment as a result of electricity consumed to deliver cooling services. Energy related emissions are discussed in greater detail in *Section 9: Energy and indirect emissions*.

⁴⁰ Reduced GWP refrigerant is a term that has been used for the purpose of this report. A number of recently developed or used HFC substances or refrigerants have significantly reduced GWP relative to those commonly used high GWP refrigerants they are designed to replace. HFC-32 (GWP of 675) and blends with GWPs less than 1400 and greater than 10, are referred to as reduced GWP refrigerants. For example, N40 (R-448A) with a GWP of 1387 is a zeotropic blend designed to serve as a replacement for HCFC-22 (GWP of 1810) and HFC-404A (GWP of 3922) in supermarket refrigeration retrofits, or in new systems. Refer to definition of High GWP Refrigerants and Low GWP Refrigerants.

⁴¹ RRA sent 7.1 tonnes of CFCs, 26.7 tonnes of HCFCs and 316.3 tonnes of HFCs for destruction in the 2016 calendar year.

5.2 Bank by class of equipment

The distribution of the bank of working refrigerants across the major classes of equipment illustrates the predominance of air conditioning services delivered, with Stationary AC employing 61% of the total bank, and Mobile AC a further 21%.



(Sources: CHF3 RAC Stock model)

The bank in MAC is unchanged from the proportion it held in 2012 (*CHF2 21%*). This refrigerant is predominantly contained in a rolling stock of around 18 million registered vehicles of all types containing HFC-134a (ABS 9309.0 2017).

The fact that MAC systems make up a similar proportion of the total bank in 2016 as compared to 2012 should not disguise the absolute growth in volumes with more than 1.1 million new vehicles being sold every year in the period, more than offsetting the estimated annual vehicle retirements of around 715,000 to 800,000⁴² vehicles per annum in the period.

The MAC contribution to the bank is expected to change as vehicle manufacturers move to the use of HFOs or carbon dioxide in MAC and decreasing charge sizes. However, HFOs will take some years to replace

⁴² ABS 9309.0, *Motor Vehicle Census, Estimated attrition rates in Australia were 717,000 (2012-3); 716,000 (2013-4); 766,000 (2014-5); 800,000 (2015-16); and 784,000 (2016-17), published January 2017.*

HFCs in the majority of MAC. With the 2017 closure of the last car manufacturer in Australia, more cars will be imported in coming years increasing the overall pre-charged equipment contribution to the bank, while bulk imports will be reduced by 160 tonnes.

The refrigerated cold food chain, which was historically the very reason that refrigeration technology was developed in the late 19th century, now accounts for 14% of the total refrigerant bank (*CHF2 11%*), with domestic refrigerators and freezers containing a further 4% (*CHF2 5%*). Thus, all the refrigeration equipment essential in the transport and maintenance of food supplies and food quality from farm paddock to household kitchen, employs only 18% of the total bank of refrigerant (*CHF2 16%*).

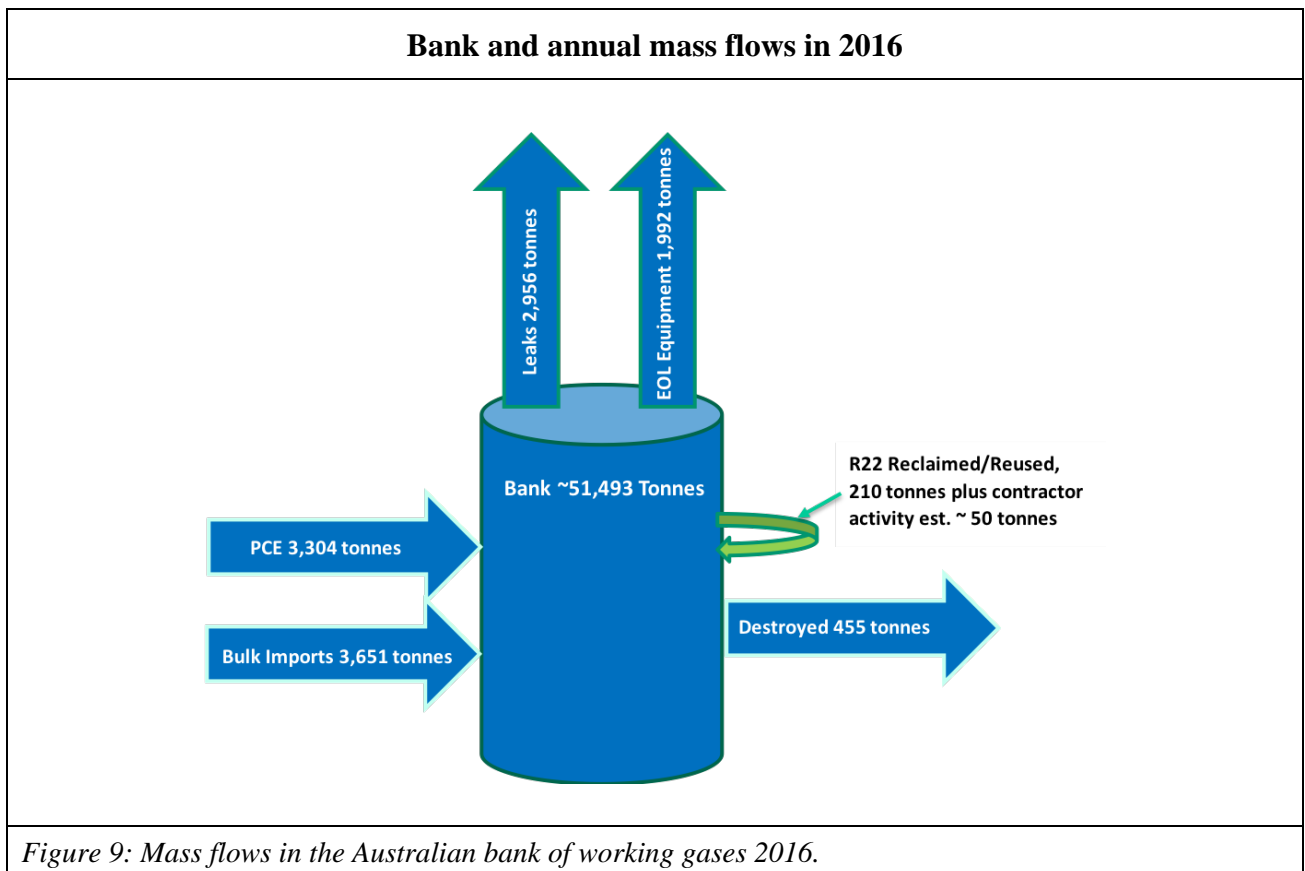
As recently as the late 1970s, even though refrigerated commercial AC systems were starting to become common in new commercial buildings, the refrigerated cold food chain, from farm to family kitchen, and including hospitality venues, hotels, commercial kitchens and food wholesaler and retailers, was the dominant application, employing the vast majority of refrigerants in the economy at that time.

5.3 Mass flows in the bank

There are two sources of growth in the bank, and two pathways by which refrigerants leave the bank. The two sources of growth are via imports of pre-charged equipment and secondly via imports of bulk refrigerant. The two pathways by which refrigerant leaves the bank are emissions to air through losses of refrigerant from the supply line, during service, from operating equipment, and from end-of-life equipment, and via refrigerant being recovered and sent for destruction by Montreal Protocol-approved technology such as an electric arc furnace.

An increasing though very small portion of the bank is ‘recycled’, after being recovered, reconditioned and then reused. This practice does not increase the overall size of the bank.

A diagram illustrating the inputs to the bank, and the means by which refrigerant leaves the bank with values for calendar year 2016 is provided below showing the major influences on both the size and composition of the bank.



(Sources: CHF3 RAC Stock model)

Each of the inputs to the bank can be broken down by species of refrigerant, in the case of bulk imports, and by type of equipment and species of refrigerant in the case of pre-charged imports (PCE).

The mix of refrigerants added to the bank every year via imports of pre-charged equipment, and changes in the refrigerants employed in pre-charged equipment, is a leading indicator of the composition of the future bank, and thus future demand for bulk refrigerant imports.

Bulk refrigerant imports supply local equipment manufacturers, are used for charging new equipment that has been imported without any refrigerant charge, for additional refrigerant for some types of pre-charged

equipment⁴³ that need additional refrigerant at installation and are used to service the stock of existing equipment.

As older equipment tends to lose more refrigerant than new equipment, the composition of bulk imports will therefore tend to be weighted towards servicing the refrigerant charges in the older portions of the stock of equipment.

As a reflection of service demand for existing equipment, bulk imports are therefore something of a lagging indicator of trends in the stock of equipment, and of the changing composition of the bank.

At any time, a small portion of the bank is in equipment that has been imported but that is not yet installed and operating. At any one time in 2016 this would equate to around 825 tonnes based on an average of having three months inventory on hand and ready to enter the market. Additionally, if we make the same assumption of three months stock of bulk refrigerant, there is around 860 tonnes of bulk refrigerant in the supply chain and already on shore available for distribution into the service market. However, irrespective of the final date of import during any calendar year, all refrigerant imported in PCE and in bulk containers is counted as forming part of the bank in the year of import.

5.4 Pre-charged equipment imports

With manufacturing of RAC systems in Australia at multi-decadal lows, following the winding back of local stationary AC manufacturing and the closure of domestic refrigeration and vehicle manufacturing, it is the refrigerant in imported equipment that predominantly drives the overall composition of the bank. PCE imports can have an impact on the bank for decades ahead with some equipment imports expected to have working lives greater than 20 years.

Pre-charged equipment imports of all sorts has been the major source of growth in the refrigerant bank, introducing an average of about 2,900 tonnes of refrigerant per annum during the last 5 years (*CHF2 five-year average total PCE refrigerant imports ~2,500 tonnes*).

In total, in 2016, there were more than 4.7 million devices pre-charged with HFCs imported to Australia and containing, in aggregate, a total of around 3,127 tonnes of refrigerant⁴⁴ (*CHF2 – 3 million devices containing some 2,557 tonnes*).

Imports of PCE have been running at historically high levels for the last decade and a half, largely as a result of the demand for small, wall-hung, split air conditioning systems.

There were more 1.25 million stationary air conditioning devices imported in 2016, accounting for more than 2,325 tonnes of refrigerant, or 70% of imported refrigerant contained in equipment in that year. More than 1.15 million of these stationary AC were classed as ‘residential’ devices that added more than 1,800 tonnes of refrigerant to the bank.

This compares to PCE imports of both residential and commercial AC systems totalling slightly more than a million pieces in 2012, at the time containing around 1,688 tonnes of refrigerant in total.

⁴³ Pre-charged air conditioning equipment is typically charged to allow for 10 to 15 meters of pipework between the evaporator and the condenser, depending on the brand and type of equipment. If the pipe length is longer than the specified length, additional refrigerant is required to achieve the critical charge for the system.

⁴⁴ A ban on imports of equipment containing HCFCs was implemented in July 2010.

PCE imports by application in 2016 (tonnes and %)

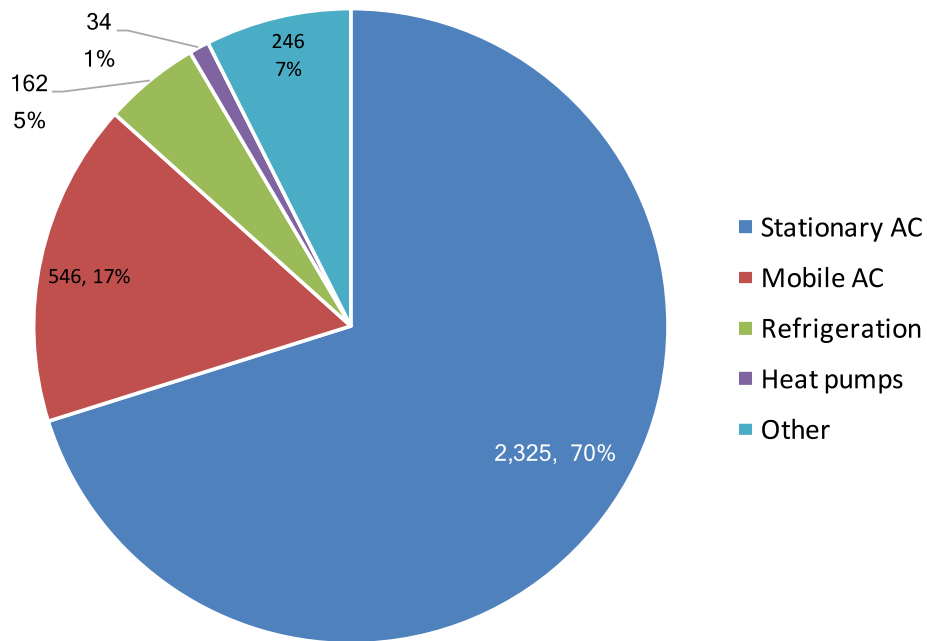


Figure 10: Tonnes of refrigerant in pre-charged equipment imports in 2016 dissected by application and per cent of annual imports.

(Source: DoEE 2017)

Single split systems sales, including wall-hung, cassette, consoles and ducted systems have grown rapidly from 2012 to 2017 with annual sales reported of 833,000 in 2012; 887,000 in 2013; 934,000, in 2014; 1,000,000 in 2015; and 1,177,000 in 2016. In 2017 a record number of 1,356,000 single split systems were sold in Australia. The overwhelming majority of split systems are single split systems comprising one indoor unit attached to one outdoor unit.

There has been significant growth in single split *ducted* systems (included in the above numbers) increasing from around 110,000 in 2012 to 197,000 in 2017. Some of the growth has come from compact bulk head units comprising 32% of sales by quantity in 2017 below 10 kW_r versus 25% in 2012.

Multi head split system (excluding VRV/F) sales have grown, from around 23,000 in 2012 and 2013 to around 40,000 in 2017. The ratio of indoor units to outdoor units sold is slowly increasing from a ratio of 1.03 in 2012 to 1.06 in 2017 as sales of multi-head units grows.

Mobile AC systems were the second largest category of PCE, containing 17% of HFCs imported in equipment in 2016 and adding some 546 tonnes to the bank, followed by commercial, domestic and mobile refrigeration systems that added 162 tonnes of HFCs to the bank.

Unfortunately, a change in the system of collecting data on pre-charged equipment in 2012 has now made it impractical to directly compare imports of air-conditioning equipment types from prior to 2012 with later imports. Equipment reporting categories were aggregated, so much of the detail is not available.

However, a breakdown of the major categories of pre-charged equipment imports reported from 2013 to 2016 is presented in *Table 19*. This demonstrates the relative scale of stationary air conditioning imports, as compared to other categories.

Table 19: Pieces of pre-charged equipment imported from 2013 to 2016.

	2013	2014	2015	2016
Residential use air-conditioning	1,005,503	1,066,378	1,168,421	1,159,087
Commercial use air-conditioning	77,024	67,660	114,803	99,169
Motor vehicle, watercraft or aircraft air-conditioning	986,923	919,906	995,687	924,854
Domestic use refrigeration	444,590	319,614	256,664	257,985
Commercial use refrigeration	110,446	91,456	117,922	108,181
Motor vehicle, watercraft or aircraft refrigeration	68,219	62,719	105,626	148,672
Commercial or domestic use heat pumps	17,124	23,083	25,815	35,125

(Source: DoEE 2017)

While individual pieces of MAC imports are approaching the numbers reported for Stationary AC, the much greater contribution to imported HFCs of pre-charged stationary AC is a result of the larger average charge sizes of stationary AC systems, which range from an average charge of 1.6 kg (*CHF2 1.7kg*) in residential systems to average charges of 5 kg in commercial systems. By comparison the average charges in all MAC imported in 2016 were only 620 grams (*CHF2 625 grams*).

The dominance of stationary AC in PCE imports is reflected in the mix of refrigerant contained in those imports in 2016, with the refrigerant of choice for stationary AC for the last decade, HFC-410A, dominating the mix.

PCE imports by major species in 2016 (tonnes)

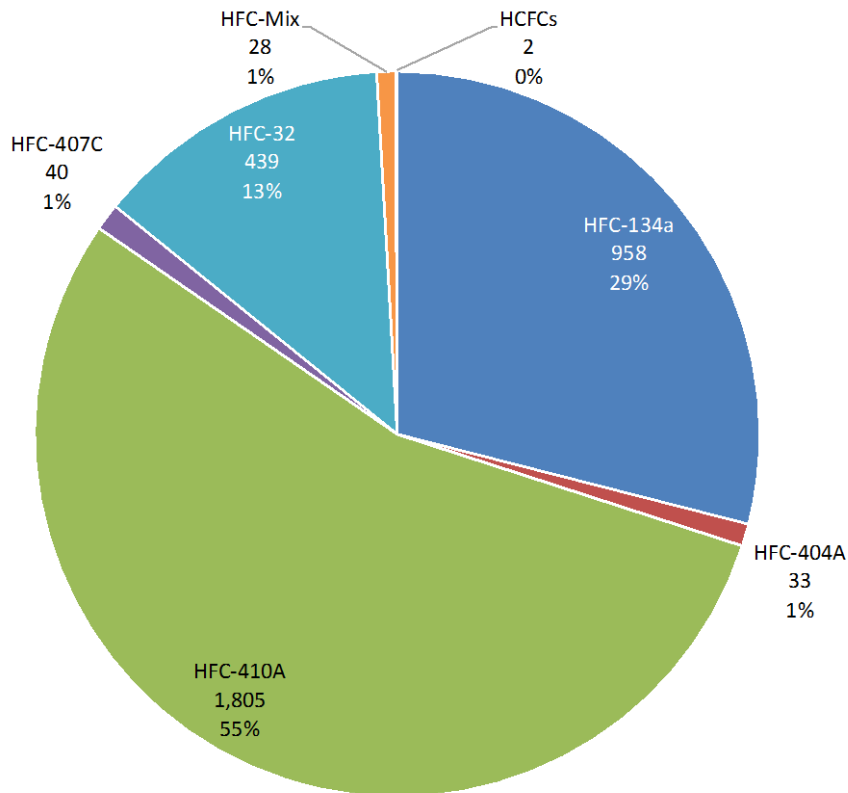


Figure 11: Pre-charged equipment imports in 2016 dissected by major species in tonnes.

At the same time HFC-32 pre-charged equipment made up 13% of imports by refrigerant volume. HFC-32 was first imported in small stationary AC models in 2012 and rapidly began to take market share. This medium GWP refrigerant has begun to cap the strong growth trend in HFC-410A charged imports that emerged from 2006 to 2016. HFC-32 charged stationary AC devices in the stock of equipment now number more than 900,000.

The rapid growth of the HFC-32 share of PCE imports can be seen in the chart below and is expected to continue to replace HFC-410A charged devices until HFC-32 becomes the dominant refrigerant in the small AC: Split system segment by around 2022.

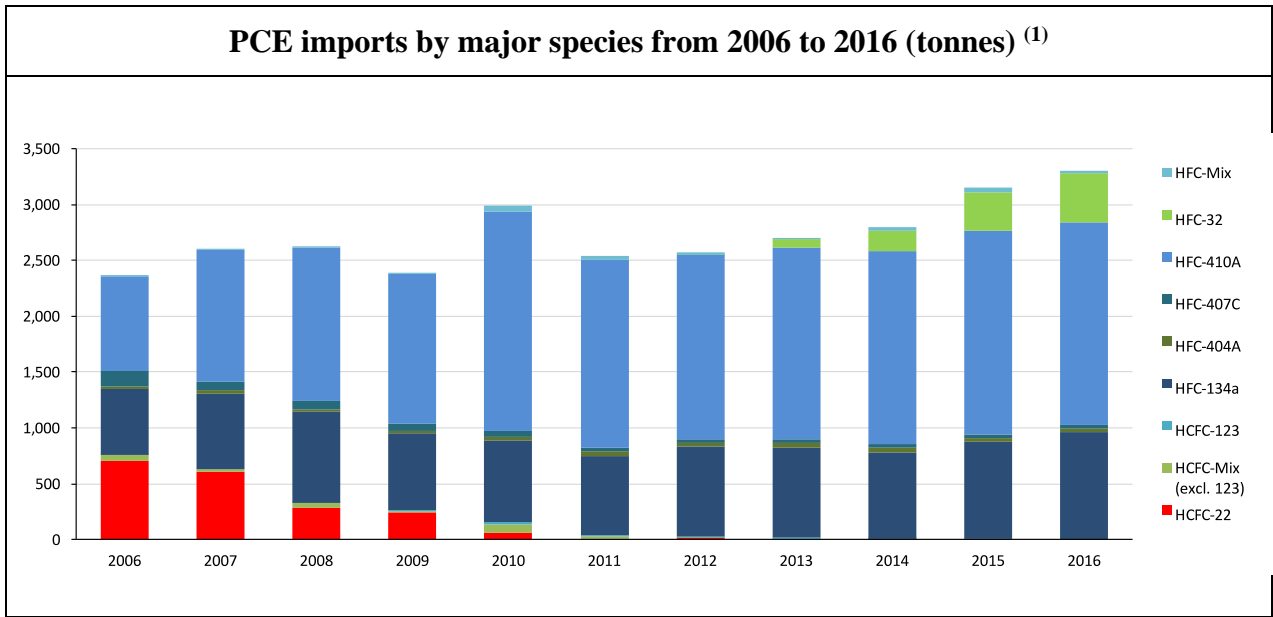


Figure 12: HCFCs and HFCs in pre-charged equipment from 2006 to 2016 by species in tonnes.

(Sources: DoEE 2017)

1. Refer to Appendix B3: Bulk imports and pre-charged equipment imports from 2006 to 2016, for tabulated data.

HFC-134a has maintained a steady share of import volumes in PCE for the last ten years as can be seen in the chart above, although a rise in HFC-134a pre-charged imports has already become discernible in the last two years of the period, as vehicle manufacturing in the country declined.

An important trend apparent in this chart is the decline of HCFC imports to near zero over the period.

5.5 Bulk refrigerant imports

The second source of growth in the bank is via the import of bulk refrigerant. A controlled substances licence is required to import bulk HCFCs and HFCs, and holders of these licences are required to report all imports.

Bulk imports of HFCs and HCFCs occur mainly in tanks containing as much as 18 tonnes each. Bulk imports are brought into the country by 43 HFC and 6 HCFC licensed importers who decant the refrigerant into smaller tanks, ranging from 5 tonne mobile road tankers, to 12 kg cylinders used by installers and service technicians. In 2012 there were only 17 licence holders in total.⁴⁵

The majority of bulk imports do not add to the refrigerant bank, as they are used simply to replace refrigerant lost from installed equipment. Some bulk imports are also used replacing HCFC refrigerant charges in older equipment in a retrofitting process as increased HCFC costs and repair costs make maintaining old equipment with HCFC charges less viable.

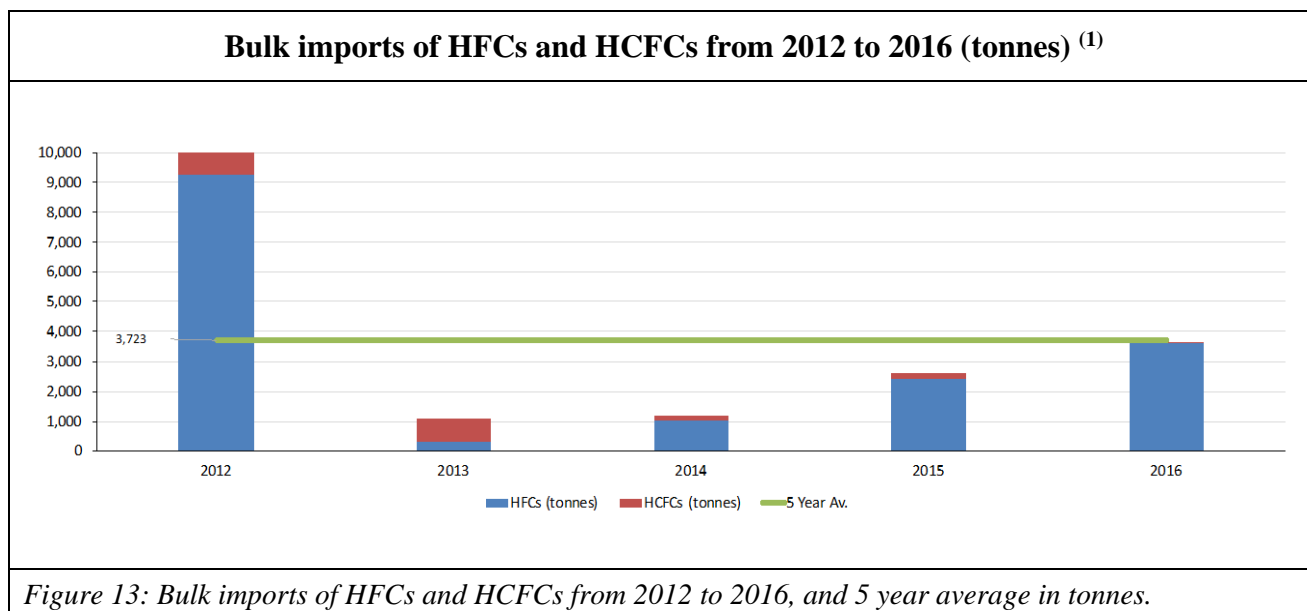
In 2016 a total of 3,606 tonnes of HFCs and 45 tonnes of HCFCs were imported as bulk gas, of which 1,120 tonnes (30%) was used to charge new equipment manufactured in Australia or to charge equipment imported without a charge of refrigerant (i.e. pre-charged with nitrogen) or used in other applications such as fire protection systems and foam blowing or exported as bulk refrigerant. Around 70% of all imports were used to maintain the existing stock of RAC equipment. In other words around 70% of annual bulk imports are being used to replace refrigerant that is lost to air from working equipment every year.

⁴⁵ List of licenses and exemptions granted under the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, issued February 2012 and October 2017.

Vehicle manufacturing in 2016 used about 100 tonnes of HFC-134a, demand which was removed from the market by the end of 2017 with the closure of the last passenger vehicle manufacturer in Australia. Approximately 187 tonnes of HFC-410A and 84 tonnes of HFC-134a was used in manufacturing commercial AC systems and domestic hot water heat pumps.

Comparing total bulk imports in 2012 to 2016 is difficult because of the major stockpiling that took place in Australia in the early part of 2012 and subsequently reduced imports for some years afterwards.

As the chart below shows actual annual imports over the period has seen large volume changes year on year.



(Sources: DoEE 2017)

1. Refer to *Appendix B3: Bulk imports and pre-charged equipment imports from 2006 to 2016*, for tabulated data in tonnes and CO₂e.

The announcements in mid-2011 of the impending introduction of the equivalent carbon tax on HFC imports resulted in a significant increase in bulk imports of HFCs in 2012, and strong growth in stocks held by businesses throughout the supply chain. This stockpiling event has had some significant impacts on the overall trends in composition of the bank, and of course on some aspects of market behaviour and pricing when the equivalent carbon tax was repealed two years after its introduction.

At the time import data indicated total imports of all species of refrigerant gas in 2012 were equivalent to more than two and a half years of average supply of HCFCs and HFCs, or a total of more than 12,511 tonnes of HCFCs and HFCs.

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 general slow-down in spending and investment during the 2011-12 financial year.

Total imports in 2012 were made up of 9,244 tonnes of bulk HFCs, 786 tonnes of bulk HCFCs⁴⁶, and 2,568 tonnes of refrigerant contained in pre-charged equipment. In the previous corresponding period only 3,152 tonnes of HFCs and 1,297 tonnes of HCFCs had been imported in bulk. HFC bulk imports in 2012 included 4,185 tonnes of HFC-134a, 2,155 tonnes of HFC-404A and 2,065 tonnes of HFC-410A.⁴⁷

⁴⁶ This includes all the species of HCFC imported, not just HCFC-22.

⁴⁷ The import data quoted in this report will vary slightly from Senate estimates as some Ozone Depleting Substances (i.e. Halons, Carbon Tetrachloride and Methyl Chloroform, and CFCs used for medical applications) and Synthetic Greenhouse Gasses (i.e. SF₆ and PFCs) are not used in RAC applications.

This stockpile (equivalent to more than 25% of the refrigerant bank at the time) was predicted to result in much lower than average imports for at least the 2012-13 and 2013-14 financial years, with a volume recovery expected during 2014-15. It was noted at the time that, to some extent, the prediction depended on other trends in the industry including the impact on leaks of improved refrigerant containment (the focus in some sectors on improved containment also being an outcome of the equivalent carbon tax), increases in reuse of refrigerant recovered from EOL equipment and during routine equipment service, and the overall level of economic activity, building and construction work, and refurbishment and equipment replacement rates.

Bulk refrigerant import data up to 2016 shows that the predicted import volume recovery did not really occur until the 2015-16 financial year, partly due to lower demand for service, as a result of dramatic reductions in leak rates in some equipment categories.

While recovery and reclamation of HCFCs has become a fixture in the Australian supply chains, recovery and recycling of HFCs that was reported in some instances soon after the introduction of the equivalent carbon tax has declined following the repeal of the legislation. The removal of the equivalent carbon tax, coupled with the multi-year stockpiles of HFCs in the country, quickly returned most HFC wholesale prices to being as cheap as they had ever been, making recovery and recycling of HFCs less economical.

To normalise the effects of the 2012 stockpiling a better comparison of changes in the trends in bulk imports might best be made by comparing average annual imports over a longer timeframe.

In the five years from 2012 to 2016 an average of 3,325 tonnes of HFCs, and 398 tonnes of HCFCs were imported as bulk refrigerant (3,723 tonnes per annum in aggregate on average). This compares with bulk imports for the 6 previous years from 2006 to 2011 averaging about 2,900 tonnes per annum of HFCs, and around 1,600 tonnes per annum of HCFCs (4,500 tonnes per annum in aggregate on average).

Because of changes to the reporting of bulk imports in 2011, this decade-long trend in bulk imports of HFCs and HCFCs, illustrated in *Figure 14* below, can only be calculated in kilo tonnes (kt or 1,000 tonnes) of CO₂e. The average over the entire period was 7,196 kt CO₂e of HFCs and 1,591 kt CO₂e of HCFCs.

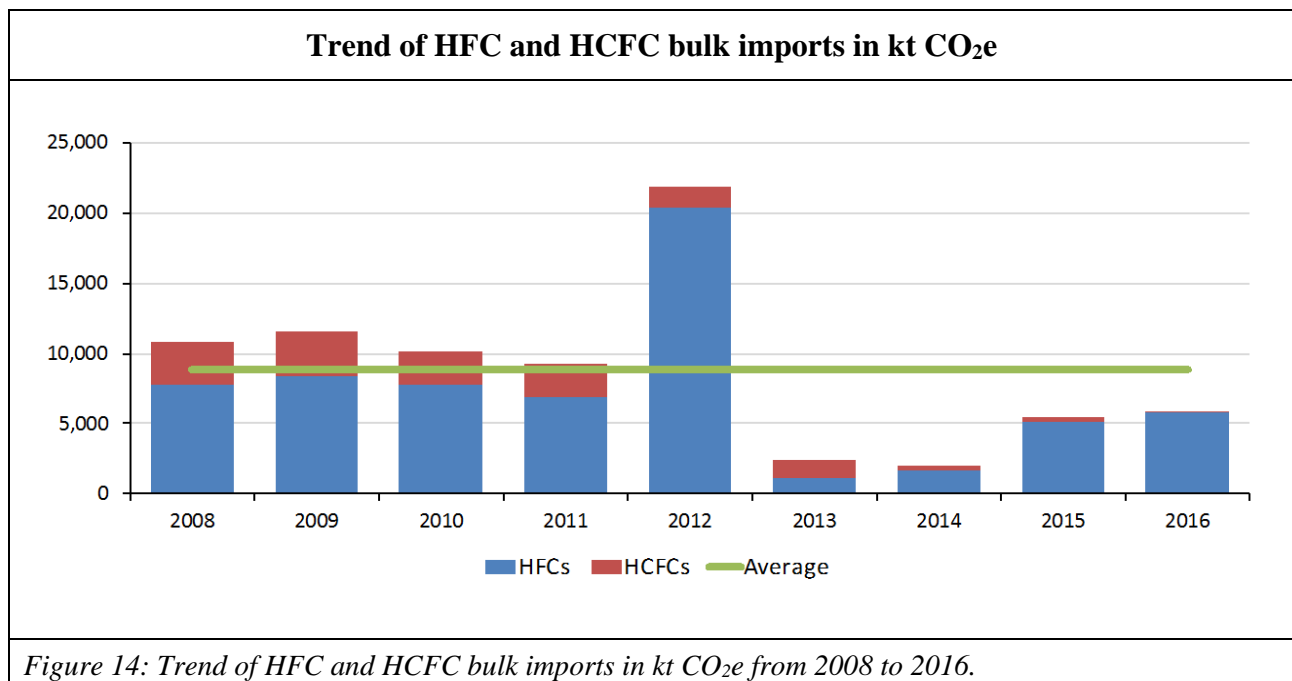


Figure 14: Trend of HFC and HCFC bulk imports in kt CO₂e from 2008 to 2016.

This longer term view demonstrates that recent bulk imports are well below the decade average and reinforce industry reporting that the overall trend of bulk imports is down.

Some of the decline in bulk imports from 2006 to 2016 can be attributed to reductions in OEM usage as manufacturing of air conditioning and refrigeration equipment. Smaller stationary AC moved off shore (i.e. Kelvinator-Electrolux) as well as closures of manufacturers of ducted system (i.e. Carrier-Apac, Uni-Arie and others). Frigrite and Orford Refrigeration, major manufacturers of refrigeration display cases closed down, and domestic refrigeration (i.e. Electrolux and Fisher & Paykel) moved off shore and transitioned to the use of HC refrigerant. Vehicle manufacturing halved before eventually ceasing in October 2017. Over that period, we saw the scaling down and closure of the Mitsubishi, Holden, Ford and Toyota factories.

Some of the decline in demand for bulk imports may be attributed to better refrigerant management in some sectors, notably in the refrigerated cold food chain and in large commercial AC where a focus on leak reduction has been delivering greatly reduced direct emissions in some categories of equipment. However, better manufactured equipment, in particular small and medium AC has contributed to significant drops in leak rates where small AC: Split system category has leaks of around 3.5% and service rate as low as 2.5% on the existing stock of HFC-410A models and lower rates on new HFC-32 equipment entering the fleet.

During the same period illustrated above, the steadily declining cap on HCFC imports, representing the limits Australia committed to under the Montreal Protocol, saw annual imports fall from 786 tonnes in 2012 to just 45 tonnes in 2016.

A significant rise in imports of HFC-410A, and a steady increase in imports of HFC-404A, is testament to the effect of restrictions on HCFC-22 imports (once the most widely used refrigerant in stationary air conditioning equipment) during a decade when Australia saw an average of 1.1 million pre-charged residential and small commercial air conditioning systems imported every year.

The continuing substantial bank of HCFCs is largely still employed in stationary AC more than the larger equipment segments, such as chillers and large commercial refrigeration plant, which have been migrating away from HCFCs to HFCs, and natural refrigerants.

Total HFC-410A imports in PCE started from a small base in 2006, and rose to more than 1,800 tonnes in 2016, accumulating to 17,100 tonnes over the 11 year period. Adding 40% of bulk imports of HFC-410A over the last five years to account for local manufacturing equates to a bank of at least 18,300 tonnes in 2016.

This demonstrates how the growth in the bank of HFC-410A was largely driven by imports of equipment pre-charged with HFC-410A, which then in turn establishes long term demand for bulk refrigerant imports to service the stock of equipment.

To demonstrate the relative proportion of different HFCs imported since 2012, *Figure 15* illustrates the five year *average* bulk imports of HFCs by species in tonnes (this chart does not include imports of HCFCs).

5 Year average HFC bulk imports by species (tonnes and %)

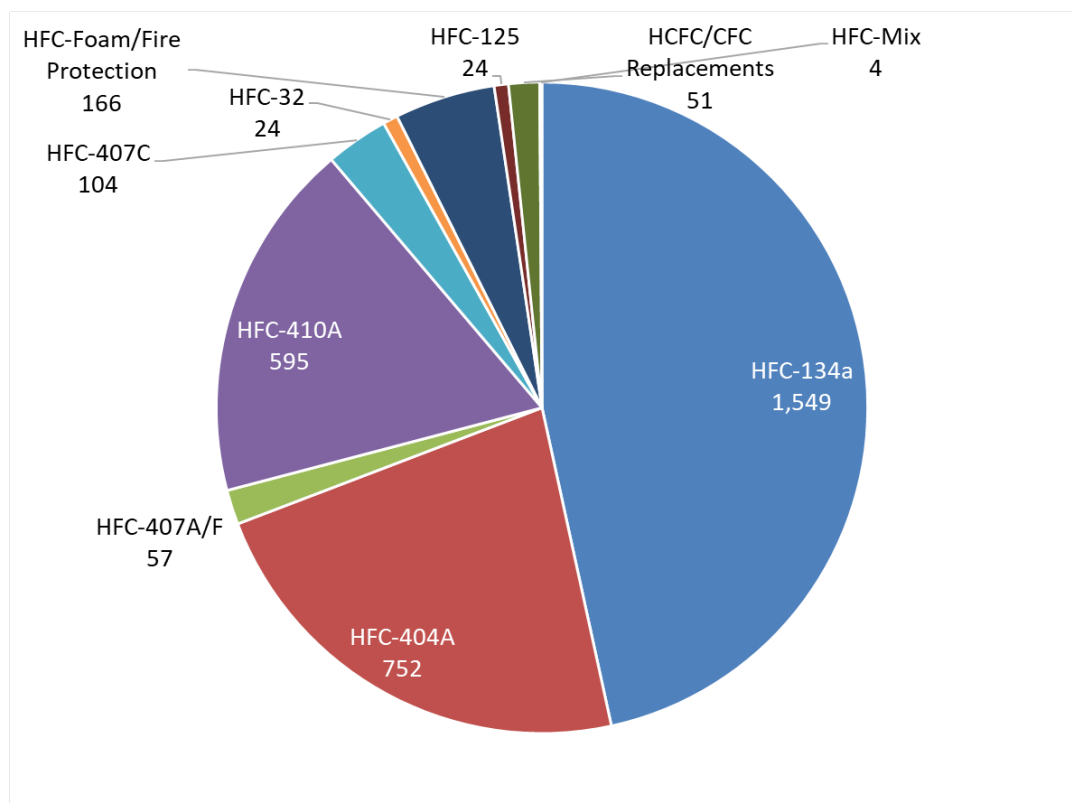


Figure 15: Five year average HFC bulk imports by species in tonnes and percent.

(Sources: DoEE 2017)

Charging new RCFC equipment and replacing refrigerant that has been lost through leaks is estimated to account for approximately 3,174 tonnes (3,534 tonnes less OEM of 360 tonnes), or 87% of all bulk imports of 3,651 tonnes in 2016.

Servicing the second largest bank of equipment, MAC, is estimated to account for 570 tonnes, or almost 16% of all bulk imports in 2016. Refer to *Table 10: Volumes of HFC-134a sold by calendar year (kgs) based on aftermarket supplier survey*, in Section 4.3 for usage over the last 3 years.

5.6 Refrigerant prices and market behavior

While the 2012 stockpiling was an obvious reaction to the certainty of greatly increased prices, underlying changes in prices and the market reaction to price changes were far wider and had longer lasting effects than just the obvious stockpiling.

Since 2010 the price of refrigerants in Australia has been impacted by a number of regulatory changes. The impact on refrigerant prices of the first two major regulatory changes in the last decade can be relatively easily discerned, while the third and most recent change (HFC phase down) has not yet commenced having any obvious impact on prices.

The first two significant regulatory impacts on price have been the step down of import caps for HCFCs and the introduction and then removal of the equivalent carbon tax. The import quota for HCFCs declined to 40 ODP tonnes per annum (equivalent to 727.3 metric tonnes of HCFC-22) in 2012, and then to 10 ODP tonnes

in 2014 and to 2.5 ODP tonnes in 2016. The introduction of the equivalent carbon tax on HFCs on 1 July 2012 imposed a tax on any imported HFCs based on the global warming potential of the refrigerant (and then its removal on 1 July 2014) produced significant and rapid changes in wholesale prices. Any changes in price of raw material were virtually insignificant relative to the price changes due to regulatory impacts.

These events have provided valuable insight into changed industry and trade behaviour as a result of higher refrigerant prices.

For the five years prior to the introduction of the equivalent carbon tax on refrigerant gases, HCFC-22, the most common HCFC in use, sold very consistently in the wholesale market for between \$20 to \$30 per kg. In 2012 the combination of the tightening of supply with the reducing import cap on HCFCs, and the introduction of the equivalent carbon tax on HFCs, provided the catalyst for HCFC-22 to rise above \$100 per kg in a period of just three to four months in mid-2012.

The equivalent carbon tax contributed to this increase because, while HCFCs themselves were not subject to the tax, the HFC refrigerants most commonly used to replace HCFC-22 were subject to the tax. For example, HFC-404A prices rose from less than \$20 per kg to as high as \$150 per kg immediately following the imposition of the equivalent carbon tax.

This dramatic change in the market for both HCFCs and HFCs, at effectively the same time, had several flow-on effects.

Firstly the majority of participants involved in the refrigerant supply chain, including those medium and large end users who were impacted by the price increases, started working to reduce leaks and refrigerant handling losses for both HFCs and HCFCs. This was particularly apparent in the very largest users of refrigerants, for whom refrigeration is mission critical to their business plans, such as in the supermarket industry and elsewhere in the refrigerated cold food chain.

The market focus on leak reduction quickly demonstrated that leak reduction strategies, such as improved equipment containment, leak inspection and automatic leak detection devices, were very cost-effective, delivering ongoing savings to equipment operators. The effects of this very positive outcome are still apparent in the market today.

Secondly, as a direct result of the increased value of the material, recovery of HCFCs, and of some HFCs, from equipment being upgraded or decommissioned increased.

While HFC prices subsequently stabilised and then declined immediately when the equivalent carbon tax was abolished on 1 July 2014, HCFC prices have remained high. HCFCs are still averaging \$100 per kg, supported by the import restriction, and a stock of HCFC charged equipment with significant remaining service life. An important outcome of the price spike for owners of HCFC charged equipment is the fact that recycling and reconditioning processes for HCFC-22, first widely adopted after the equivalent carbon tax came into force, proved that recovery, reclamation and reuse of HCFC-22 was profitable.

An active and effective HCFC recycling supply chain is in operation today, and it is estimated that it has recovered, reclaimed and delivered more than 210 tonnes of HCFC-22 back to the market in 2016. Assuming that activity has avoided the release to air of at least some portion of the recycled HCFC and noting that the availability of the recycled refrigerant may have depressed demand for importation of virgin HFCs that might have been used to replace the HCFCs, this is overall a positive environmental outcome.

For some equipment owners who were not aware of the likely impact of the equivalent carbon tax prior to its introduction, nor of the decreasing caps on HCFC imports, the period from 2012 to 2014 brought price shocks, changes in equipment buying behaviour and investigation of, if not investment in cutting edge developments in refrigeration technology.

One insight into the impact of the sudden quadrupling (or more) of refrigerant prices is available from the fishing industry. Most registered fishing trawlers in Australia, until 2012, had very hard working and often very leaky on-board blast freezers and chillers that were charged with HCFC-22. These marine systems can often contain more than 500 kg of refrigerant. Without this equipment the fishing vessel cannot operate.

Following the 2012 price rises there were stories circulating of trawler owners being caught after some accidental catastrophic loss of refrigerant from their systems and facing bills of more than \$70,000 to re-fill their freezer systems. One result of this price shock was that parts of the industry participated in a research and development program to design, build, install and test a much more highly energy efficient and leak proof freezer system for prawn trawlers that did not use HCFCs. This demonstrated technology is now being widely adapted in the fleet and provides a technology transition path for hundreds of heavy duty marine refrigeration systems. This innovation was a direct outcome from the strong price signal of 2012.

By August 2014, following the repeal of the equivalent carbon tax, HFC prices had readjusted with HFC-404A selling for \$28 per kg (down from \$150 per kg) and by 2016 HFC prices had returned to wholesale prices similar to prices in the market prior to introduction of the equivalent carbon tax. HCFC prices have however remained at close to \$100 per kg.

Table 20: Average refrigerant prices in 2013 and 2016.

	2013	2016
HCFC-22	\$107	\$98
HFC-134a	\$50	\$18
HFC-404A/507A	\$90	\$20
HFC-407C	\$69	\$25
HFC-407A/407F	\$50	\$24
HFC-410A	\$71	\$22
All HCFC-22/CFC Replacements	\$111	\$45
HFC-32	n.a.	\$44

Notes:

1. Average prices based on sales by major wholesalers to contractors.
2. Prices exclude GST and include levies and taxes.

5.7 CHF2 bank projections and predictions

In CHF2, retirement and replacement rates for equipment types, coupled with assessments about the rate of change in equipment design, plus expectations for refrigerant charges moving to lower GWP refrigerants, were used to project changes to the composition of the bank in each equipment segment for the five years from 2013 to 2017. These predictions were made while the market for refrigerants was subject to the equivalent carbon tax, which was subsequently repealed.

Changes predicted in the refrigerant employed in each segment were then used to produce a projection for the entire refrigerant bank between 2013 and 2017 as seen in *Figure 16*, as originally published in CHF2 and reproduced below. Note that data from 2010 to 2012 was actual data at the time.

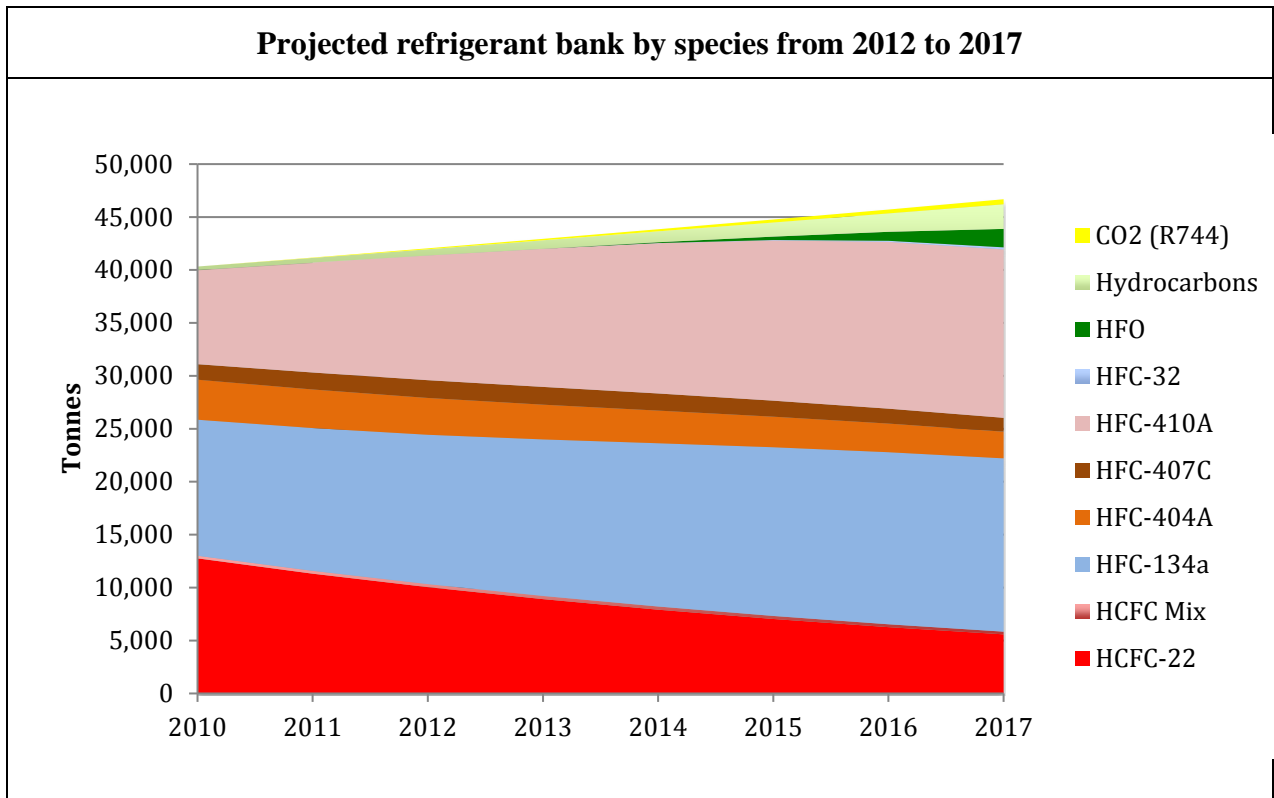


Figure 16: Projected development - refrigerant bank trend by species from 2012 to 2017 (2010 to 2012 actual).
 (Sources: DSEWPaC 2013b)

Because there are significant differences in the volumes of working refrigerant required to achieve similar levels of thermal transfer when using some ‘natural’ versus some synthetic refrigerants, modelling of the ‘natural’ refrigerants (CO₂, hydrocarbons and ammonia) is done by expressing them in terms of the tonnes of HFCs or HCFCs they are expected to replace, rather than the actual (smaller volume in the case of hydrocarbons) volumes of natural refrigerants employed. This provides a more accurate picture of the proportion of the energy services provided by the bank that natural refrigerants will deliver.

These projections predicted a strong decline in the main HCFC presently employed in the bank, HCFC-22, from an estimate of approximately 11,300 tonnes at the commencement of 2012 down to a 2016 and 2017 estimate of approximately 6,300 and 5,600 tonnes respectively.

This prediction has proven to be an over estimation of the rate of decline with the actual HCFC-22 in the bank now estimated to be more than 35% higher at 8,500 tonnes in 2016. The larger than expected bank can be partly attributed to the degree of recovery and reclamation of HCFC-22 in the market, and the high capital cost to replace medium and large RAC equipment.⁴⁸

The CHF2 projections predicted the overall bank would grow steadily from 43,500 tonnes to more than 45,700 and 46,700 tonnes in 2016 and 2017 respectively.

This was an underestimation of the rate of growth of the refrigerant bank with the 2017 bank currently estimated to be around 14% larger than predicted at approximately 52,000 tonnes. This can be partly attributed to underestimating the continuing strong growth of small and medium commercial AC sales which we had expected would moderate. However strong growth throughout the period in the construction of new apartments, the willingness of householders to install multiple split AC systems in homes and continued

⁴⁸ In 2016 the ODP cap was 2.5 tonnes, equivalent to 45.5 metric tonnes of HCFC-22. Therefore usage in 2016 is estimated at 210 tonnes plus 45.5 tonnes equating to 255.5 tonnes of HCFC-22 to virgin refrigerant specification as per AHRI 700. There was other refrigerant reuse by contractors where refrigerant is not recycled to AHRI 700 specification.

strong growth in sales of small AC into small and medium business premises of all types has seen sales of AC continue to climb.

HFC-134a and HFC-410A were projected to continue to grow (the latter particularly so) and together were expected to comprise nearly 70% of the refrigerant bank by 2017. This projection has proved to be roughly correct with the predicted trend being realised, although the combined volume of HFC-134a and HFC-410A was actually greater than expected but still only made up about 69% of the much larger than expected bank in 2016 and 2017.

Based on what was known of manufacturers' plans for the introduction of HFC-32 at the time, and partly due to the higher energy efficiencies that can be achieved with HFC-32 in high ambient regions, the use of HFC-32 was projected to increase as a stand-alone refrigerant despite what were, at the time, challenging skills barriers due to the mild flammability of the refrigerant. Nevertheless, dedicated efforts by the industry, working through standards processes and conducting training courses, cleared the way for the introduction of an entirely new class of refrigerants with mild flammability (A2L refrigerants) and HFC-32 charged AC exhibited remarkable growth, with the 2012 projection of some 188 tonnes of HFC-32 in the bank by 2017 falling well short of the current estimate of more than 1,800 tonnes in the bank in 2017.

HFC-404A was projected to decline by about 30% in the period to 2017. The industry had been moving away from use of this refrigerant in the few years prior to 2012 in preference for 'natural' refrigerants (CO₂, hydrocarbons and ammonia), and other HFCs such as HFC-134a on medium temperature commercial refrigeration applications.

This projection proved to be wrong and HFC-404A in the bank has actually grown by 30% from roughly 3,300 tonnes to 4,400 tonnes. This growth can partly be explained by the stockpiling of this refrigerant that took place in 2012 in the lead up to the introduction of the equivalent carbon tax, which saw more than 2,155 tonnes of HFC-404A imported ahead of the tax on this high GWP refrigerant.

When the tax was repealed the price of HFC-404A immediately returned to a very competitive wholesale price which has had the effect of extending the life of HFC-404A charged equipment in the market, where it is widely used in medium commercial refrigeration systems with remote condensers in the cold food chain. This high GWP refrigerant's affordability following the price collapse after the removal of the carbon tax has driven a growing stock of equipment using this refrigerant.

HFC-407C was also projected to decline, as it was already being substituted with HFC-410A by equipment manufacturers (local and overseas) prior to the introduction of the carbon tax on HFCs. The prediction of HFC-407C of 1,410 tonnes in 2016 and 1,310 tonnes in 2017, aligns with the CHF3 RAC Stock model at 1,340 tonnes in 2017.

Driven largely by legislative changes in Europe, the European directive on mobile air conditioning systems (Directive 2006/40/EC) aimed at reducing emissions from air conditioning systems fitted to passenger cars mandates that impacted vehicles must use a refrigerant gas with a GWP of 150 or less. In practical terms, the use of HFC-134a is not permitted for charging newly type-approved vehicles sold in the European Union from January 2011, and all new vehicles sold from January 2017. More recently the US Environmental Protection Agency (US EPA) and the US Department of Transportation's National Highway Traffic Safety Administration (NHTSA) implemented a program to reduce greenhouse gas emissions and improve fuel economy for light-duty vehicles with model years 2017 through 2025. This program induced many automotive suppliers to transition mobile AC of effected vehicles to HFO-1234yf to assist in achieving the emission targets under this scheme.

HFOs were predicted to enter the Australian market around 2015 as imports of new vehicles charged with HFO-1234yf arrived in Australia and some early adopters took up HFOs in some stationary applications. It was noted at the time that a significant proportion of HFC-134a charged applications could potentially use HFOs if the refrigerants were at least comparable in price, and if the HFC-134a equipment was redesigned to account for the higher flammability of the HFO replacement.

The species that was expected to be most widely employed by 2016, primarily in MAC, was HFO-1234yf with a GWP of 5.⁴⁹ As well as being marketed for use in mobile air conditioning systems, HFO-1234yf was promoted by international suppliers as being suitable for beverage vending machines and domestic refrigeration.

However, this projection proved to be largely wrong with almost no HFOs being seen in the market in new cars by 2016, although some large auto service chains are equipped and ready to handle HFOs in MAC and wholesale suppliers are holding some stocks of HFOs. This situation is expected to change relatively quickly in the years ahead.

While the introduction of HFO-1234yf in MAC has not progressed at the projected rates, large chiller manufacturers are now offering chiller models that employ HFO-1234ze (GWP of 5), although the impact of this development on the bank of HFC-134a employed in chillers, which are designed to have very long service lives, will take some years to be noticeable.

Importantly, blends of both the HFOs with proprietary mixes of other gases, mostly blends of HFCs, are being trialled in stationary RAC applications. These new blends with GWPs of 200 to 600 are still relatively high GWPs but a great improvement on the current HFC refrigerants where the most common products have GWPs ranging from 1,300 to as high as 3,260.

CO₂ and hydrocarbons were expected to grow to an equivalent tonnage of approximately 2,797 tonnes in 2017, or 6% of the total refrigerant bank. This prediction proved wrong, partly due to an overestimation of the volumes of HCs employed in the bank in 2012, but also due to the much more rapid expansion of the bank of HFCs. As a result, CHF3 estimates that in 2016 CO₂ and hydrocarbons had grown to an equivalent tonnage of approximately 700 actual tonnes in 2016, or 1.4% of the total refrigerant bank, and natural refrigerants are 10% of the bank if we include the estimated 4,800 tonnes of ammonia.

At the time of conducting the research for CHF1 and CHF2, ammonia refrigerant had already been long established in most of the larger cold storage facilities, because of both the energy efficiency benefits it provides in large plant, and because of its low cost and ready availability. The focus of CHF1 and CHF2 was primarily on the use of synthetic greenhouse gas refrigerants and including those parts of the stock of equipment where natural refrigerants were replacing high GWP refrigerants.

As ammonia was not thought at the time to have a significant role in displacing SGGs, the full extent of ammonia refrigerant use was not reflected in the starting point of this illustration above (*Figure 16*), nor in projections of future refrigerant mix in the bank. Expected new uses of ammonia in applications outside cold storage facilities, such as in industrial process refrigeration, only represented 0.2% of the bank, equating to approximately 89 tonnes of ammonia at the time, and was not visible on the scale of this illustration. Since that time use of ammonia in newer commercial refrigeration applications, larger than 30 kW, has started to expand. This wider adoption of ammonia in areas of the cold food chain was not predicted in 2012.

⁴⁹ The AR4 GWP-100 value for HFO-1234yf and HFO-1234ze was 5, whereas the AR5 calculation uses a GWP value of 1.

6 Natural refrigerants

The total mass of natural refrigerants employed in the bank for refrigeration and air conditioning would otherwise require approximately 5,400 tonnes of high GWP refrigerants to deliver the same amount of cooling services, equivalent to as much as 8% of the total GWP bank. The physical tonnes of natural refrigerants employed in the bank was estimated at 4,800 tonnes in 2012.

Growth has been observed in the use of all natural refrigerants between 2012 and 2016. The growth is particularly notable in the use of CO₂ (up 59%) driven by cascade systems in the supermarket industry, and in hydrocarbons (up 77%) including HC-600a, HC-290 and HC-436 due to penetration in domestic refrigeration and self-contained commercial refrigeration equipment and as a result of retrofitting of HCs in older mobile air conditioning systems. However, these two refrigerants were growing rapidly off very small banks in comparison to the overall bank of refrigerants.

On the other hand, the bank of ammonia has seen comparatively slow growth, increasing 9% over the period. Applications employing ammonia refrigerant have been in wide use for decades, particularly in large cold stores and distributions centres in the refrigerated cold food chain. As such growth of the ammonia bank is starting from a relatively large base (as compared to the volumes of the other natural refrigerants in use). In line with the trend across most RAC systems, ammonia refrigeration systems are also being designed with smaller and smaller refrigerant charges. Thus, even while the energy services delivered by ammonia charged systems are increasing, the rate at which the bank of this zero GWP refrigerant has expanded has been slower than the rate of growth in refrigeration services delivered.

Importantly, increased demand for ammonia charged systems from large end-users in the cold food chain has been somewhat constrained by the capacity of the RAC industry to design and deliver these systems. The design and engineering skills required are quite specialised. Like many complex niche technologies, increasing demand cannot necessarily be matched with readily available service providers due to the extensive technical expertise required to design, install and maintain this complex technology. Some of these skills can only be developed over many years of experience in the field.

Table 21: Low GWP refrigerant bank 2012 and 2016 in tonnes.

Species	Bank 2012 (Tonnes)	Bank 2016 (Tonnes)	Change (%)
CO ₂	80	127	59%
Ammonia (R717)	4,400	4,800	9%
Hydrocarbons	320	566	77%
Total ⁽¹⁾	4,800	5,366	14%

1. Sources: In-confidence market survey of all major participants provided actual 2016 market volumes, which was used to derive estimates of the natural refrigerant bank by type.

6.1 Ammonia refrigerant

Ammonia, known in the industry as R717, makes up by far the largest portion of the natural refrigerants in the bank.⁵⁰ However, because ammonia is manufactured domestically and there is no requirement to report use of ammonia as a refrigerant to any central agency, estimates of the total ammonia bank have to be derived from a combination of data sources including a consumption survey of the key suppliers, a partial survey of operating facilities and secondary sources of information.

The main applications where ammonia systems are found include cold storage facilities (typically 5,000 to 1,000,000 m³), large chilling, blast freezing and ice making systems in the primary and secondary stages of the cold food chain, and some chemical processes and mining air conditioning applications.

There is an estimated 14.8 to 15.1 million m³ of cold storage space operating on ammonia systems. Assuming a benchmark obtained from industry sources of 29 kg per 1,000 m³ of storage space, this equates to around 430 to 450 tonnes of ammonia in cold stores.⁵¹

Other applications where large charges of ammonia systems can be found in single installations are in high volume blast freezing applications that are extremely energy intensive, requiring snap freezing of large masses of perishable goods such as in meat processing, poultry processing and other primary and secondary processes in the refrigerated cold food chain (i.e. vegetables, dairy, beverages, frozen foods).

Some individual meat processing facilities are known to contain up to 150 tonnes of ammonia.⁵² In June 2017 there were 105 meat/poultry processing facilities in Australia that employ more than 20 and less than 200 people, and 54 that employ more than 200 people (ABS 8165.0).

Large ammonia systems are also found in some industrial and mining applications where full time engineering staff are at hand and overall cooling loads are high. For instance, in some fertiliser plants, metal processing facilities, and in providing chilled water for cooling underground mining operations.

A survey of suppliers of bulk ammonia estimated 545 tonnes was delivered to customers in 2012 and, based on the research undertaken on ammonia charged refrigeration facilities, an estimate of the ammonia bank in 2012 was 4,400 tonnes in total.

Since that time a survey of the major suppliers of ammonia has been repeated annually from 2014 to 2016 and reported an average of 709 tonnes sold during those three years.

Table 22: Volumes of ammonia sold by calendar year (tonnes) based on supplier survey.

2014	2015	2016
837.1	712.4	577.2

Notes:

1. Volumes exclude non-HVAC&R applications.
2. Survey participants include major participants at the top of the supply chain as well as suppliers further down the supply chain, however these suppliers were not double counted.

Noting that ammonia systems, due to regulatory requirements and design considerations, enjoy very low leak rates, it can be concluded that most of the ammonia sold every year is being employed in new ammonia refrigeration systems.

⁵⁰ Ammonia used in refrigeration systems is anhydrous Ammonia meaning it does not contain water, the chemical symbol is NH₃ and the ASHRAE refrigerant number is R717.

⁵¹ Industry source: Refrigerated Warehouse and Transport Association.

⁵² JBS Australia, one of Australia's largest meat processors and exporters has a large plant in Dinmore, Qld contains as much as 150 tonnes of ammonia.

The bank is estimated to have only grown by around 100 tonnes per annum. Although this is considerably less than the annual volumes reported as sold, market intelligence suggests that a significant proportion of ammonia sold in the past few years is going into new systems installed at existing enterprises, replacing old ammonia systems. What is more, the new systems have smaller refrigerant charges than the systems being replaced, contributing in part to the relatively slow growth of the bank, even while the service providers in this segment are reported to be operating at full capacity.

The new 'packaged' designs are characterised by smaller ammonia charges, reduced piping, ease of maintenance and installation, and safer start-up routines, all of which help make low-charge ammonia packaged units appealing to end users and technicians. Compared to the conventional older large charge ammonia designs, the modern, small charge ammonia plants are proving to be readily adaptable to a large range of applications and site layouts, with high degree of mobility.⁵³

Most importantly from a business perspective, the annual energy consumption of the new ammonia systems can be as little as one third of the older HFC/HCFC based systems. The capital cost of the new systems is also substantially lower than traditional designs with the smaller ammonia plants now able to compete head-to-head with 100 kW_r HFC-based systems. Combined with the strong energy saving returns, small charge packaged ammonia systems –whether new plant or retrofitted – are able to pay for themselves within 3 to 6 years based on energy savings alone.

From a business planning perspective ammonia is also an attractive option because ammonia charged systems are essentially future proofed against the effect of HFC restrictions.

In this particular segment of the industry it is generally acknowledged that the technicians available to handle ammonia refrigerant systems are operating at capacity.

While the relative simplicity and safety of new ammonia designs does make it easier to train technicians, the trend to more compact, cheaper and safer systems also mean that this market could experience rapidly rising demand in capacities below 50 kW, opening up a much wider range of applications along the cold food chain. If this trend meets with a limited supply of qualified technicians, then industry constraints could limit an important opportunity for segments of the cold food chain to move away from the use of HFCs in the decade ahead. The recent opening of a privately funded dedicated ammonia refrigeration training facility in Sydney is an important step towards overcoming the skills bottleneck.

The acceleration of wider ammonia adoption is also likely to benefit from low-charge packaged ammonia units for industrial applications where ammonia-CO₂ cascade systems are sometimes employed.

Wider demonstration of these systems could see substantial demand arising from other food industry trends such as the rise of ready-made meal businesses like Lite n Easy. Other segments of the cold food chain that could move rapidly to these systems, where there is both new investment and existing plant being taken off HFC charged equipment, include beverage processors (e.g. dairy, beer, soft drinks), packaged frozen food producers, ice cream makers, and vegetable processing plants (e.g. potato chip lines, peas, broccoli, etc.)

It should also be noted that large-scale heating projects are proving fertile ground for ammonia charged systems in colder climates in Europe. Industrial heat pump manufacturer Mayekawa reported ammonia charged industrial heating applications are demonstrating similar efficiencies to cooling technologies. While the Australian climate may limit the growth of this market, it points to rapid technological development in ammonia systems.

6.2 Carbon dioxide refrigerant

Commercial refrigeration systems employing CO₂ refrigerant have been proliferating in Australia during the last decade. There are now more than 800 supermarket refrigeration systems containing CO₂, the majority of these (>95%) are HFC/CO₂ cascade systems that employ a high GWP HFC in the primary cooling loop, and

⁵³ Refer Scantech Refrigeration Technologies plug and play solution discussed in *Accelerate Australia & NZ, Autumn 2017*.

a charge of CO₂ in a secondary refrigerant circuit. These systems are very effective in large supermarkets employing as much as 1,000 kg of refrigerants, of which around two-thirds will be HFC-134a and one-third CO₂.

CO₂ cascade and 'CO₂ only' systems are displacing considerable HFC refrigerant use, particularly in supermarkets and applications where the energy efficiency of these systems makes them increasingly attractive as rising electricity costs erode profit margins.

This is not a trend confined to just the major supermarket chains. Drakes Supermarkets in South Australia is an example of an independent supermarket operator committed to 'CO₂ only' systems or 'CO₂ trans-critical' systems as they are referred to by engineers. With the majority of their 60 stores located in South Australia, a region with high electricity prices, Drakes reports savings of between 20% and 25% on operating costs in supermarkets fitted with CO₂ trans-critical systems as compared to those with older HFC charged systems.

Since their first investment in CO₂ systems in 2007, Drakes has fitted out 14 stores with these more capital intensive systems, but as owner operators, captured the strong returns on the total cost of ownership which includes operating costs, including electricity and refrigerant usage over the life of the equipment. In 2018 they were planning to have three additional stores fitted with CO₂ trans-critical systems in the first quarter of the year.

The active adoption of cascade refrigeration, and steady growth in 'CO₂ only' systems by the supermarket sector is discussed further in *Section 4.4.3 RCFC3 Supermarkets*. CO₂ systems are also being employed in smaller numbers in large licensed clubs and food processing applications.

The supply chain for CO₂ is very complex with multiple steps, comprising many resellers, and suppliers sometimes going direct to end users, or with end users purchasing CO₂ from further up the supply chain at the wholesale level as part of a project or new development. Expert Group collects sales data from many of the supply chain participants and estimates the average sales volume over the last three years is approximately 120 tonnes per annum (*CHF2 ~70 tonnes per annum*).

Although aggregate supplies of CO₂ were estimated to be 120 tonnes in 2016 the installed base of equipment suggests that a portion of this gas is carried in the supply line, and on site as back-up supplies in manifolded cylinder pallets (i.e. Manpacks) to cover catastrophic failures (i.e. compressor failures or ruptures of gas lines).

While designs of CO₂ systems are improving, owners and suppliers of CO₂ refrigerant report the systems occasionally suffer gas line or seal failures and lose their entire charge, as CO₂ systems have very high operating pressures. These factors lead to the current estimate of a relatively small refrigerant bank of CO₂ refrigerant of around 127 tonnes.

It should be noted that whilst a loss of charge is very inconvenient for the end user, the environmental impact is relatively insignificant as the refrigerant has a GWP of 1.

It is expected that with the now extensive base of installed CO₂ refrigerant technology in enterprises with full-time engineering support, the technology and the expertise to design and operate them will continue to evolve rapidly and be employed in a wider range of applications in the cold food chain, including large food processors. CO₂ systems are also being used in truck and automotive air conditioning, small refrigerated vending machines and merchandisers, hot water heat pumps and for refrigerated containers known as reefers. One such new small scale example of a CO₂ application is the EcoCute technology, widely available in Europe and Japan, that uses CO₂ refrigerant technology on hot water heat pumps to achieve high efficiencies and lower running costs.⁵⁴

In Europe and the US some end users and manufacturers of CO₂ equipment are predicting CO₂ will increasingly enter the industrial arena and are expecting ammonia systems to face increased competition from

⁵⁴ Sanden Eco Hot water heat pump system achieves coefficients of performance of around 4.5.

CO₂ trans-critical systems in the industrial sphere, while foreseeing strong growth in ammonia heat pumps (i.e. low-charge packaged ammonia systems).⁵⁵

Recent innovations developed by equipment suppliers include demonstrations of micro-cascade air-cooled condensing units available in capacities from capacities as small as 2.5 kW_r and upwards. These units offer hybrid refrigeration (HFC-134a/CO₂) systems for use in smaller sites and have potential for application across a broad range of commercial refrigeration applications.

6.3 Hydrocarbon refrigerant

The majority of hydrocarbons are employed in very small charge systems such as domestic refrigerators, self-contained commercial refrigeration equipment and retrofitted automotive systems.

The growth of hydrocarbon charged domestic refrigerators and freezers in the stock has accelerated dramatically since 2012, with nearly 4.7 million devices (~24%) containing HC-600a in 2016 (*CHF2*, 1.1 million, ~7%).

A small survey of 66 fridge-freezers in a large retail outlet was undertaken at the end of 2010. Fifty-one products were found to contain HFC-134a (Fisher & Paykel, Samsung, LG, Kelvinator and Westinghouse). Fifteen products (29%) contained HC-600a (Electrolux, Westinghouse, Hisense and some larger LG models).

In a follow up survey in 2013 of seventy-six products in the same store 54% of products contained hydrocarbon refrigerant. Notably more brands had converted to HC-600a, including Electrolux, Westinghouse, Hisense, Fisher & Paykel, Sharp, Panasonic and some larger LG models.

A retail survey of domestic refrigeration and freezer stock on the floor of a leading retailer conducted in July 2017 found just 6 models out of 123 inspected (<5%) charged with HFC 134a. This strong trend first noted in *CHF2* is expected to see the migration of all new sales of domestic equipment to HC charges approach >95% during 2018.

The use of hydrocarbons (HC-600a and HC-290) is now also firmly established as an option for buyers of new small commercial refrigeration equipment in Australia.

A trend that had barely started in 2012, smaller self-contained commercial refrigeration equipment is the leader in this trend with sales of new HC charged equipment in this category increasing more than 30 times (up 3000%) since 2012, or nearly 20,000 units in 2016 compared to a little over 600 units in 2012. The range of HC charged commercial refrigeration equipment being sold includes upright and horizontal freezer cabinets, refrigerated retail display cabinets, wine coolers and ice cream merchandisers. This strong trend is continuing with volumes in 2017 estimated to be more than 30,000 pieces, up a further 50% on 2016.

Self-contained refrigeration display cabinets containing small charges of hydrocarbon refrigerant can now be found in the majority of the 490 Aldi supermarkets⁵⁶ (up to 36 individual cases per store with a charge equal to or less than 150 grams in each case) currently operating in Australia.

Even with this rapid sales growth in self-contained commercial refrigeration equipment, the high efficiency of the refrigerant, and the small charge sizes has resulted in a 2016 estimate of the bank of HC employed in commercial refrigeration of just 10 tonnes.

The total actual hydrocarbon refrigerant bank is estimated at 565 tonnes in 2016 (1,215 tonnes equivalent charge) comprising 379 tonnes in Domestic Refrigeration, 170 tonnes in Mobile AC, 10 tonnes in commercial refrigeration, and, 6 tonnes in Stationary AC, including hot water heat pumps.

A survey of the major suppliers of hydrocarbon refrigerant from 2014 to 2016 shown in *Table 23* reported an average of 77 tonnes sold annually during those three years. Supply volumes are down from the previous survey of 105.9 tonnes in 2012. Total bulk HC refrigerant sales have been impacted by two main factors, the

⁵⁵ *Ammonia 21 publication by Shecco, Media, January 2018.*

⁵⁶ *Aldi had 482 stores in August 2017.*

closure of the Electrolux domestic refrigerator factory in Orange in April 2016, and the repeal of the carbon tax that resulted in a reversal of the high price of HFC-134a. Following the Electrolux closure, the majority of hydrocarbon refrigerant (>70%) is supplied to the automotive aftermarket sector with around 15% in the Cold Food Chain, and less than 10% into Stationary AC applications including hot water heat pumps.

Table 23: Volumes of hydrocarbon sold by calendar year (tonnes) based on supplier survey.

2014	2015	2016
82.1	75.3	72.0

Notes:

1. Survey participants include all current suppliers of HC.

7 The future bank – projections of the bank to 2030

The refrigerant bank in the economy is determined by the mix and type of RAC equipment employed. The aggregate charges of the stock of equipment make up the bank, and in turn determine the mix of bulk imports required for servicing that bank.

The Australian industry has already successfully transitioned through two generations of post WWII synthetic thermal media, effectively eliminating CFCs from the economy, and is on track to phase out use of virgin HCFCs by 2030 in accordance with the Montreal Protocol.

Natural refrigerants and the fourth generation of synthetic refrigerants are now starting to be seen in a wider array of applications than ever before.

Figure 17 illustrates the evolution of refrigerant species and how they are managed under international environmental protocols.

Figure 17: Refrigerant types and international industrial gas management regimes.

Refrigerant types and progression of synthetic refrigerants			
Natural refrigerants ⁽¹⁾			
Ammonia		ODP = 0	GWP = 0
Carbon dioxide		ODP = 0	GWP = 1
Hydrocarbons		ODP = 0	GWP ≈ 4
Synthetic refrigerants			
Montreal Protocol (in response to ODP)		Kigali Amendment to the Montreal Protocol (in response to GWP)	
CFC		HCFC	HFC
Low GWP			
1st Generation CFC-12 GWP > 10000 ODP = 1	2nd Generation HCFC-22 GWP = 1810 ODP = 0.055	3rd Generation HFC-404A GWP = 3922 ODP = 0 GWP ≥ 1430	4th Generation HFO-1234yf ODP = 0 GWP < 10 HFO blends GWP < 1430
		3.5 Generation HFC-407F (GWP of 1825)	

Notes:

1. The term 'natural' implies the origin of the fluids, i.e. gases that are used as natural refrigerants occur in nature as a result of geological and/or biological processes, unlike fluorinated refrigerants that are synthesized chemicals. However natural refrigerants are all industrially produced and processed and transported in large and small pressure vessels to market.

Having engineered a transition away from ozone depleting refrigerants, the global industry and governments have now agreed a phase down of HFCs, effectively seeking a transition to lower GWP refrigerants to further reduce the impact of direct refrigerant emissions from the industry on global warming.

This new driver of technological change is resulting in an increasing diversity of refrigerants in the bank as lower GWP refrigerants are engineered or proven in specific applications. It is this requirement to reduce demand for HFCs that is going to be the main influence on the future bank.

A simple visual has been prepared in *Table 24* for major equipment classes to provide technology signals (green, amber and red) to indicate the general suitability for transition to lower GWP HFCs, or away from HFCs to an alternative refrigerant. This framework, along with interviews of technical experts from global equipment suppliers form the basis for predicting new equipment sales mix projections to 2030, which in turn lead to the projections below of the future composition of the bank.

Table 24: Summary of technology opportunities for new equipment by GWP threshold in 2018.

New equipment	New equipment technical capability (GWP threshold)			
	150	750	1500	2500
Domestic refrigeration	Green			
RCFC: Self contained	Green			
RCFC: Remote	Yellow	Yellow	Green	Green
Supermarket: Cascade systems	Yellow	Yellow	Green	
Supermarket: CO ₂ only systems	Yellow			
RCFC: Transport ⁽¹⁾	Red	Red	Yellow	
Small AC: Sealed ⁽²⁾	Green			
Small AC: Split	Red	Green		
Medium AC	Red	Green		
Large AC: Chillers other	Green			
Large AC: Centrifugal Chillers	Yellow	Yellow		
Small MAC	Green			
Large MAC	Yellow	Yellow		
Fire Protection	Green			
Key to technology signals:				
Green	Threshold suitable (but may need small number of exemptions in some sectors)			
Yellow	Threshold may be suitable for part of sector, but more commercial development needed			
Red	Threshold not suitable at this time, 2018			

1. There are difficult applications in the fishing industry that have no clear technology path. For example, deep freeze applications less than -35°C on vessels less than 30 meters in length.
2. Small AC comprises sealed (i.e. self-contained) unitary equipment, mostly window/wall units and portable units sold into domestic applications. Portable units have no MEPS requirements and have been sold into Australia with hydrocarbon charges for at least 5 years (i.e. Delonghi). Australia currently has the highest MEPS levels in the world for window/wall units and no hydrocarbon charged units are currently registered in Australia. There are several overseas suppliers that manufacture window/wall units that operate on hydrocarbons and those products that do not currently meet Australian MEPS but could be re-engineered to do so.
3. There are many variants and safety issues with large MAC however it is thought that 50% of large MAC technology can achieve GWP <150, while the other 50% requires further development.

7.1 Projections of the bank 2016 to 2030

Starting with the stock of equipment in 2016 and applying a series of factors and assumptions as set out in *Appendix A: Methodology – Taxonomy, data and assumptions*, and *Appendix B3: New equipment sales mix by segment* a projection of the development of the bank from 2016 to 2030 has been produced.

The bank of refrigerants in the Australian economy is expected to expand by more than 35% to approximately 70,000 metric tonnes in the 14 year period of the projections from 2016 to 2030.

The projections of the bank include HCFC-22 and HCFC-123 to demonstrate the diminishing presence of these substances. HCFC-22 and HCFC-123 are not counted as part of the GHGs reported under the Kyoto

Protocol or United Nations Framework Convention on Climate Change, as they are managed through the Montreal Protocol.

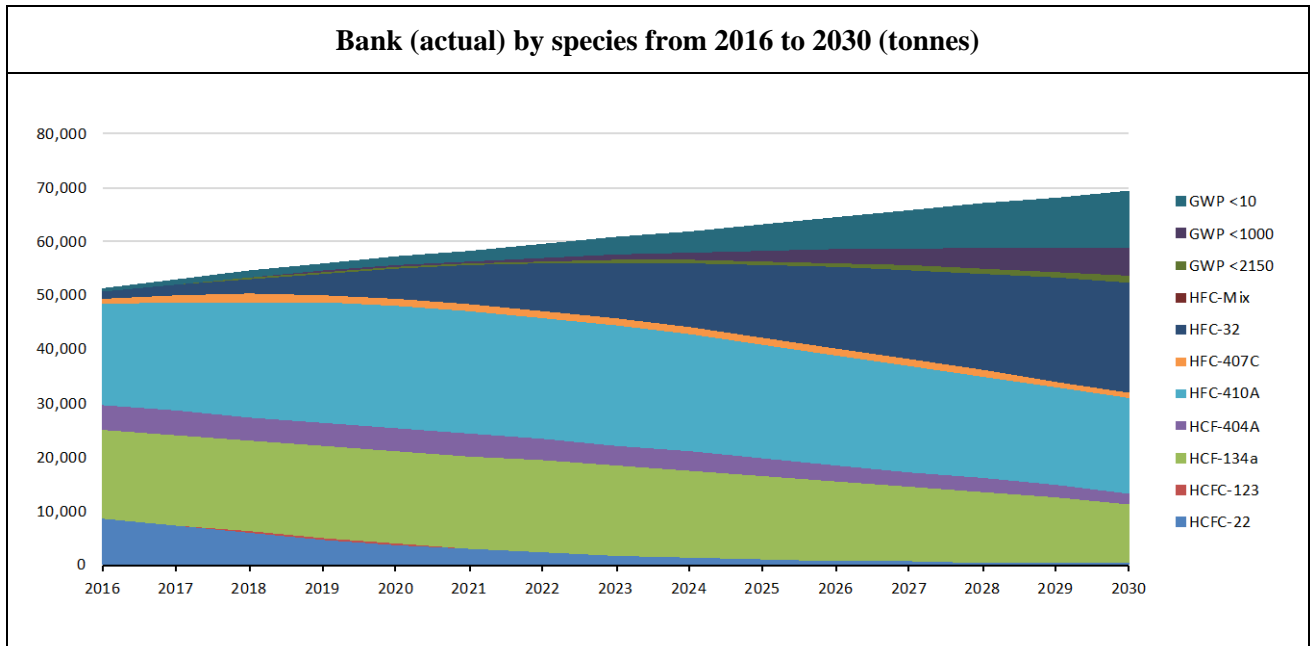


Figure 18: Refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

In CO₂e terms the bank in 2030 is expected to fall by more than 18% in the period, from a CO₂e value of more than 99 million tonnes in 2016 to less than 81 million tonnes in 2030.

The projection predicts the CO₂e value of the Australian bank of refrigerant will peak at more than 102.6 million tonnes of CO₂e in 2019 before falling steadily for the following decade.

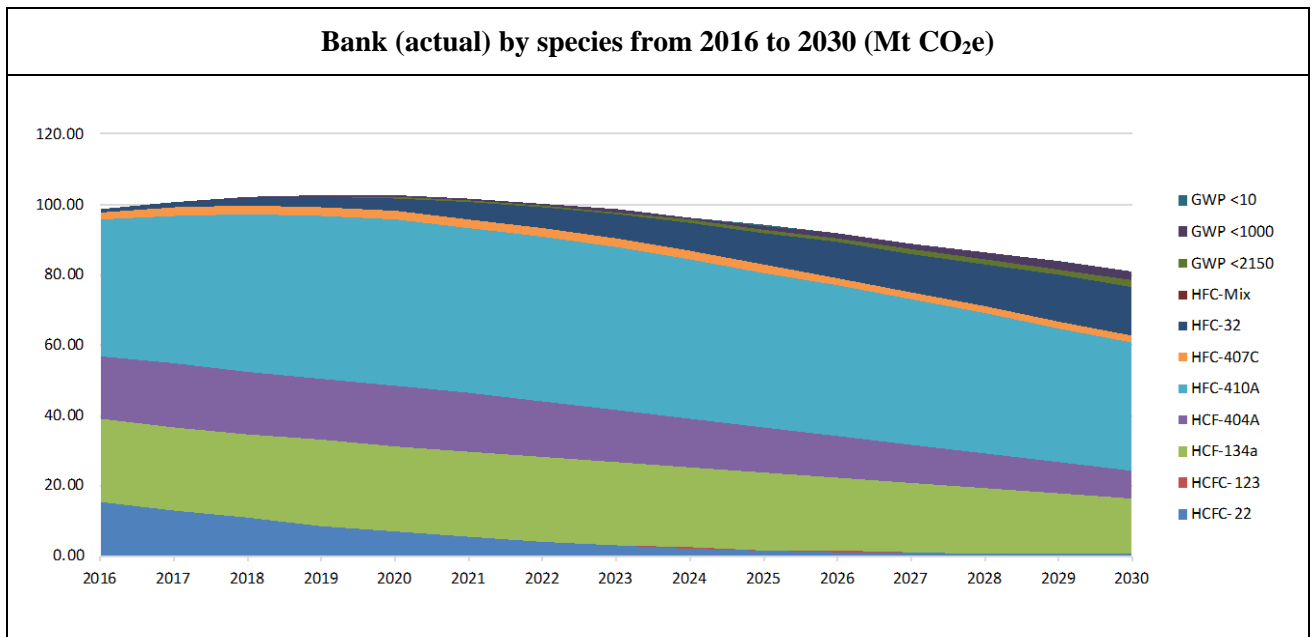
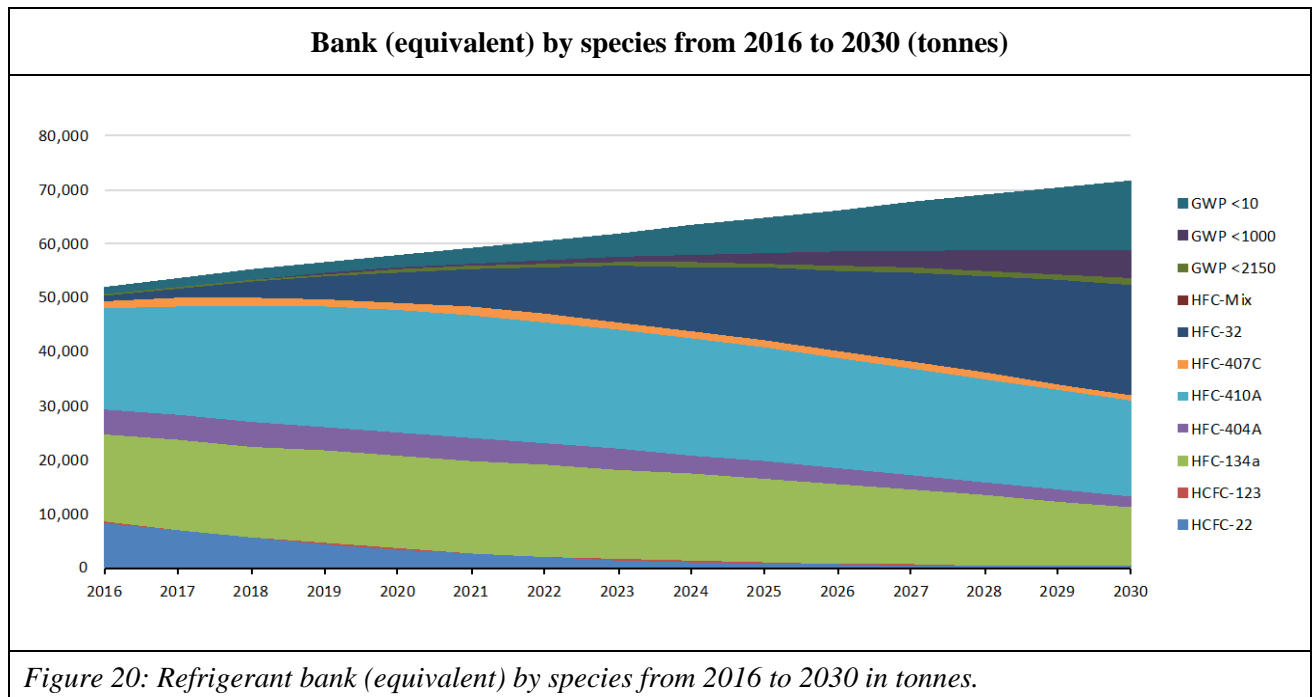


Figure 19: Refrigerant bank (actual) by species from 2016 to 2030 in Mt CO₂e.

(Source: CHF3 RAC Stock model)

This outcome is predicted based on the impact of the HFC phase down, the adoption of a range of lower GWP synthetic refrigerants, and an expansion in the use of natural refrigerants in the economy over the period, delivering more energy services, with a growing bank of refrigerants, an increasing number of which will have zero or very low GWP (GWP<10) as compared to the bank in 2016.

To illustrate the effect of those segments where refrigerants with a GWP<10 are adopted over the projection period, the chart below shows how large the bank would be, if equipment charged with natural refrigerants were instead employing the most common synthetic refrigerant currently used in that application (i.e. 69,480 tonnes versus 65,629 tonnes).⁵⁷



(Source: CHF3 RAC Stock model)

As can be seen, the ‘equivalent’ bank, in the absence of refrigerants with a GWP<10, such as HCs in domestic refrigerators, would have been nearly 2,400 metric tonnes larger in 2030, equal to an additional 3.4 million tonnes of CO₂e at that time.

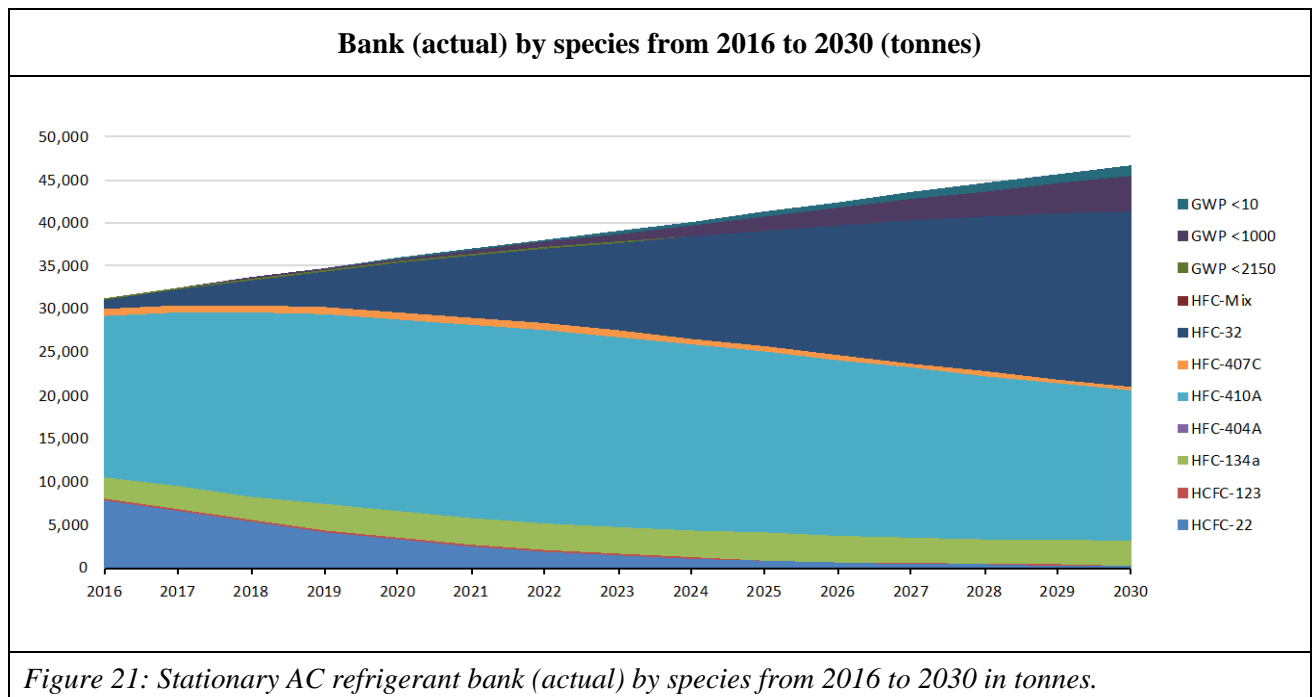
The projections above have been built from projections of the bank employed in each major class of equipment, themselves involving projections of refrigerant demand and use in many of the smaller equipment segments.

All of the main classes and many of the segment projections are in the sections to follow with some commentary alongside each projection.

⁵⁷ There is a further 6,800 tonnes of low GWP HFOs, and this less GWP<10 does not include the industrial refrigeration ammonia bank.

7.2 Stationary AC

Overall the refrigerant bank in stationary air conditioning, across all segments from the very small self-contained units to the largest chillers, is predicted to expand by nearly 50% between 2016 and 2030 to more than 46,700 metric tonnes, representing more than 67% of the total refrigerant bank in 2030, an increase in bank share for stationary AC from slightly more than 60% in 2016.



(Source: CHF3 RAC Stock model)

Two of the main high GWP HFCs are expected to maintain a significant presence in the stationary AC bank over the projection period:

- HFC-410A to grow from more than 18,500 metric tonnes in 2016 to a peak of more than 22,450 metric tonnes in 2021 before declining to around 17,500 metric tonnes in 2030; and,
- HFC-134a to grow from around 2,550 metric tonnes in 2016 to a peak of nearly 3,200 metric tonnes in 2023 before declining to around 2,700 metric tonnes at the end of the projection period.

Over the same period the rapid growth of HFC-32 in the small AC: split segment, capping growth of the much higher GWP HFC-410A, plus larger falls in CO₂e intensity of the stationary AC bank, helps cap the bank growth in CO₂e value terms with a slight fall over the 14 years of the projection period of approximately 3%, to some 57.3 million tonnes of CO₂e from the 2016 value of just more than 59 million tonnes CO₂e.

However, the projection suggests the total CO₂e value of the stationary AC bank will peak at more than 62.7 million tonnes CO₂e in 2020 before slowly falling throughout the following decade.

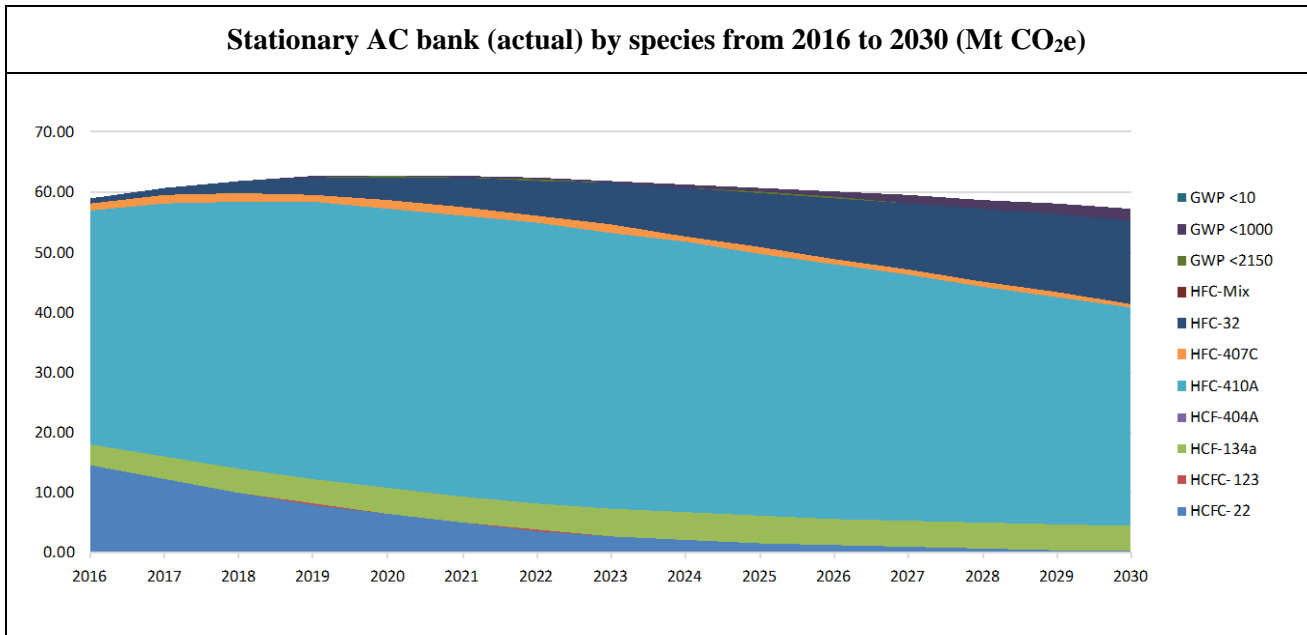


Figure 22: Stationary AC refrigerant bank (actual) by species from 2016 to 2030 in Mt CO_{2e}.

(Source: CHF3 RAC Stock model)

During the projection period the majority of the currently HCFC-22 charged AC systems across all stationary AC segments are expected to be retired or be retrofitted. HCFCs (includes HCFC-123) in stationary AC is predicted to fall from the nearly 8,000 tonnes presently in use to around 305 tonnes still employed by 2030.

Small AC: Split

The greatest single gain in CO_{2e} reductions in the bank is predicted to come from the transition of small AC split systems from being primarily charged with HFC-410A (GWP of 2088) to being primarily charged with HFC-32 (GWP of 675). In this segment the bank of HFC-410A is predicted to fall from more than 9,300 metric tonnes in 2016 to around 1,250 tonnes in 2030, while the bank of HFC-32 is predicted to grow from just 970 tonnes in 2016 to more than 16,300 tonnes in 2030.

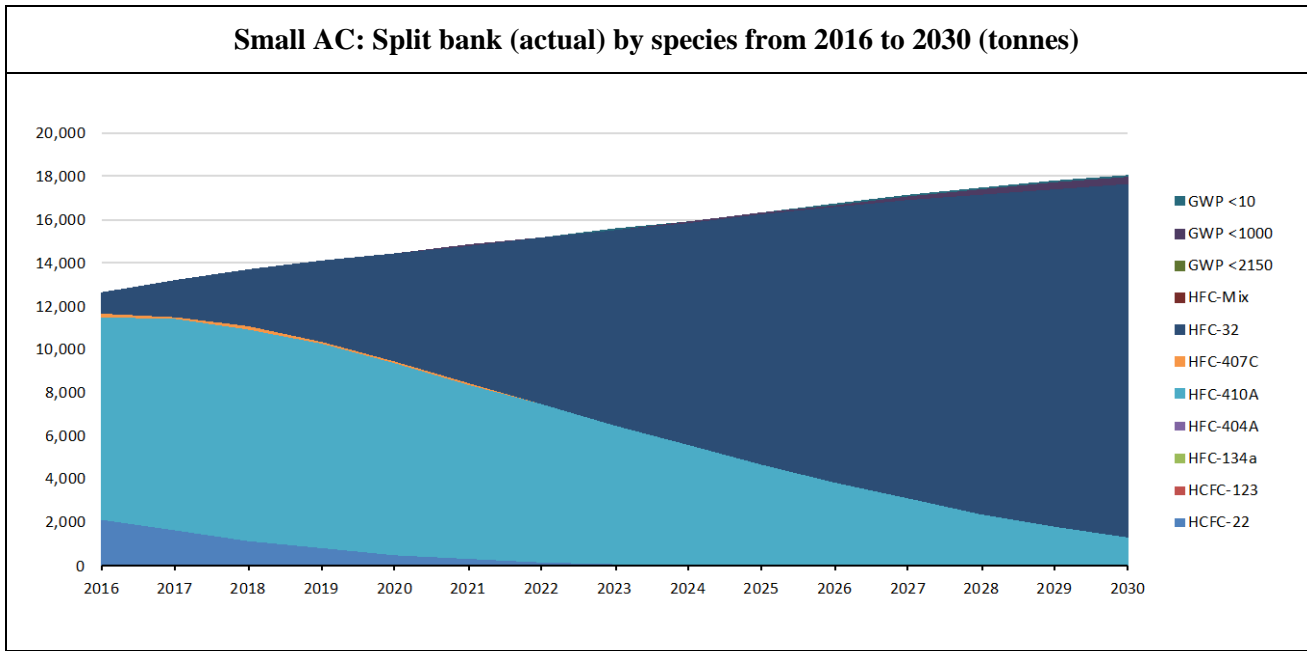


Figure 23: Small AC: Split refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

As a result, while the actual bank of refrigerant in this segment grows by more than 25% from more than 12,600 metric tonnes in 2016 to more than 18,000 metric tonnes in 2030, the transition to HFC-32 sees the CO₂e value of this portion of the bank predicted to fall by more than 43% from more than 24.3 million tonnes CO₂e in 2016 to around 13.8 million tonnes CO₂e in 2030.

During the projection period all of the currently HCFC-22 charged small AC split systems are expected to be retired from use with HCFC-22 in this segment falling from more than 2,100 tonnes in 2016 to zero by the end of the projection period.

Medium AC: Ducted split and light commercial

The bank projection for larger split systems and light commercial AC, based on current information about available and emerging refrigerants, does not predict the same shift to lower GWP refrigerants as seen in the populous small AC segment. This is due to technical standards and associated risk that limit the charge sizes of mildly flammable refrigerants such as HFC-32 being widely employed in Medium AC.

The actual bank in this segment is predicted to grow by more than 83% from around 12,600 metric tonnes in 2016 to more than 23,100 metric tonnes in 2030 with the CO₂e value of this portion of the bank growing by more than 49% in the period from around 29.3 million tonnes of CO₂e to more than 37.7 million tonnes of CO₂e by 2030.

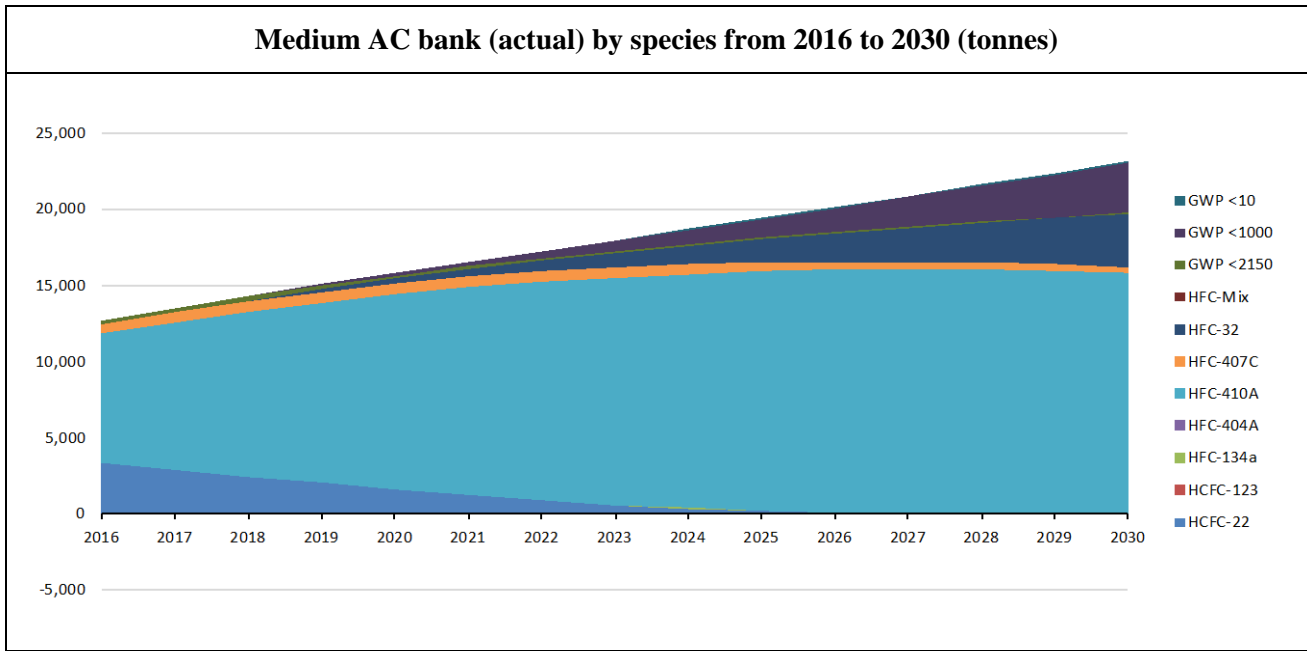


Figure 24: Medium AC refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

This outcome is largely driven by the growth of the HFC-410A portion of the bank in this segment. The use of HFC-410A is predicted to rise by more than 84% from a 2016 starting volume of around 8,500 tonnes in 2016 to a 2030 bank of more than 15,800 tonnes of this high GWP refrigerant (with a CO₂e value at that time of more than 33 million tonnes). The growth of this bank is driven by expected continued strong growth in the stock of equipment in this segment driven largely by strong growth of multi split, and VRV/VRF split systems that will substitute for single split systems and large space chillers.

By the end of the projection period the Medium AC segment of the stationary AC class employs, on its own, more than 33% of the total bank.

This significant increase in the bank of HFC-410A occurs despite the projection for this important segment predicting that there will be an uptake of HFC-32 in the smaller charged medium AC equipment with as much as 3,550 tonnes employed by 2030. The model also predicts that refrigerants with a GWP <1,000, expected to be a HFC/HFO mix (possibly non-flammable Class A1 refrigerant), will be employed at similar levels to HFC-32, with about 3,200 tonnes expected to be employed by 2030, plus much smaller quantities of CO₂ (133 tonnes by 2030).

Given the work underway with HFC/HFO blends, and the commercial imperative to find non-HFC refrigerants as the timetable for the HFC phase down under the Kigali Amendment progresses, it is reasonable to expect that the major chemical companies will be experimenting with non-HFC and low GWP alternatives for this important segment.

During the projection period nearly all of the currently HCFC-22 charged medium sized split and smaller commercial AC systems are expected to be retired from use, with HCFC-22 in this segment falling from more than 3,300 tonnes presently in use.

Large AC: Chillers

While demand for large commercial chillers is expected to grow strongly, the bank in this segment is predicted to expand by a modest 6.4% over the projection period from around 4,200 metric tonnes in 2016 to approximately 4,650 tonnes in 2030 as chillers are being substituted with other AC technology such as VRV/F systems.

This relatively small portion (8% by mass in 2016) of the refrigerant bank is generally employed in very long lived equipment with operating lives longer than 25 years in many cases. Despite this, the highly engineered and managed equipment has more opportunities for retrofitting than smaller classes of equipment, so this segment is more readily able to adopt new refrigerants as they are proven in the market.

The overall GWP of this bank is predicted to fall during the projection period by more than 25% from around 6.4 million tonnes CO₂e in 2016 to around 4.8 million tonnes CO₂e in 2030. HFC-134a holds its share of this bank, rising slightly from 2,300 metric tonnes in 2016 to 2,560 tonnes in 2030. Similarly, small quantities of HFC-410A and HFC-407C are roughly maintained over the projection period at 150 and 26 tonnes respectively by 2030. HFC-32 is expected to climb from zero in 2016 to around 200 tonnes in 2030. However the trend in falling CO₂e values in this segment is driven by an expected combined bank of more than 1,350 tonnes accumulating between 2016 and 2030 of refrigerants with a GWP<1,000, comprising HFO blends, and refrigerants with a GWP<10 such as HFO-1233zd, HFO-1234yf and ammonia.

During the projection period the majority of the currently HCFC-22 and HCFC-123 charged Large AC systems are expected to be retired or refitted. HCFCs in this segment is predicted to fall from more than 1,750 tonnes presently in use to around 310 tonnes still employed by 2030.

7.3 Mobile AC

The second largest portion of the bank is contained in mobile AC (MAC), employing nearly 11,000 tonnes in 2016, slightly more than 21% of the bank in total. This bank is contained in two broad segments, Small MAC which includes passenger and light commercial vehicles, employing more than 93% of the MAC bank in 2016, and Large MAC found in large buses, passenger trains, recreational vehicles, caravans and a range of off-road and unregistered vehicles including equipment like mobile cranes, combine harvesters, road building equipment, etc.

The MAC bank is projected to grow to more than 13,000 tonnes in 2030, spread across more than 24.7 million vehicles at that time, but representing only 19% of the much expanded total bank at that time. This projection assumes a very low take up of electric vehicles over the projection period.

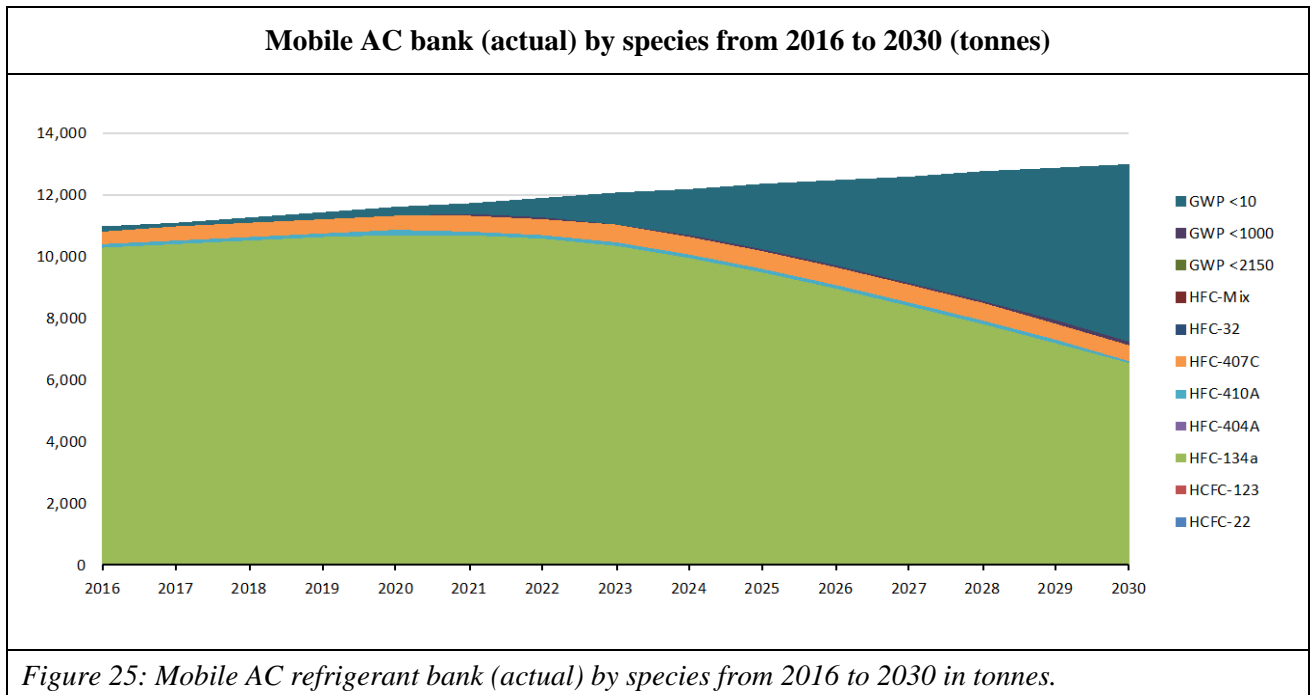


Figure 25: Mobile AC refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

Importantly, with the introduction of low GWP HFO-1234yf in new vehicles, the CO₂e value of the MAC bank is projected to fall by nearly 33% from an estimated 15.6 million tonnes CO₂e in 2016 to 10.5 million tonnes CO₂e by 2030.

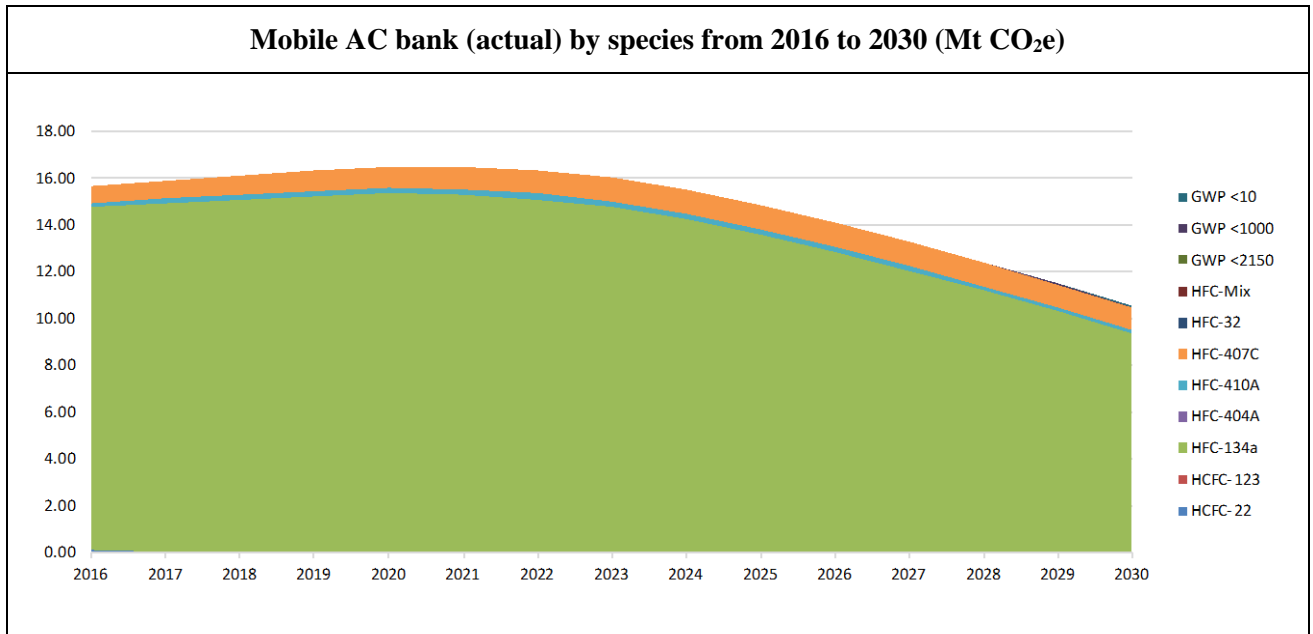


Figure 26: Mobile AC refrigerant bank (actual) by species from 2016 to 2030 in Mt CO₂e.

(Source: CHF3 RAC Stock model)

The bulk of HFOs is expected to be employed in small MAC found in passenger and light commercial vehicles, with more than 5,400 tonnes of HFOs predicted to be found in Small MAC, out of a total Small MAC Bank at that time of approximately 11,900 tonnes, making up more than 17% of the total bank in 2030.

The considerable HFO portion of the Small MAC bank is predicted to make up more than 41% of the total MAC bank by 2030. The uptake of HFOs in Small MAC is expected to reduce the bank of HFC-134a in Small MAC from its peak of around 10,400 tonnes in 2020, to around 6,300 tonnes in 2030.

Hydrocarbons in Small MAC is predicted to grow modestly, in line with the fleet growth, from 170 tonnes in 2016 to 210 tonnes in 2030. Comparing the two figures below for the actual and equivalent banks show a slightly larger wedge of refrigerants with a GWP<10 in the equivalent bank. This is due to the lower equivalent charge of the older vehicle fleet charged with HC as the actual charge is only 30% of HFC-134a.

A small bank of around 60 tonnes of CO₂ is predicted to be in operation in Small MAC by 2030.

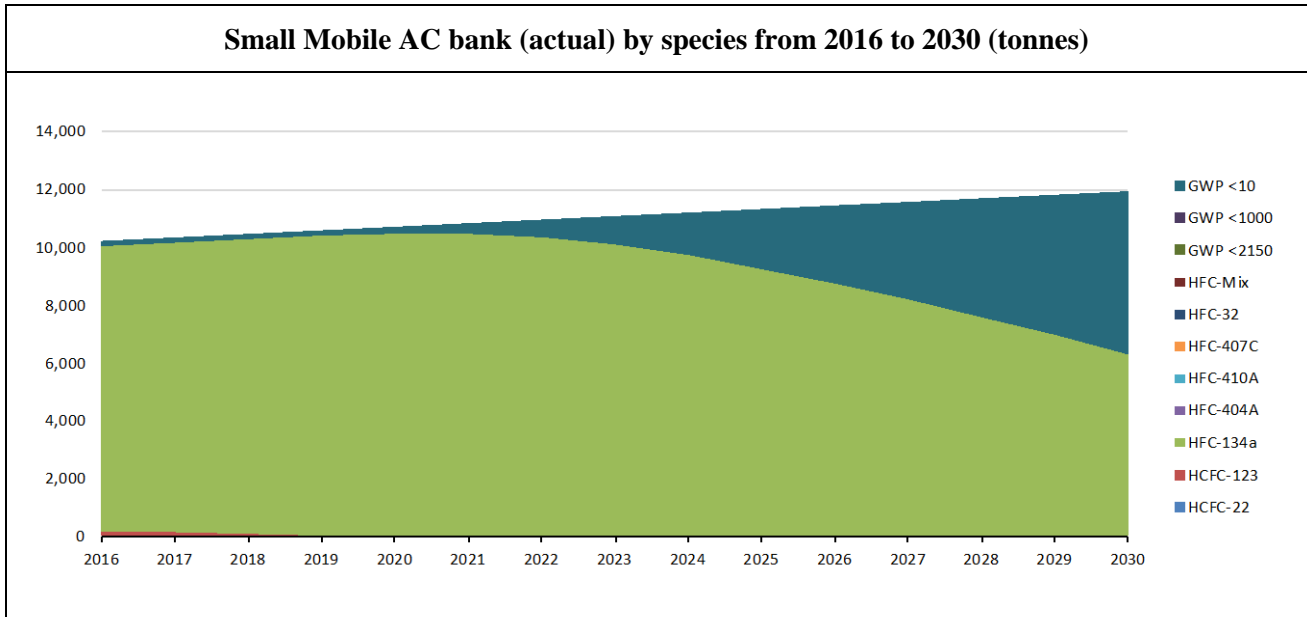


Figure 27: Small Mobile AC refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

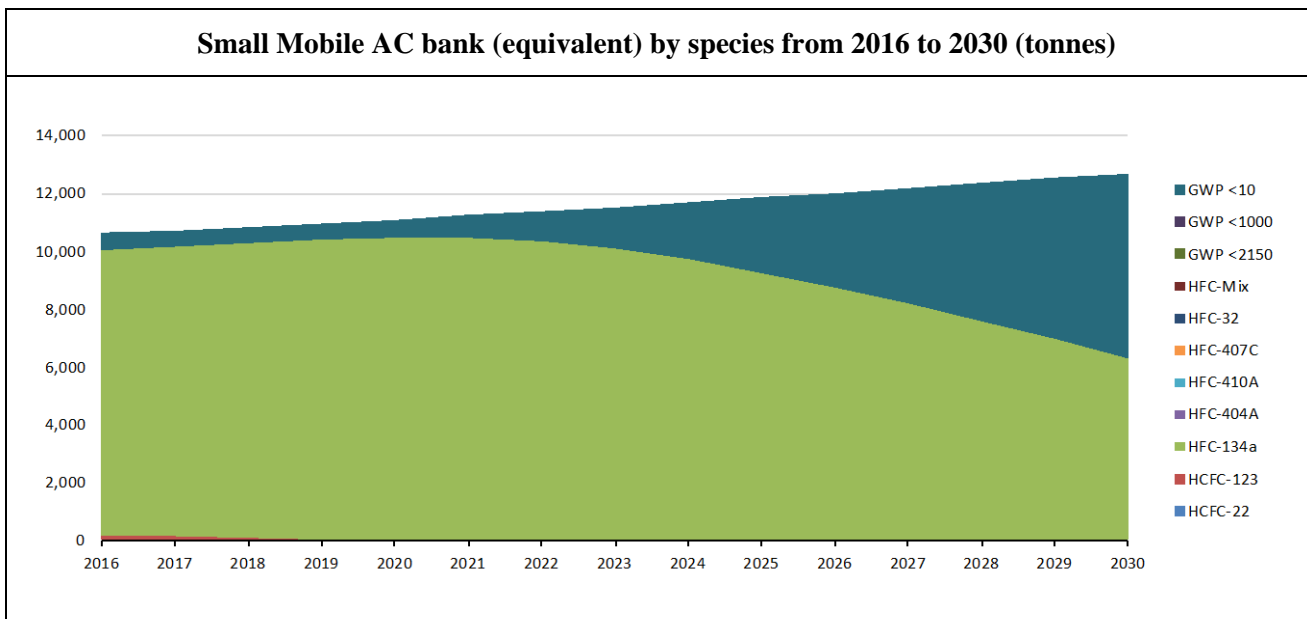


Figure 28: Small Mobile AC refrigerant bank (equivalent) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

The more complex and specialized segment, Large MAC, includes a range of applications for which high GWP HFCs are required to deliver the performance required. Current components of the Large MAC bank that are expected to either grow or roughly maintain their share of this segment include:

- HFC-407C, from 390 tonnes in 2016, rising to a peak of 580 tonnes in 2025 before starting to exhibit a gentle decline to around 530 tonnes in 2030;
- HFC-134a, from 227 tonnes in 2016 to 256 tonnes in 2030; and,

- HFC-410A, from 87 tonnes in 2016 to 81 tonnes in 2030.

The Large MAC bank is predicted to grow from around 740 tonnes in 2016 to approximately 1,070 tonnes in 2030, at that time comprising around 1.5% of the total bank.

While there are some low GWP refrigerants in this segment, HFC-407C is predicted to continue to be employed in a significant portion of the equipment in this segment, rising to a peak of 580 tonnes in 2025.

During the projection period nearly all of the currently HCFC-22 charged Large MAC systems are expected to be retired or be retrofitted. HCFC-22 in this segment is predicted to fall from around 33 tonnes presently in use to effectively zero by 2030.

7.4 The refrigerated cold food chain

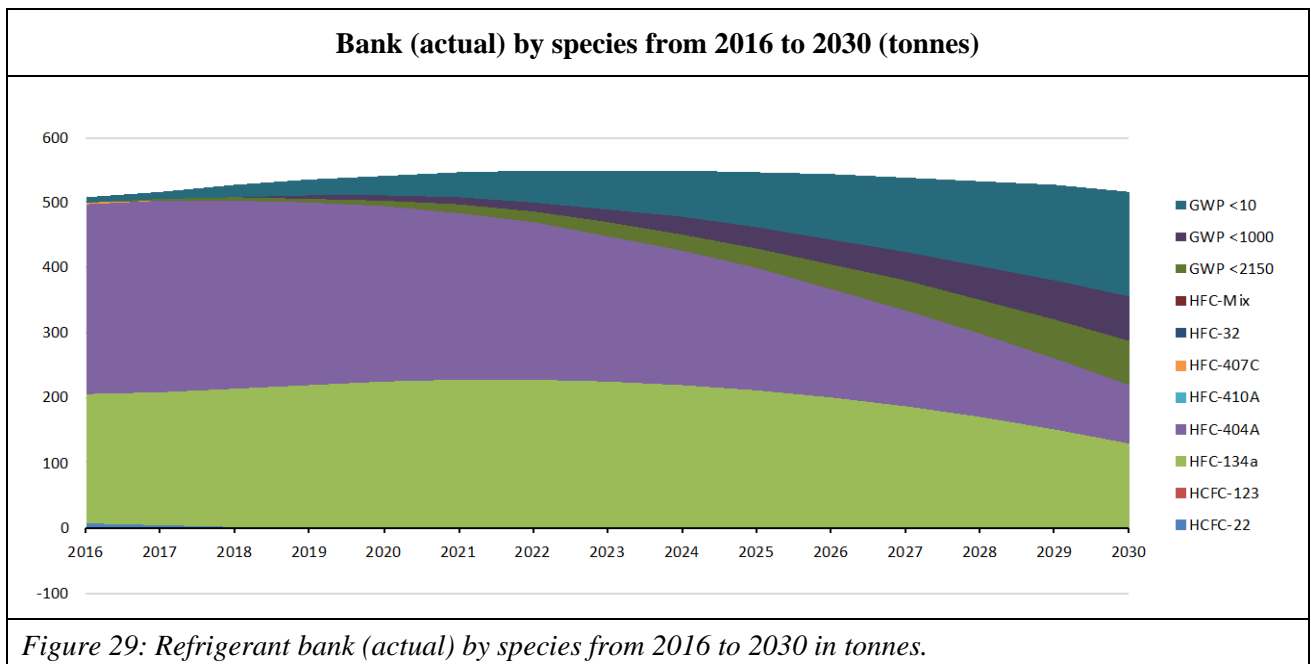
The refrigerated cold food chain (RCFC), that stretches from farm shed to local food retailers, and which in many retail and hospitality settings is incorporated into bespoke cabinets and equipment formats, employs a diverse bank to suit the wide range of temperature conditions (typically from -25°C to +7°C) and outputs required.

Employing about 14% of the total bank, or about 6,900 tonnes of refrigerant in 2016, the bank in this relatively small but critical class of equipment is analysed in great detail in four broad segments including self-contained equipment, remote equipment, supermarket systems and transport refrigeration.

Small commercial refrigeration

Small commercial refrigeration predominately comprises self-contained equipment and is estimated to contain around 7% of the RCFC bank in 2016, or around 510 tonnes of refrigerant. This bank is not a large segment; however, it highlights the extent of diversification of the bank that is expected to accelerate in the coming decade.

In 2016 more than 97% of this small segment was charged with either HFC-134a (199 tonnes) or HFC-404A (293 tonnes). By the end of the projection period the bank of HFC-134a is expected to decline by more than 34% to just 130 tonnes and HFC-404A is expected to decline by nearly 70% to just 90 tonnes.



(Source: CHF3 RAC Stock model)

Stepping in to replace these refrigerants in a bank that stays roughly stable, growing to around 520 tonnes, are HFOs, HC and CO₂, which together are projected to increase from just 7 tonnes in 2016 to more than 162 tonnes in 2030. Refrigeration display cases and storage cabinets have already experienced a rapid transition to HC with more than 20,000 devices imported in 2017 with a charge less than or equal to 150 grams of HC per refrigeration circuit. These low GWP refrigerants (GWP<10) will comprise more than 31% of the bank in this segment by the end of the projection period.

Additionally, roughly equal volumes of emerging medium GWP refrigerants in the GWP<2150 bin, and the GWP<1000 GWP bin, are expected to be employed with around 67 tonnes of refrigerant each in small commercial refrigeration equipment by 2030.

An insight into the diversification of the bank in this segment is instructive. What this projection suggests is that a refrigerant technician being called out to repair or maintain any one of the dozens of formats of self-contained refrigeration equipment in a commercial setting in 2030 has to be prepared to deal with any one of seven different refrigerants, including small charges of highly flammable HC, mildly flammable A2L refrigerants and high pressure CO₂ equipment, as compared to having to work with just two main Class A1 non-flammable refrigerants (HFC-134a and HFC-404A) only a few years ago.

Medium commercial refrigeration

The developing diversity of the bank is even more acute in the broad and numerous segment of remote equipment, comprising an evaporator(s) with a remote condensing unit, where there are already five different high GWP refrigerants in use, and at least six more refrigerant blends either starting to be employed now or on the near-term horizon.

Remote condenser driven systems allow a huge variety of refrigerated spaces to be constructed, most often seen as ‘cool rooms’, ranging from very small spaces of just a few cubic metres to very large cool rooms able to be worked with forklifts, built into or adjacent to other buildings. Remote systems are very hard working, almost always have some ‘bespoke’/situational design consideration, and very often have exposed refrigerant lines connecting the external condenser and the refrigerated space.

Importantly, remote condenser systems, as one of the backbone elements of the cold food chain, can be designed to provide very low temperatures down to -25°C and lower for blast freezing or medium temperature refrigeration services (zero to +7°C).

Employing a total bank of more than 4,010 tonnes in 2016, representing nearly 57% of the bank in the RCFC, various types of remote systems can employ HFC-134a, HFC-404A, HFC-410A or HFC-407C. Overall the bank employed in remote condenser systems is expected to only grow modestly over the projection period, largely driven by a reduction in charges sizes over the period. By the end of the projection period this segment is predicted to contain more than 53% high GWP HFCs which illustrates some of the technical challenges facing this sector during the HFC phase down.

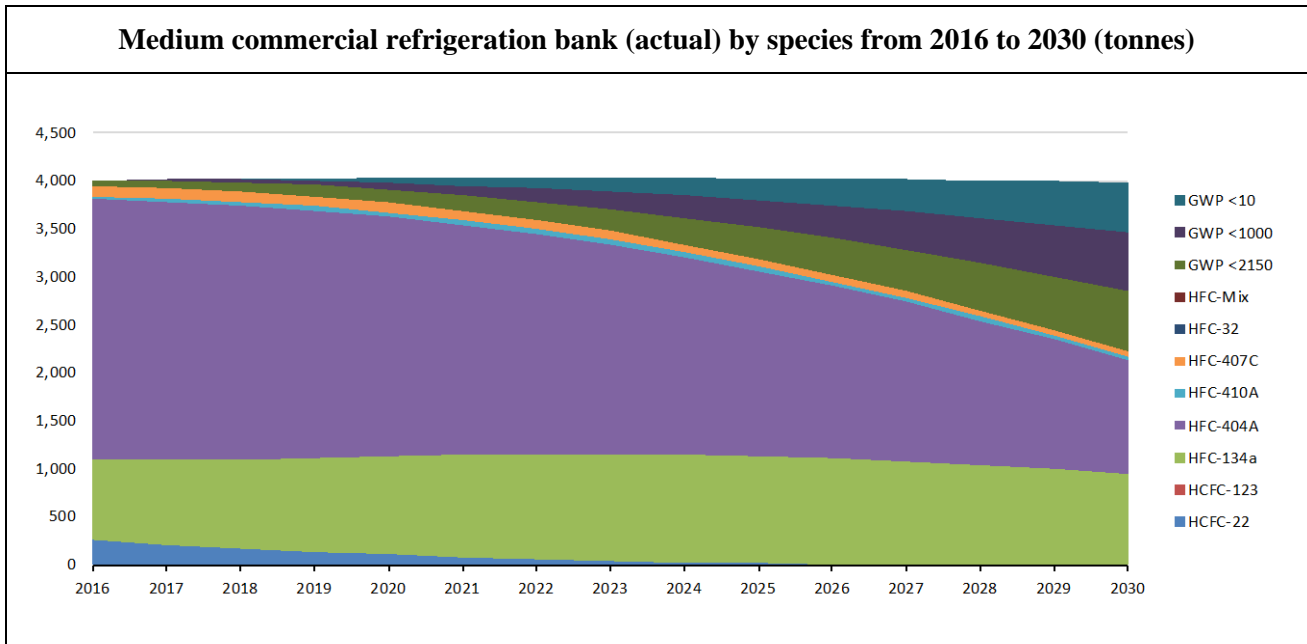


Figure 30: Medium commercial refrigeration refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

Banks of these high GWP refrigerants in this segment are estimated as follows:

- HFC-134a of around 835 tonnes in 2016 to grow steadily to 950 tonnes in 2030;
- HFC-404A of more than 2,700 tonnes in 2016 to fall steadily by more than 56% to around 1,185 tonnes by 2030;
- HFC-410A of around 30 tonnes in 2016 to end roughly stable by the end of the projection period at 35 tonnes;
- HFC-407C to decline from around 100 tonnes in 2016 to 85 tonnes in 2024 before ending the projection period at around 45 tonnes;
- A small bank of emerging blends HFC-448a and HFC-449a in the <2150 GWP bin is predicted to grow to nearly 630 tonnes by 2030; and,
- New blends in the <1000 GWP bin are expected to enter the market strongly in the early part of the projection period, growing from zero to around 620 tonnes by 2030.

All of the low GWP refrigerants are also predicted to grow into a small portion of this complex bank with HC, HFOs, CO₂ and ammonia charged systems either already being deployed or expected to be so soon:

- A small bank of HC charged equipment was already in the market in 2016 and is expected to grow to some 75 tonnes;
- HFOs starting from zero are predicted to grow to a bank of around 105 tonnes;
- CO₂ systems are predicted to grow from zero at the start of the period to a bank of more than 355 tonnes by 2030; and,
- Ammonia charged systems in low temperature remote applications of more than 40 kW_r are demonstrated and economic and are expected to grow from zero to more than 55 tonnes by 2030.

During the projection period most of the currently HCFC-22 charged remote condenser systems are expected to be retired or refitted. HCFC-22 in this segment is predicted to fall from around 313 tonnes presently in use to just 12 tonnes by 2030.

Apprentices starting in refrigeration engineering courses now will be working in an increasingly complex technical and regulatory environment by the time they graduate in the early years of the 2020s and, in this segment, potentially handling any one of 11 different refrigerants.

Supermarkets

Supermarket refrigeration systems were estimated to employ around 2,300 tonnes of refrigerant in 2016, at that time comprising nearly 32% of the RCFC bank. This is expected to expand modestly to some 3,200 tonnes and around 40% of the RCFC bank in 2030.

Supermarket systems are generally large centralised or remote systems, designed to the specific site but using well tested standard components which are generally well maintained.

Due to the highly concentrated structure of the Australian supermarket industry, with the main players being well capitalised and highly performance focussed, the bank in supermarket systems has reflected these large corporations' commitments to efficiency and environmental stewardship in the last decade, with a quite rapid and accelerating trend towards refrigerant leak reduction and transition to low GWP refrigerants.

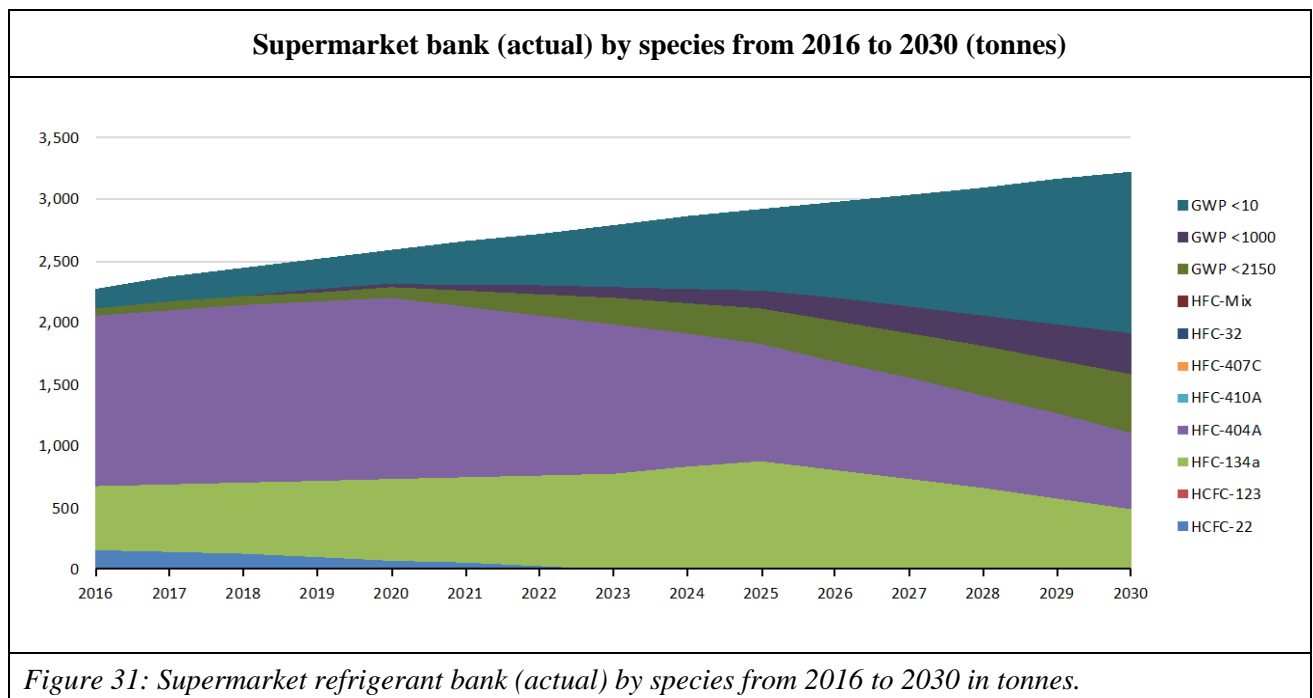


Figure 31: Supermarket refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

The mainstay high GWP HFC-404A is predicted to see a decrease of more than 55% in the projection period from a 2016 bank of around 1,370 tonnes, climbing to around 1,470 tonnes in 2020 before falling steadily to less than 620 tonnes by 2030. HFC-134a, starting with a bank of around 520 tonnes in 2016 is expected to climb to around 880 tonnes in 2025 before declining steadily to around 490 tonnes in 2030, maintaining its role in two stage cascade refrigeration systems, at the same time as HCFCs are removed entirely from supermarket systems within just the next few years.

Emerging blends HFC-448a and HFC-449a in the <2150 GWP bin are predicted to grow steadily from a 2016 estimate of some 55 tonnes of HFC-407F in 2016 to a sizeable bank of around 485 tonnes in 2030. New blends in the <1000 GWP bin are predicted to enter the market in the early years of the period and increase to nearly 325 tonnes by 2030.

Highly efficient and demonstrated two stage HFC-134a/CO₂ cascade systems, and emerging pure CO₂ systems will see large CO₂ charged centralised refrigeration systems build a bank of CO₂ from around 170 tonnes in 2016 to more than 1,130 tonnes by 2030.

HFOs, just starting to be employed at the start of the period, will add to the very low GWP bank in supermarkets, growing from zero to approximately 160 tonnes by 2030.

By the end of the period the low GWP portion of the supermarket bank is expected to make up more than 40% of the bank in this segment and is expected to be growing its share of this segment bank strongly at that time.

During the projection period all of the currently HCFC-22 charged systems in supermarkets are expected to be retired or refitted. HCFC-22 in this segment is predicted to fall from around 160 tonnes presently in use to zero by 2023.

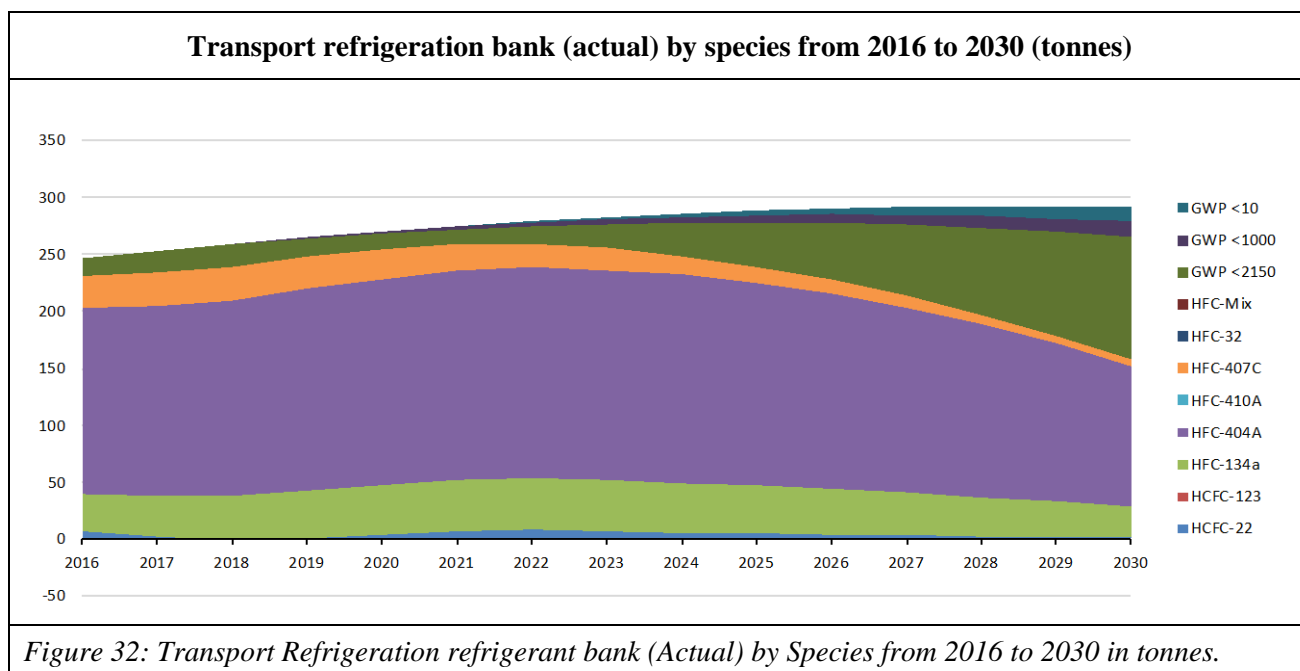
RCFC Transport

There is a small bank of high GWP refrigerants employed in the essential link of transport refrigeration in the cold food chain. This involves refrigeration formats ranging from small refrigerated vans, refrigerated ‘pantechs’ to semi-trailers and ‘reefers’ – the refrigerated multi-modal shipping containers used for the international shipping of frozen and chilled foodstuffs.

The bank in RCFC Transport in 2016 is estimated to be around 245 tonnes, equal to a bit less than 3.5% of the complete RCFC bank and less than 0.5% of the total national bank of refrigerants.

Refrigerated transport services in Australia are increasing, not just with increases in population and the requirements of delivering chilled foods to new shopping centres in new suburbs, but also driven by increased Australian food exports and on the back of food industry trends such as growth in sales of home deliveries, prepared meals, and large catering businesses winning work outsourced from aged care homes, hospitals, etc.

This bank is projected to grow steadily to around 290 tonnes by 2030, but with limited options currently available to move to lower GWP refrigerants. The CO₂e value of this small bank is expected to decline slightly from around 775,000 tonnes CO₂e in 2016 to around 700,000 tonnes in 2030.



The RCFC Transport bank, while small, illustrates some of the technical challenges facing the wider RAC industry in the HFC phase down. In a number of demanding applications where high ambient temperatures are likely to be encountered in working situations, with high vibration and high dust loads, at the same time that compact and robust mobile refrigeration units are required to deliver low temperature storage, there are currently limited lower GWP alternatives to the range of high GWP refrigerants that are able to deliver these services.

There were trials undertaken with CO₂ open loop systems that have not proven to be viable, and now the closed loop vector technology under review in Europe may provide an alternative in the next five to ten years. At present the refrigerant of choice is HFC-404A on larger systems and HFC-134a on smaller systems with HFC-452A (GWP of 2141) as an option that has not been taken up in Australia.

7.5 Domestic refrigeration

All domestic refrigeration and freezers in the economy are estimated to contain around 2,670 tonnes of refrigerants, or about 4.5% of the total bank, of which approximately 83% (1,900 tonnes) is HFC-134a, with the balance (380 tonnes) being hydrocarbons.

This is projected to change relatively quickly to effectively reverse that situation by 2030 with a larger stock of domestic devices expected to operate on a bank more than 25% smaller at around 1,700 tonnes, of which more than 91% is hydrocarbons and the balance a rapidly declining bank of just 145 tonnes of HFC-134a.

This class is a good example of how quickly the composition of the bank can change, when the technological and market circumstances align. In this case domestic refrigeration and freezer manufacturers, who have been continuously improving designs and cutting production costs in a highly competitive market for more than 70 years, realised that energy efficiency gains and cost savings were available by moving to small hydrocarbon charges. This is a trend that has been underway for more than a decade and is now almost universal in this class with more than 95% of products sighted in a large white goods retailer in 2017 being charged with hydrocarbons.

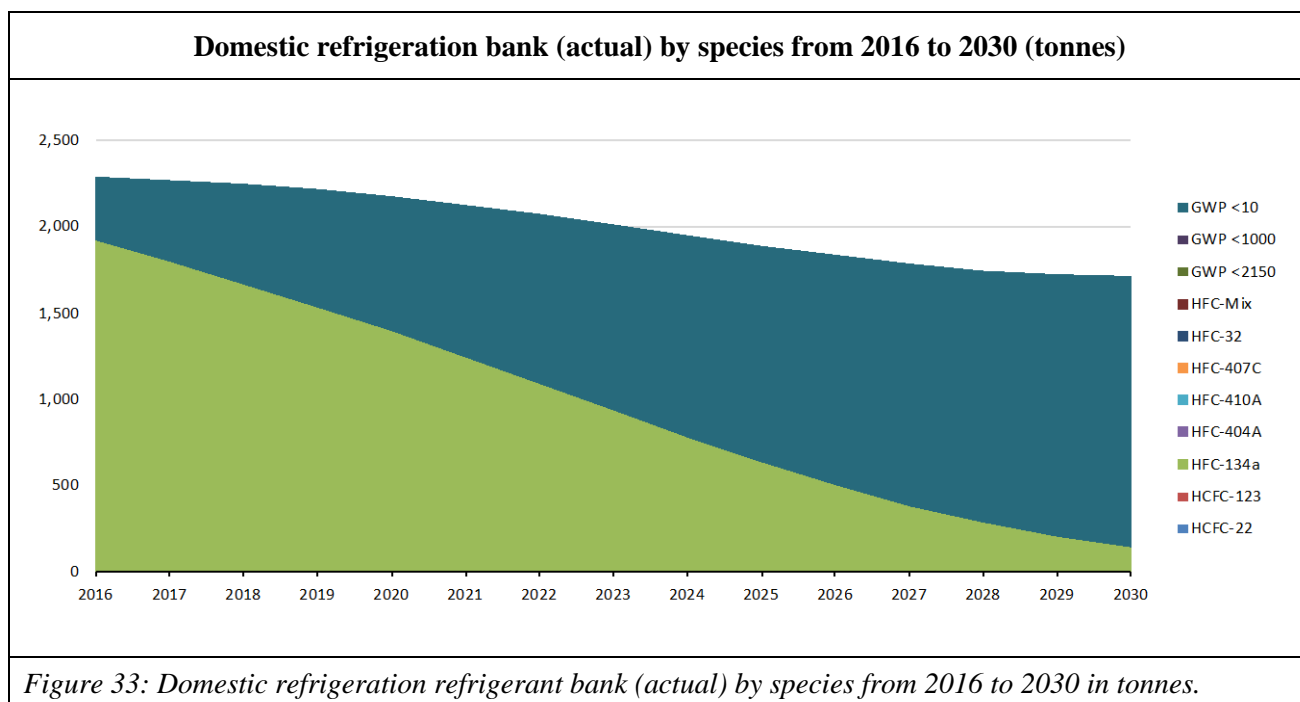


Figure 33: Domestic refrigeration refrigerant bank (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

The energy efficiency improvements provided by hydrocarbons in this situation are illustrated by comparing the two charts provided showing the ‘actual’ bank (above) in metric tonnes of total refrigerant employed in this class, and the ‘equivalent bank’ (below), that illustrates how much refrigerant would have been required had HFC-134a, and hydrocarbons, shared an identical capacity to deliver cooling. Energy savings are captured in HC charged systems because the substance used is better at transporting heat, and therefore less refrigerant is needed, meaning there is physically less material required to be pumped around the system.

The equivalent bank to provide domestic refrigeration services in 2030, if it had all been provided with HFC-134a, or a refrigerant with the characteristics of HFC-134a, would be more than 58% larger than the projected actual bank, requiring more than 1,200 more tonnes of refrigerant than the projected actual bank to deliver the same level of services that the hydrocarbon bank will be delivering.

At the same time as providing significantly improved energy efficiency and reduced production costs, the result of this comprehensive shift from a HFC refrigerant to a hydrocarbon refrigerant reduces the CO₂e value of this bank by more than 90% in the projection period from more than 2.7 million tonnes CO₂e in 2016 to just 0.21 million tonnes CO₂e in 2030.

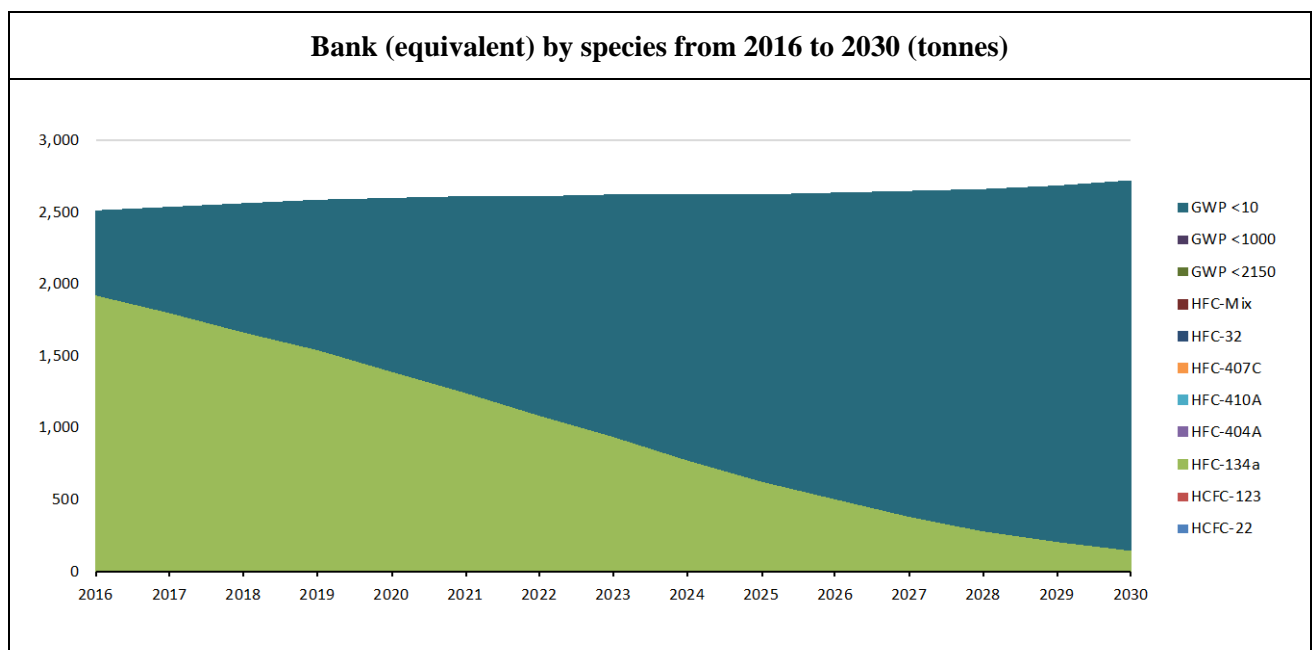


Figure 34: Refrigerant bank (equivalent) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

Domestic refrigeration is a technology that has benefited from decades of design improvements, in part driven by regulatory efforts to drive energy efficiency improvements. This class of equipment does not require a large refrigerant charge in individual devices (average 55 grams of HC), which means the flammability issues of hydrocarbons are mitigated. This example illustrates the important relationship between refrigerant type, energy use and overall GWP impacts of RAC technology.

8 Refrigerant use and direct emissions

8.1 Refrigerant use

Insight into the volumes of annual use of refrigerant in the Australian economy has been noticeably improved over the course of the last decade and is now informed by a quarterly annual survey of refrigerant wholesalers that provides robust data that can be reconciled against annual bulk imports.

Refrigerant is used for several purposes including:

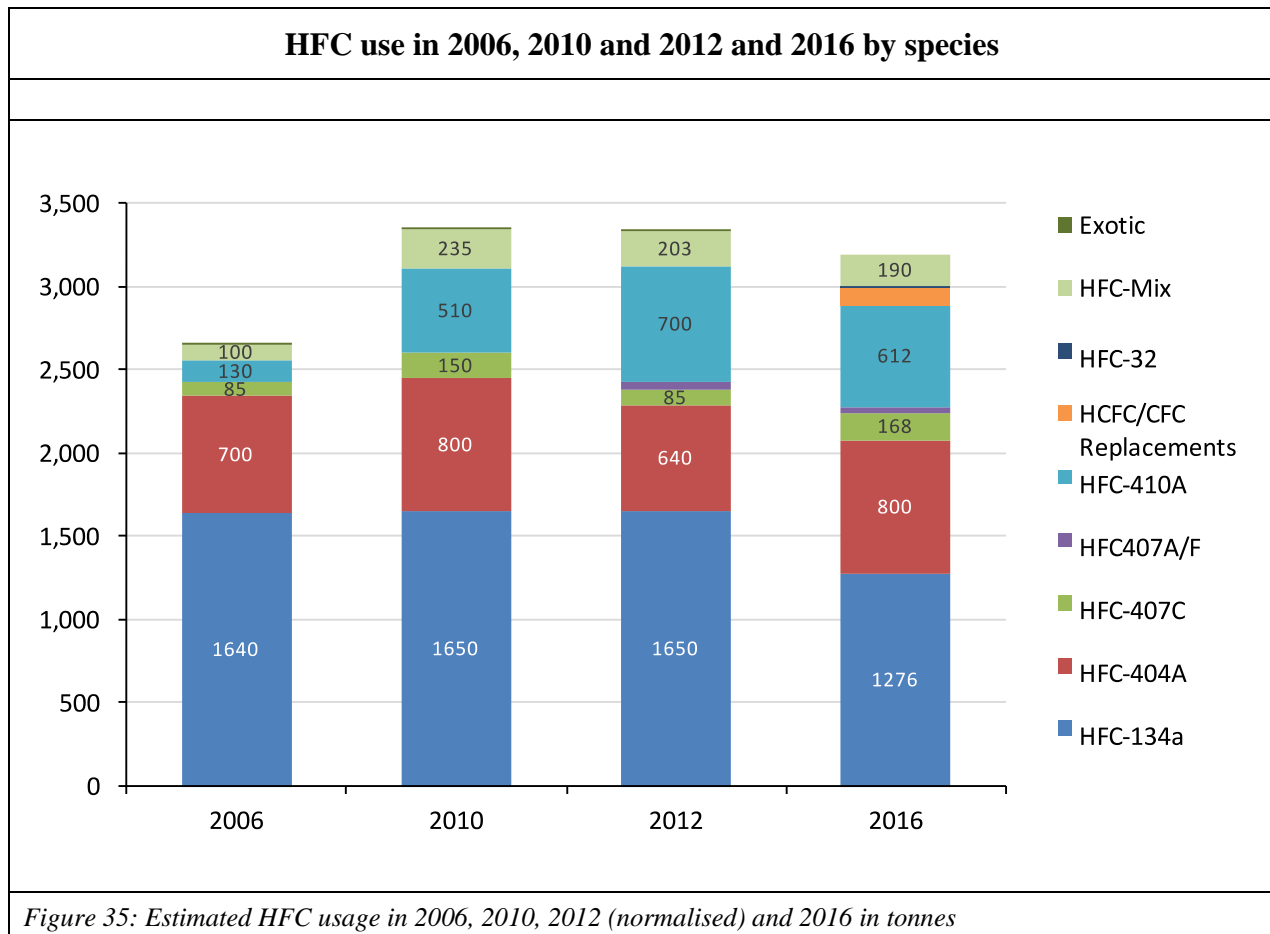
- Local equipment manufacturing, particularly in medium commercial AC, space chillers and refrigerated display cabinets where Australia retains some successful manufacturers;
- Charging or adding to a partial charge for new equipment at point of installation where the device may have been imported without any refrigerant charge (or partial charge), or needs an addition to its pre-charged volume when installed and commissioned;
- Retrofitting existing equipment with a new refrigerant, for instance in cases where equipment originally designed and installed to run on HCFC-22 is able to be retrofitted with drop in replacements⁵⁸. For a period directly after the introduction of the carbon tax HFC-404A was retrofitted with HFC-407F due to the difference in GWPs. Refrigerants such as HFC-448A and HFC-449A are now being considered as retrofit replacements for HFC-404A; and,
- Servicing the stock of equipment to maintain charge levels as a result of leaks or catastrophic losses of refrigerant including handling losses across the supply lines.

The largest demand is for refrigerant used in servicing the stock of equipment. As a result, annual refrigerant use, supplied by bulk imports, only provides a relatively small addition to the overall bank every year as the majority of refrigerant used for servicing equipment is offset by direct emissions from the stock and supply lines.

⁵⁸ HCFC-22/CFC retrofits replacements include HFC-422D, HFC-437A, HFC-417A, HFC-422A, HFC-438A, HFC-426A, HFC-424A, HFC-428A, HCFC-508A, HCFC-508B, HCFC-408A and HCFC-409A.

8.2 Refrigerant usage 2006 to 2016

As a result of studies on refrigerant usage and bulk imports conducted by the authors, four annual snapshots of annual usage are able to be provided in the chart below for 2006, 2010, 2012 and 2016.



Notes:

1. The above chart only includes HFC use and does not include natural refrigerants or HCFCs.
2. Usage estimates in 2006 and 2010 are based on top down (imports) versus bottom up (stock model) reconciliation.
3. 2012 estimates were top down estimates projected from 2011 imports and adjusted to account for industry changes in behaviour (i.e. stockpiling, transition to other refrigerants, recycling, improved containment, etc.).
4. The 2016 estimate is based on actual sales data from Expert Group market intelligence reports in conjunction with the mobile aftermarket survey, plus OEM and HFC-mix usage data provided by industry participants.

Trends identified in CHF2 have continued with usage of all of the main HFC species, except HFC-134a, continuing to grow as HFC pre-charged equipment imports expand the bank and underpin increased service demand for HFCs overall.

A significant rise in pre-charged imports of HFC-410A, and a steady increase in bulk imports of HFC-410A, is testament to the effect of regulations imposing higher energy efficiency standards for small AC, combined with restrictions on HCFC-22 imports. HCFC-22 was once the most widely used refrigerant in stationary air conditioning equipment, however designs for small AC using HCFC-22 found it hard to meet increasing requirements for energy efficiency. New designs that could meet the minimum energy performance standards

and employing HFC-410A were introduced at the start of a decade when Australia saw an average of 1.1 million pre-charged residential and small commercial air conditioning systems imported every year.

The continuing substantial bank of HCFCs is largely still employed in small stationary AC more than in the larger equipment segments, such as chillers and large commercial refrigeration plant, which have been migrating away from HCFCs to HFCs and natural refrigerants in niche applications.

Total HFC-410A imports in PCE, starting from zero in 2002 to 845 tonnes in 2006, rose to more than 1,800 tonnes in 2016⁵⁹, accumulating to 17,100 tonnes over the 11 year period. Adding 40% of bulk imports of HFC-410A over the last five years to account for local manufacturing, and ignoring retirements, equates to a bank of at least 18,300 tonnes in 2016.

This demonstrates how the growth in the bank of HFC-410A was largely driven by imports of equipment pre-charged with HFC-410A, which then in turn establishes long term demand for bulk refrigerant imports to service the stock of equipment.

During this period from 2006 to 2012 the usage of HFC-134a, by far the most commonly used HFC, maintained a steady trend of around 1,650 tonnes over that period. Following changes in market behaviour, primarily improved containment, arising from the equivalent carbon tax, and the decline in OEM usage, the five year average of bulk imports is 15% lower at 1,400 tonnes per annum with usage estimated at 1,276 tonnes in 2016. Various economic and technological trends capped demand for bulk HFC-134a imports, including the closure of Australian vehicle manufacturing, and the closure/move off-shore, and transition to the use of hydrocarbons manufacture of domestic refrigeration (i.e. Electrolux and Fisher & Paykel) and refrigeration display cases (i.e. Orford Refrigeration and Frigrite Refrigeration).

Following a steady decline in domestic manufacturing capacity since the turn of the century, manufacturing of commercial AC has remained fairly stable since 2010. *Table 25* provides the HFC and HCFC use estimate by species in 2016.

⁵⁹ Pre-charged equipment imports of HFC-410A from 2006 to 2016 were 845; 1,182; 1,375; 1,348; 1,964; 1,687; 1,656; 1,718; 1,723; 1,821; and, 1,805 tonnes (DoEE 2017a).

Table 25: High GWP refrigerant use in domestic OEM in 2016 in tonnes.

Species	Usage (tonnes)
HCFC-22 ⁽¹⁾	255
HFC-134a	1,276
HFC-404A	800
HFC-407C	168
HFC-407A/F	33
HFC-410A	612
HCFC/CFC Replacements	99
HFC-32	16
HFC-Mix	190 ⁽²⁾
Total	3,449

1. Maximum imports for 2016 are capped at 2.5 ODP tonnes, which equates to 45.5 metric tonnes of HCFC-22. The additional 210 tonnes refrigerant has been reclaimed to AHRI 700 standard and resold. There would be additional HCFC-22 recovered by contractors and re-used.
2. Majority comprises used in foam and fire protection applications as well as 24 tonnes of HFC-125 that could be used in refrigerant blends.

Since 2012 the introduction of HFC-32 into small stationary AC has had the effect of capping growth in HFC-410A, while HFC-32 PCE imports have started to become a noticeable and rapidly increasing portion of the bank.

The HFC-32 bank has grown from zero in 2013 to 1,040 tonnes by the end of 2016 and is approaching the tonnage of HFC-407C with 1,340 tonnes in 2016. This trend is predicted to accelerate with PCE charged with HFC-410A expected to level off before declining in the five years ahead as HFC-32 and other alternatives are adopted by more equipment manufacturers and accelerate their growth in the bank.

A very small proportion (<2%) of bulk imports are used in applications that are not refrigeration or air conditioning and do not form part of the refrigerant bank, such as in fire protection systems and in aerosols.

Additionally, it is estimated that around 100 to 120 tonnes of HFCs are re-exported, mostly in shipping vessels and in pre-charged equipment (i.e. ~30 tonnes in 50,000 motor vehicles in 2016, plus some stationary AC). This value will decline with the closure of local automotive manufacturing.

8.3 Refrigerant use projection from 2016 to 2030

In 2016 usage was approximately 3,535 tonnes of HCFCs and HFCs, plus around 770 tonnes of natural refrigerants (577 tonnes of ammonia, 120 tonnes of CO₂ and 72 tonnes of HC).

This use of HCFCs and HFCs is projected to decline by almost 24% to around 2,700 tonnes of refrigerants in 2030. Overall refrigerant usage is projected to increase over the projection period with HFOs and natural refrigerants accounting for the growth.

In line with the decrease of the CO₂e value of the bank, and direct emissions, the CO₂e value of refrigerants used is expected to drop by more than 47% from around 8.0 million tonnes CO₂e, to around 4.2 million tonnes CO₂e in 2030.

As annual refrigerant use is largely for servicing equipment, it includes some amount of every type of refrigerant in the economy.

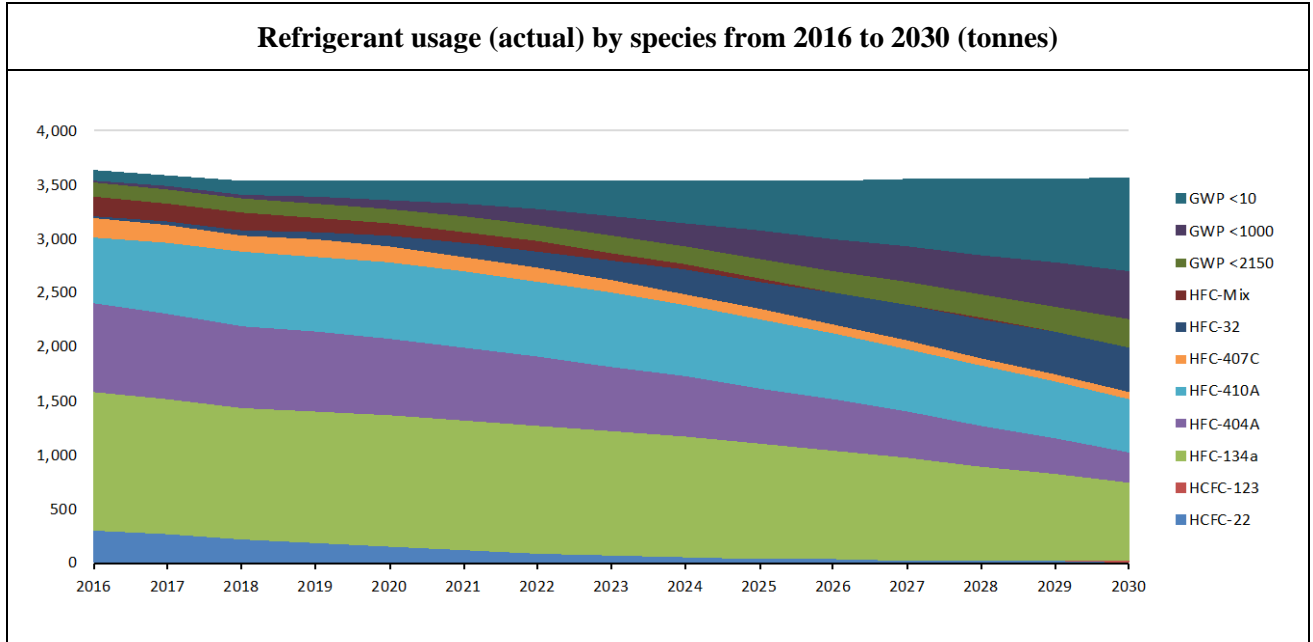


Figure 36: Refrigerant usage (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

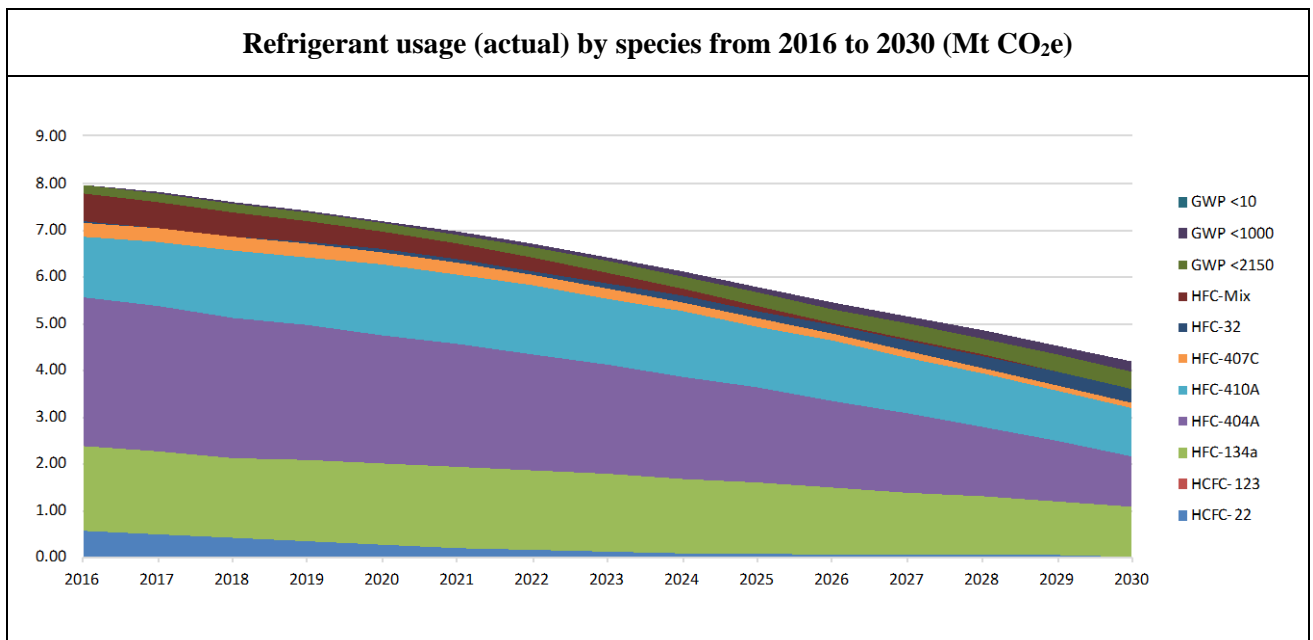


Figure 37: Refrigerant usage (actual) by species from 2016 to 2030 in Mt CO₂e.

(Source: CHF3 RAC Stock model)

As older equipment tends to leak more than new equipment, to some extent annual usage is a lagging indicator of the nature of the stock of equipment and the composition of the bank.

For instance, while HFC-32 has increased its share of the bank to more than 1,000 tonnes in just the few years prior to 2016, annual usage of HFC-32 is estimated to have been less than 16 tonnes (including filling supply lines) in that year as this refrigerant is employed in an entirely new stock of equipment.

At the same time, while there were only approximately 45 tonnes of bulk imports of HCFC-22 in 2016, it is estimated that more than 500 tonnes are required to service the HCFC-22 bank of more than 8,500 tonnes in aging equipment. In reality the service volume is much less and estimated to be around 300 tonnes as some equipment is retired instead of being serviced. In the years 2016 and 2017, the total amount of recovery and reclamation of HCFC-22 in the economy back to virgin refrigerant specification was 210 tonnes. Higher leak rates in the older generation of equipment charged with HCFC-22, and accelerated rates at which this equipment is being taken out of service means that this bank is declining rapidly, with recovery and recycling of HCFC-22 predicted to fall to less than 50 tonnes in 2025 and to just 10 tonnes in 2030.

Notably HFC-32 is projected to be the only HFC in which annual usage increases by the end of the period, rising from near zero to more than 420 tonnes by 2030. Annual usage of all of the other HFCs is expected to decline significantly by the end of the period as the impacts of the HFC phase-down accelerate a predicted shift away from high GWP HFCs across all classes of equipment. Reductions in annual usage predicted include:

- HFC-410A, reflecting the relative young stock of equipment it is contained in, the lack of alternatives for some HFC-410A applications, and presently servicing the largest portion of the bank, falling 19% from its 2016 estimate of nearly 615 tonnes to stay stubbornly high at more than 500 tonnes in 2030;
- HFC-134a, presently servicing the second largest portion of the bank by species, falling by 43% from a 2016 high of 1,285 tonnes to a 2030 estimate of 730 tonnes;
- HFC-404A falling by 65% from just under 810 tonnes in 2016 to around 280 tonnes in 2030;
- HFC-407C falling by more than 61% from 160 tonnes in 2016 to just 60 tonnes in 2030;
- HFC mixes for specialist applications falling more than 64% from 170 tonnes in 2016 to just 60 tonnes in 2030.

These falls are projected to be matched by significant rises in use of non-HFC and low or zero GWP (GWP<10) refrigerants following the lead of changes in the composition of the bank.

The model also suggests a 30 fold rise in refrigerants with GWPs<1000 due to the low starting base, not including HFC-32. These medium GWP refrigerants are expected to be HFO/HFC blends, some of which are already in the market and many of which are being tested, which, it is expected, will allow retrofitting of older equipment and charging of new equipment with high performance refrigerants containing a small fraction of the HFCs presently employed to do the same task.

8.4 Service rates

The CHF3 RAC Stock model has been developed since CHF2 with the intention of better representing mass flows of refrigerant in the supply lines, and into and out of the stock of equipment. Earlier models attempted to reconcile bulk imports, with leak rates from the stock of equipment, and inherently assumed that 100% of the refrigerant lost from equipment was replaced over the life of the equipment. However, as data improved this assumption was undermined by observations of partial residual charges left in various types of equipment when it was removed from service.

This suggests only part of the refrigerant lost from operating equipment is replaced in its service life. Across a stock this might manifest as some pieces of equipment being well maintained, and kept at optimal charge, and other equipment being very poorly maintained and operating on very sub-optimal partial refrigerant charges for much of its service life.

These observations are further supported by reports from field technicians of the condition of equipment that they are called in to service, or repair in the case of break downs.

While this assumption was based initially on observations of partial operating charges, or partial residual charges left in equipment at the end of its service life, it also easily passes the so called ‘pub test’⁶⁰. Anecdotal reports are easy to find about how infrequently home owners, or car owners, or indeed business owners, might get their equipment serviced, whether it is a domestic refrigerator, a residential air conditioner, the car air conditioning or glass fronted display refrigerator at the local deli or supermarket.

Some product categories lose less refrigerant over their service life than others, such as domestic refrigeration as compared to truck refrigeration units as two extremes, and some enjoy a much greater degree of service than others, such as supermarket systems and large commercial chillers that are generally closely monitored and maintained, as compared to residential and small business air conditioners.

Working back from the remaining refrigerant charge when a piece of equipment is taken out of service, applying a theoretical leak rate to the product, and knowing the year that the equipment entered into service, a model of its likely refrigerant charge at any point in its service life can be created. This modelling can be extended to the stock of equipment.

Among other improvements a cohort-based model of the stock of equipment has been created to allow variations in leak rates to be introduced for older equipment. As a result of applying variable service rates, and cohort-based leak rates, the model now produces estimates of the expected actual bank contained in a product category at any one time. This development was undertaken based on outcomes of studies into the size of residual charges left in equipment at the end of its useful life.

The bank of refrigerant, analysed in detail in *Section 5*, was calculated on the basis of the service rates applied to various product categories.

The service rate for an equipment segment or product category is the annual rate of replacement of losses of refrigerant from operating equipment, expressed as a percentage of the total possible bank in that stock of equipment. For instance, the service rate for the remote condenser segment of the RCFC class of equipment is calculated to be 15% in 2016. Small MAC is estimated to be around 5%.

The difference between the service rate for a product category, and the leak rate, is the degree to which the bank in that stock of equipment is under serviced or under-charged per annum.

Service rates in some equipment segments are expected to improve over time, as leak rates reduce and designs improve, and a focus on maintenance of an optimal charge becomes more common among equipment owners.

Appendix A: 11.2.11 Bank by product category shows the service rates applied to the 2016 bank by equipment segment, and the 2030 bank by equipment segment.

8.5 Refrigerant leaks

RAC equipment using vapour compression refrigeration, by definition, uses a compressor to transfer refrigerant from an externally located compressor and heat exchanger inside the conditioned space. This is all possible because a refrigerant is employed as a phase change material, moving easily from the liquid phase to the gaseous phase, and in that step, of becoming vapour, essentially absorbing heat from the surrounding space.

The compressors, heat exchangers and pipes through which the refrigerant moves, as either a liquid or a vapour, have to last for years, maintaining the refrigerant in a closed loop, because if the refrigerant is lost, the equipment will eventually not be able to deliver the cooling services. Yet it is physically impossible to seal equipment perfectly, particularly equipment where liquids and vapours are operating at different pressures to air pressure, and where different temperatures inevitably create thermal expansion and

⁶⁰ Australian term, often used by the media, to describe the collective opinion of everyday Australians.

contraction of pipes, valves, connections, seals, and other materials. As a result, some refrigerant is lost to air every year from some of the millions of pieces of equipment that provide cooling services. As a piece of equipment ages, leak rates will gradually increase as materials and components wear and fatigue.

Occasionally a piece of equipment will experience a ‘catastrophic loss’. This occurs when some element of the containment of the refrigerant fails, such as when a compressor blows a seal, or a pipe or capillary fractures. These catastrophic failures are sometimes the result of material or component fatigue, and sometimes the result of human error, impact or vibration. There are classes of equipment in which this happens more often, particularly in the harder working equipment in the harsher environments such as in transport refrigeration systems that are subject to vibration and in remote condenser systems around cool rooms in warehouses and farm sheds.

Refrigerant is also lost to air at various points along the supply lines to end users, although the businesses involved in importing, decanting, distributing and selling refrigerant have a strong vested interest in minimising those losses. There are also likely to be refrigerant losses when equipment is first installed and later serviced.

All these losses, along the supply line, during installation, commissioning and servicing, and during lifelong operation, are defined as direct emissions, and sometimes also just referred to as ‘leaks’. This boundary of direct emissions does not include refrigerant lost from equipment that has been removed from service and discarded. End-of-life (EOL) equipment and end-of-life losses are calculated separately.

Direct emissions from most product categories increase more slowly than the stock of equipment itself over the life of the projection as two long term trends continue to drive improvements in equipment performance. RAC equipment performance relies on effective refrigerant containment. As a result, improvements in design, manufacturing methods, materials selection and installation and maintenance procedures in the field have, over the past several decades, improved containment and reduced leaks from all refrigerating equipment. Leak rates are not uniform across product categories, or even across various generations of equipment within product categories, but overall leak rates are seen to be steadily reducing.

Secondly the refrigerant charge size in many products is steadily being reduced by improved design and higher efficiency components, such as improved heat exchanger efficiency and design. Coupled with lower loss rates, this trend reduces direct emissions during operation, and even in the instance of catastrophic losses, because equipment simply has less refrigerant to lose (e.g. small AC charged with HFC-32).

Appendix A: 11.2.11 Bank by product category lists the theoretical leak rates, average charge, end-of-life factors and average lifespans for all the product categories in 2016. Refer *Table 38: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan) for most common substance*.

8.6 Direct emissions estimates and projections

The CHF3 RAC Stock model estimates that in 2016 more than 2,955 tonnes of HCFCs and HFCs were lost to air as a result of leaks from the supply lines and operating equipment. This implies an average leak rate across the entire refrigerant bank of around 5.8% per annum, although the leak rates in the model vary greatly across all of the equipment categories, from 1% per annum for domestic refrigeration to as much as 15% in some segments of the refrigerated cold food chain, such as in transport refrigeration units.

It should be noted that direct emissions do not include losses of refrigerant from equipment at the end of its working life. This value is calculated separately because the economic, regulatory and work place practices that might be effective in collecting refrigerant gas from EOL equipment are very different from the measures that can be taken to reduce losses from operating equipment. EOL emissions are discussed in *Section 8.7*.

The direct emissions projections include HCFC-22 and HCFC-123 to demonstrate the diminishing presence of these substances. They are not counted as part of the GHGs reported under the Kyoto Protocol or United Nations Framework Convention on Climate Change, as they are managed through the Montreal Protocol.

By 2030 the direct emissions of HCFCs and HFCs are expected to decline slightly to just under 2,910 tonnes from the much larger bank implying an improved average leak rate across the entire stock of equipment at that time of around 4.96% of the HCFC and HFC bank. Note that the bank in 2030 is projected to have a much lower GWP.

Direct emissions in 2016 are calculated to be equivalent to just under 6.4 million tonnes of CO₂e (CHF2 5.4 million tonnes). While the absolute quantum of refrigerant losses is expected to rise throughout the projection period, the CO₂e value of direct emissions is expected to fall by more than 27% in the period, to 4.7 million tonnes CO₂e in 2030. Given the total bank in the period, and the total stock of equipment, is expected to expand steadily, reducing the CO₂e value of losses is a good outcome. Even so, total aggregate direct emissions over the course of the 14 year projection are still expected to be nearly 94 million tonnes CO₂e.

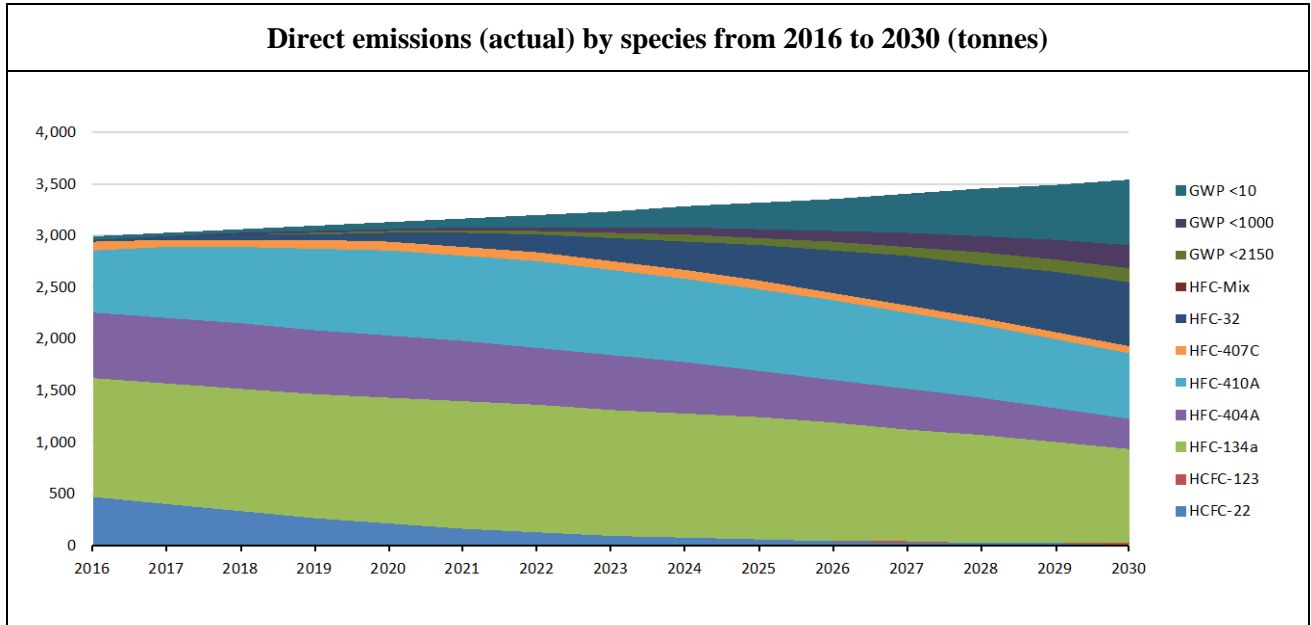


Figure 38: Direct emissions (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

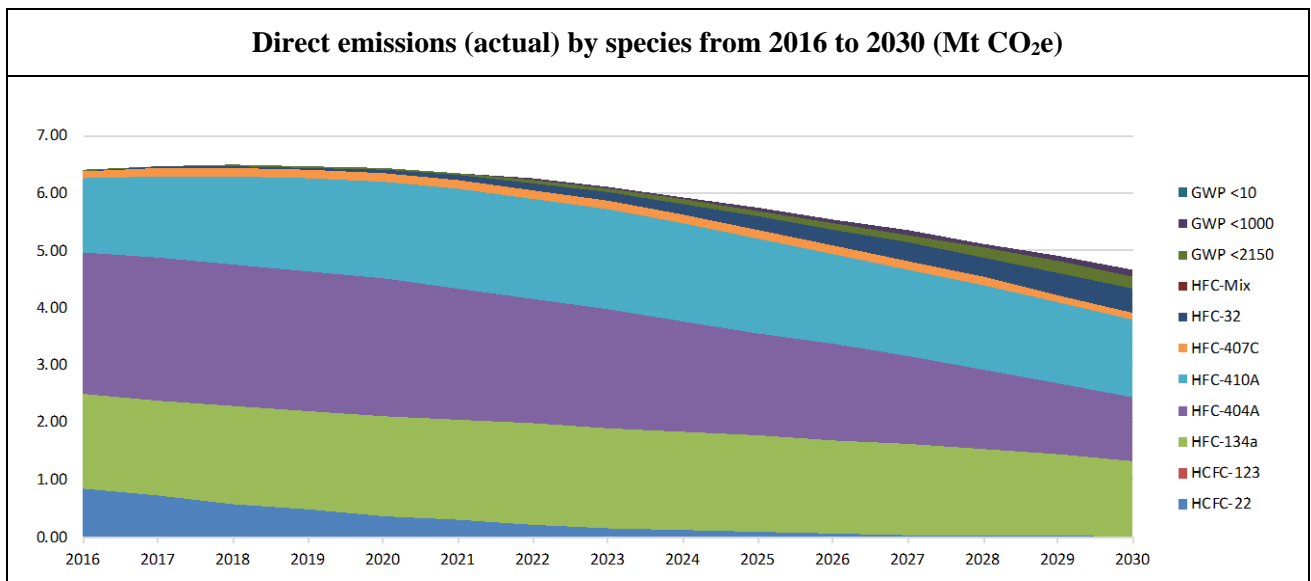


Figure 39: Direct emissions (actual) by species from 2016 to 2030 in Mt CO₂e.

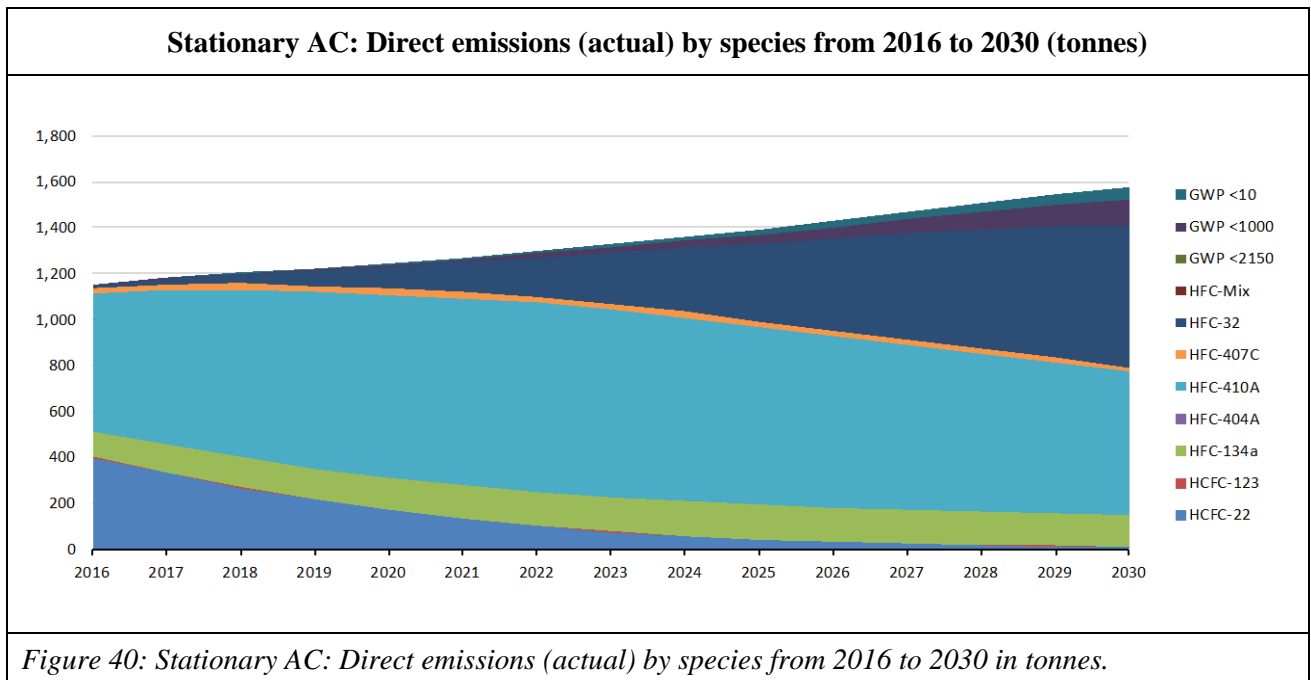
(Source: CHF3 RAC Stock model)

This overall reduction in the CO₂e of annual losses from across the stock of operating equipment is driven by reductions in CO₂e values of direct emissions from almost every major product segment, with few exceptions, even while the absolute tonnes of refrigerant lost to air increases in most categories as the stock of equipment grows.

Of course, the largest class of equipment, stationary AC, also contributes the largest portion of the direct emissions of the entire stock of equipment. Even with the significant shift of small AC to employ HFC-32 charges, stationary AC overall is expected to increase direct emissions of HCFCs and HFCs from around 1,150 tonnes in 2016 to more than 1,525 tonnes in 2030, increasing the overall share of direct emissions of stationary AC from the entire stock of equipment from 34% to more than 43% by 2030.

While decreasing the absolute emissions over the period and reducing the CO₂e value of annual direct emissions from this class from around 2.2 million tonnes of CO₂e to 2.0 million tonnes CO₂e, stationary AC increases its overall contribution to the CO₂e value of losses to air from RAC, rising from 34% of the total in 2016 to more than 43% in 2030.

This is despite the expected move to HFC-32 charges in new small AC, and adoption of HFOs in some chillers and larger classes of equipment. Direct emissions from the medium AC split and light commercial segment grow from about 426 tonnes in 2016 to more than 750 tonnes in 2030 with an increase in the CO₂e value of emissions from this segment from around 0.84 million tonnes CO₂e in 2016 to nearly 1.3 million tonnes CO₂e in 2030. This growth is part of the reason stationary AC increases its overall share of CO₂e emissions at the end of the projection period. By 2030 emissions from the medium AC segment make up more than 27% of all direct emissions on a CO₂e basis, up from 14% in 2016.



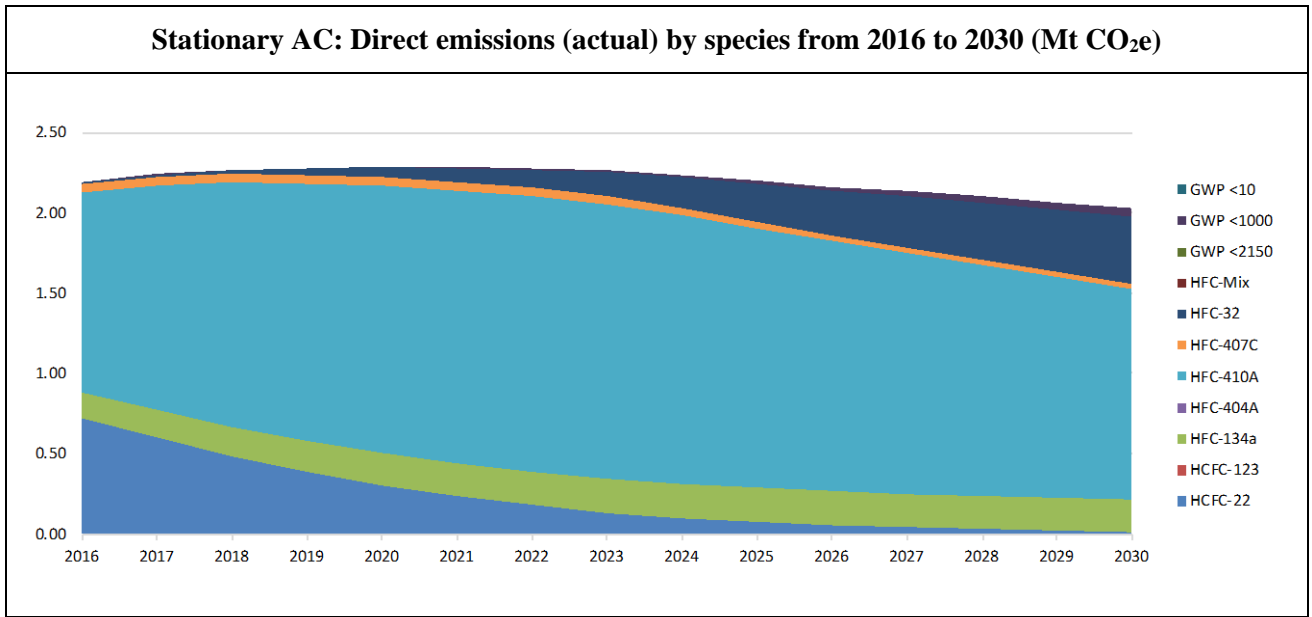


Figure 41: Stationary AC: Direct emissions (actual) by species from 2016 to 2030 in Mt CO_{2e}.

(Source: CHF3 RAC Stock model)

Even while the vehicle fleet is expected to grow substantially, as a result of the planned adoption of HFOs by vehicle manufacturers small MAC is expected to reduce its contribution to direct emissions by more than 28% from a 2016 estimate of more than 1.1 million tonnes CO_{2e} to around 800,000 tonnes CO_{2e} in 2030. This results in an overall decline in direct emissions from MAC of more than 24%, even while losses from large MAC rise slightly from around 122,000 tonnes CO_{2e} to 134,000 tonnes CO_{2e}.

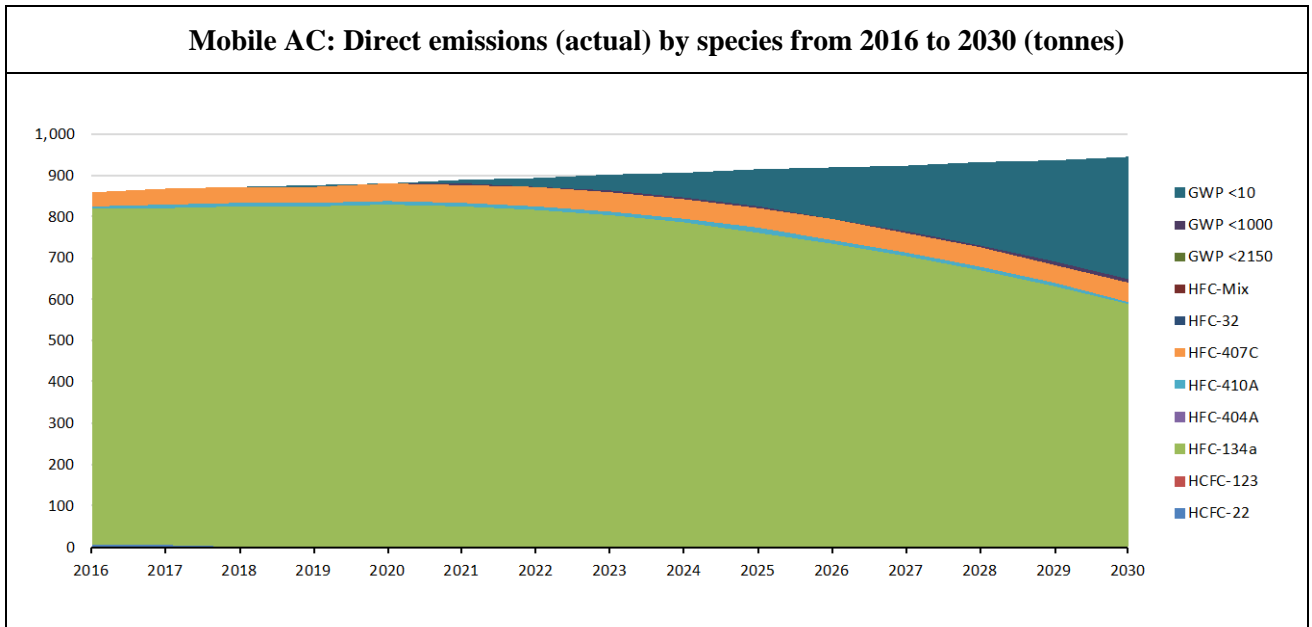


Figure 42: Mobile AC: Direct emissions (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

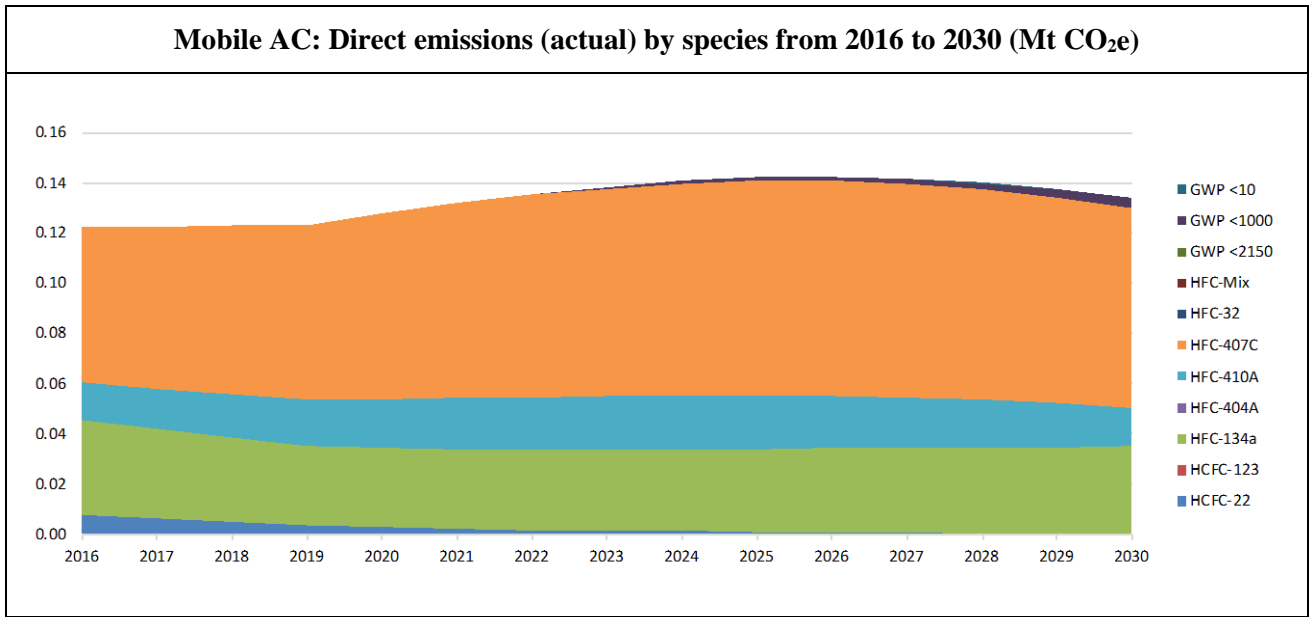


Figure 43: Mobile AC: Direct emissions (actual) by species from 2016 to 2030 in Mt CO₂e.

(Source: CHF3 RAC Stock model)

A number of equipment categories show steep declines in the CO₂e value of their direct emissions as a result of being able to migrate to low or zero GWP refrigerants (GWP<10). For instance, the entire class of domestic refrigeration, with its simple bank comprising just two refrigerant species, is already well advanced in moving to hydrocarbons, and away from HFC-134a.

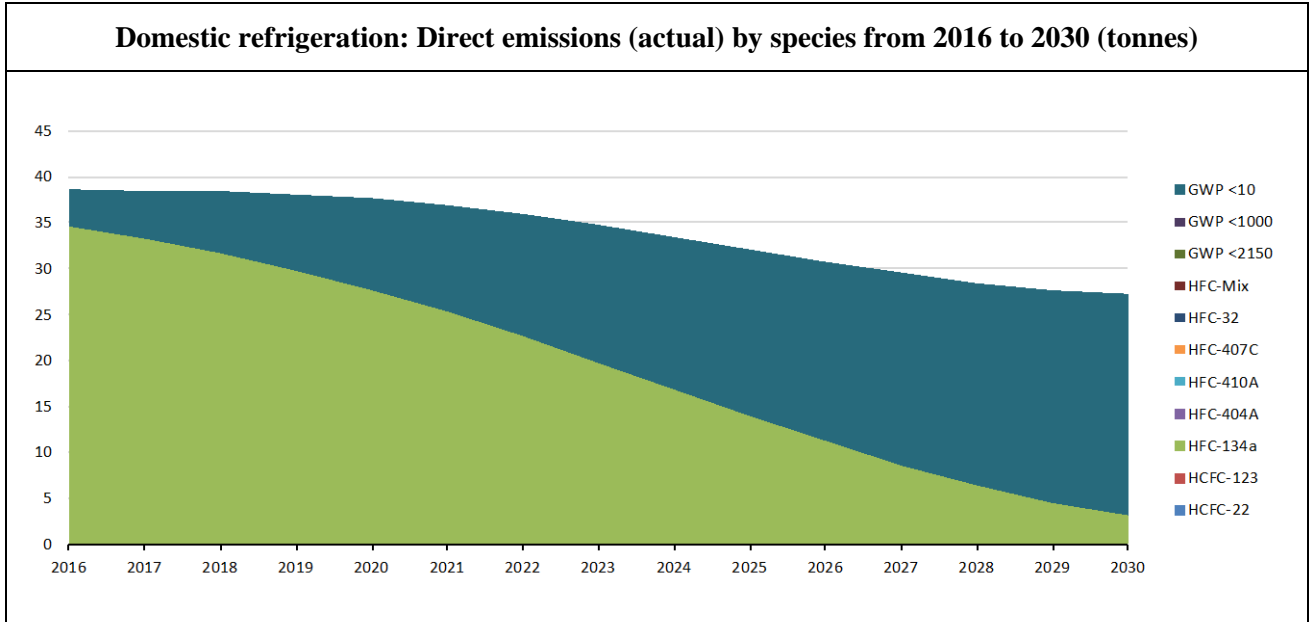
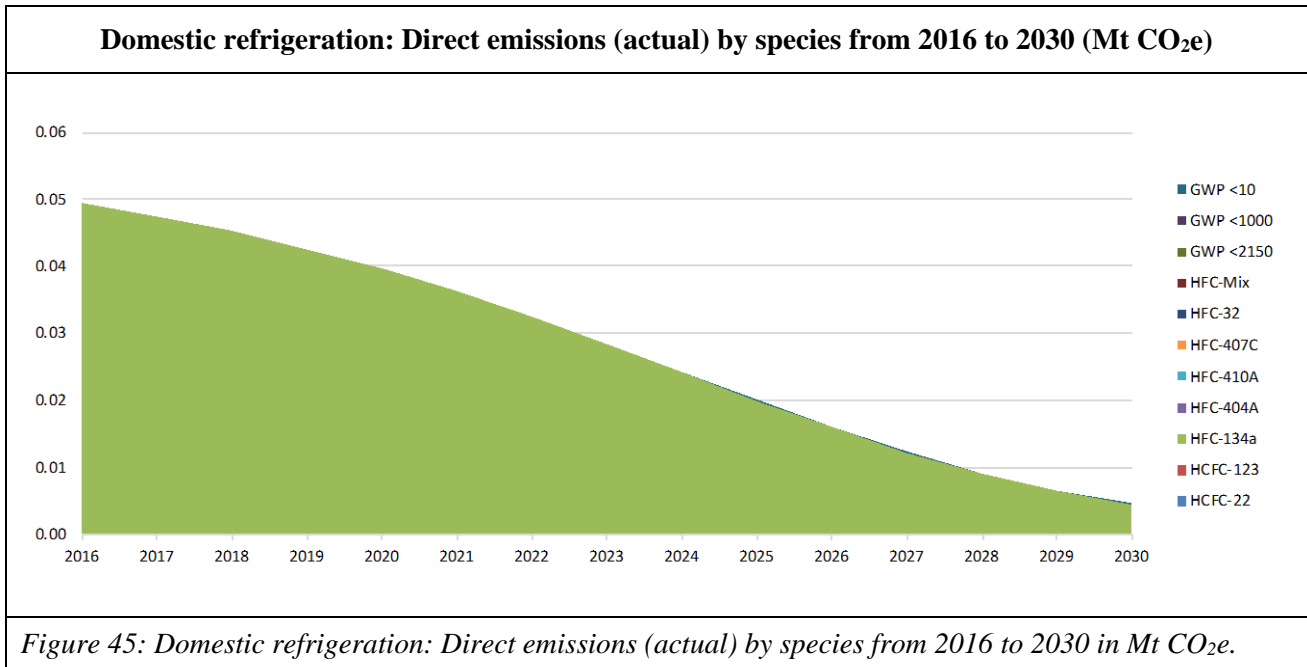


Figure 44: Domestic refrigeration: Direct emissions (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)



(Source: CHF3 RAC Stock model)

The refrigerated cold food chain is the hardest working and traditionally the leakiest class of all RAC equipment. However, some segments show solid improvements over the period.

Supermarkets are projected to cut their direct emissions by more than half from a 2016 estimate of more than 720,000 tonnes CO₂e to less than 350,000 tonnes CO₂e by 2030.

Annual direct emissions of HCFCs and HFCs in the RCFC decrease by about 20% over 2016 with an estimated 735 tonnes of annual losses as compared to about 910 tonnes of losses in 2016. Adoption of lower GWP refrigerants across the class helps lead the entire RCFC class to reduce the CO₂e value of annual losses by more than 42% from a 2016 estimate of 2.9 million tonnes CO₂e to a 2030 estimate of around 1.7 million tonnes of direct emissions. While only comprising 14% of the total bank in 2016, (as has always been the case from the huge stock of varied equipment across the hard working refrigerated cold food chain) the RCFC class is the second highest contributor to direct emissions of all RAC equipment. The RCFC class is forecast to contribute nearly 36% on a CO₂e basis to total emissions in 2030 down from nearly 46% of direct CO₂e emissions in 2016.

Even the leakiest products in the RCFC class, remote condenser systems, are estimated to reduce HCFC and HFC refrigerant losses by around 11% in the period, from around 640 tonnes in 2016 to more than 570 tonnes in 2030. The CO₂e value of losses in remote condensers fall by almost 39% from around 2.1 million tonnes CO₂e in 2016 to around 1.3 million tonnes CO₂e by 2030. Even with these gains, direct emissions from remote condenser units will make up nearly 28% of all direct emissions in 2030. On a CO₂e basis, this is almost equal to the medium AC segment, the largest single contribution of any equipment segment in 2030.

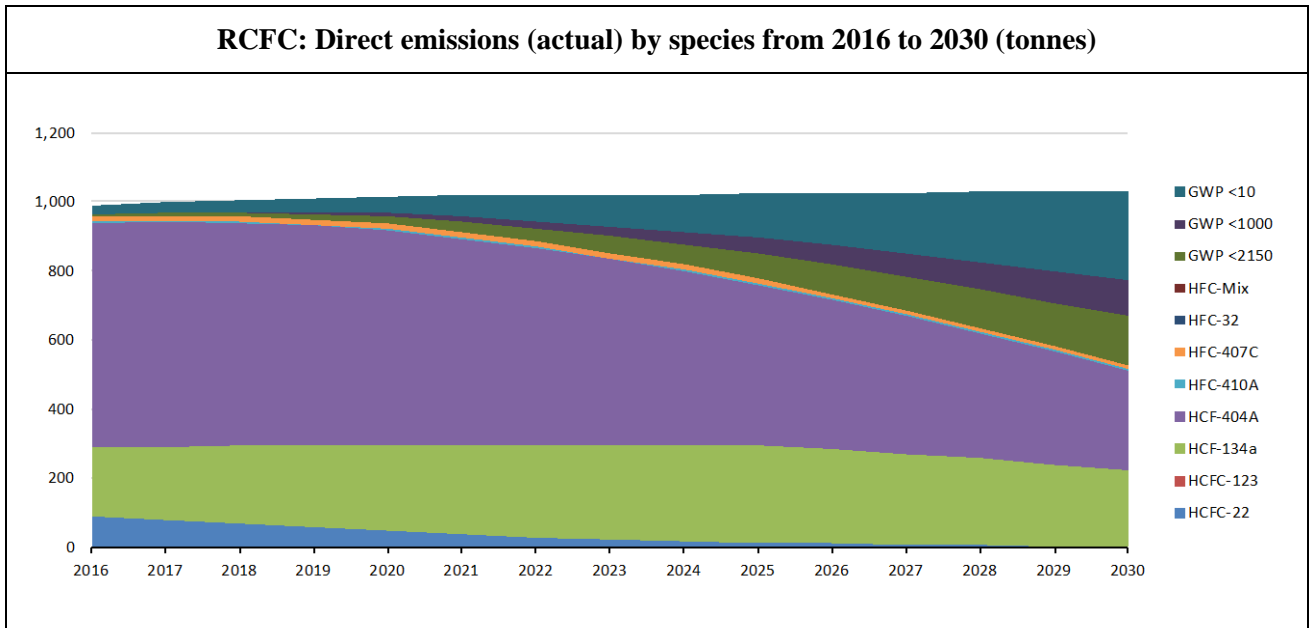


Figure 46: RCFC: Direct emissions (actual) by species from 2016 to 2030 in tonnes.

(Source: CHF3 RAC Stock model)

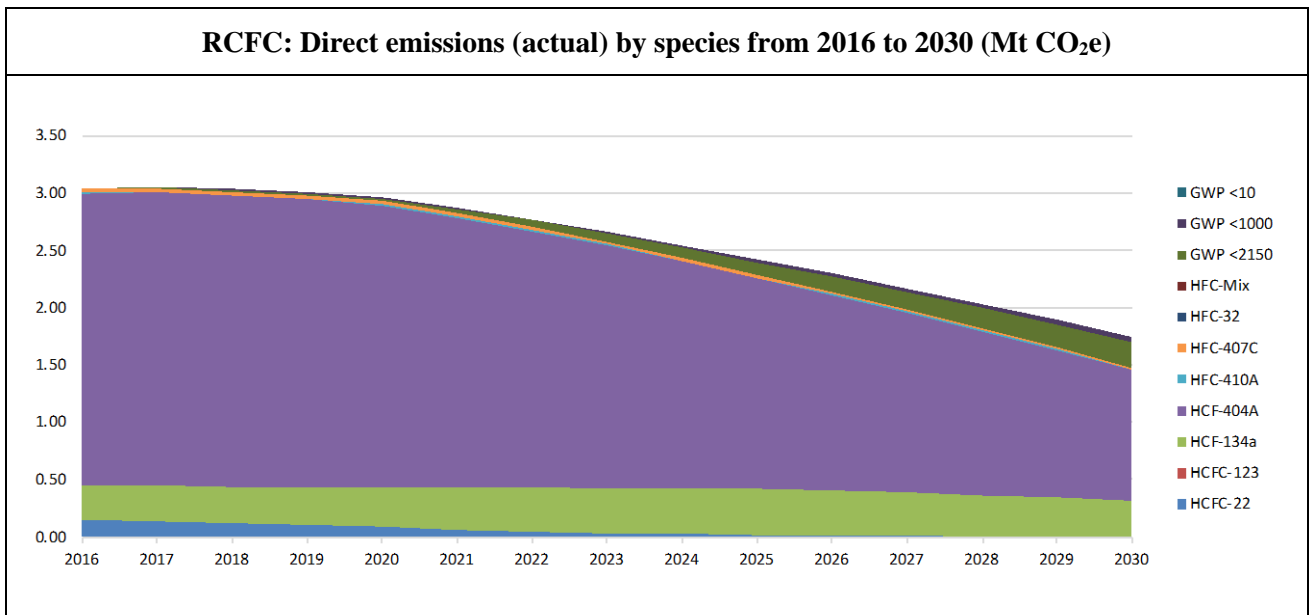


Figure 47: RCFC: Direct emissions (actual) by species from 2016 to 2030 in Mt CO₂e.

(Source: CHF3 RAC Stock model)

8.7 End-of-life emissions and refrigerant recovery

8.7.1 End-of-life emissions

End-of-life (EOL) emissions calculations are a product of the model, which calculates the refrigerant charge remaining in equipment when it is removed from service by applying the average leak rate to a product category, multiplied by the expected average life of the equipment, and by the expected service rate throughout the equipment life. All refrigerant calculated as remaining in a piece of equipment at the end of

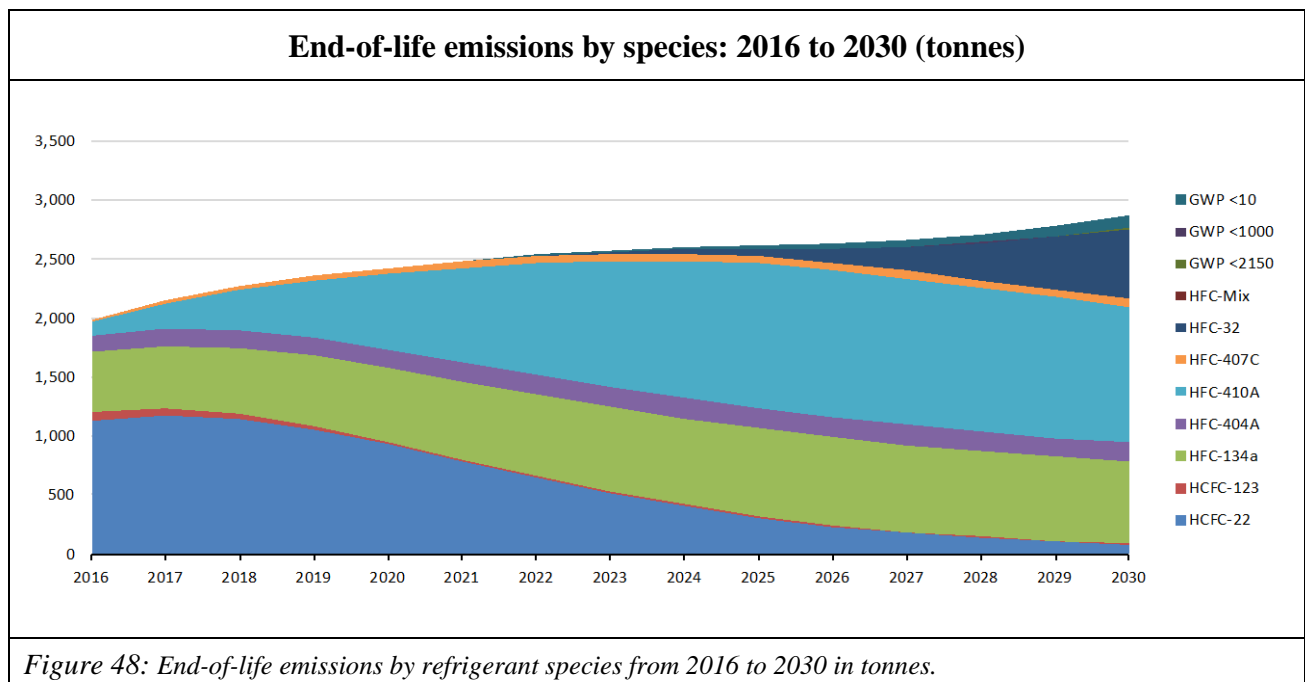
its average service life (EOL charge percent multiplied by original charge) is counted as being released in that year.

The projections of end-of-life emissions include HCFC-22 and HCFC-123 to demonstrate the presence of these substances. They are not counted as part of the GHGs reported under the Kyoto Protocol or United Nations Framework Convention on Climate Change, as they are managed through the Montreal Protocol.

For some product categories the model relies on several pieces of data from industry and previous studies by the authors that provide insight into likely average charges remaining in various equipment types at the end of their useful life. For instance, the likely refrigerant charge remaining in the average passenger car is estimated to be two thirds of the original charge, however the same cannot be said for many classes of stationary AC, where field work has been limited.

Total EOL emissions across the stock of retiring equipment is reduced by the refrigerant reported as being recovered and destroyed every year. In addition, there was 210 tonnes of HCFC-22 reclaimed to AHRI 700 standard (i.e. virgin refrigerant specification) and resold in 2016 and 2017. A further small reduction from total estimated EOL emissions is made for unreported HCFC recoveries for reuse.

The CHF3 RAC Stock model estimates that EOL emissions totalled more than 1,990 tonnes of all types of refrigerants, equivalent to more than 3.6 million tonnes of CO₂ (CHF2 1,700 tonnes, 2.7 million tonnes CO₂e). These emissions are expected to grow throughout the projection period, in both absolute and CO₂e terms, with EOL losses of HCFCs and HFCs in 2030 estimated to have grown by nearly 45% to more than 2,760 tonnes. The growing retirements present both stewardship risks and opportunities for industry and government regulators.



(Source: CHF3 RAC Stock model)

Notes:

1. The CHF3 RAC Stock model assumptions include an EOL and technical recovery percent for each segment.
2. The model assumes EOL profile includes warranty period generally for 5 years then follows a linear decline from 100% charge in year five to EOL percent of original charge at retirement.

Just as bulk imports, weighted as they are towards the service demands of the older and leakier portion of the stock of equipment, are something of a lagging indicator of the make-up of the bank, so too are EOL equipment emissions a lagging indicator of the stock.

As such it is no surprise that more than 56% of EOL emissions in 2016 were estimated to be more than 1,100 tonnes of HCFC-22, as older stationary AC is removed from service. The model projects continuing EOL emissions of HCFC-22 at, or near these levels until 2020, when the decline of HCFC-22 in the bank starts to feed through into a decline in HCFC-22 EOL emissions.

By the end of the projection period HCFC-22 is expected to contribute only 3% of total EOL emissions with HFC-410A growing its share of EOL emissions from around 117 tonnes, or 6% of the total in 2016, to more than 1,150 tonnes, or 42% in 2030. Throughout the period HFC-134a maintains a roughly 25% share of EOL emissions, rising from around 504 tonnes at the start of the period to more than 740 tonnes by 2025 before falling to around 690 tonnes in 2030.

The CO₂e value of the total EOL emissions rises by nearly 40% to reach more than 5 million tonnes of CO₂e per annum in 2024 before declining slowly from that peak to end the period nearly 30% higher at 4.69 million tonnes.

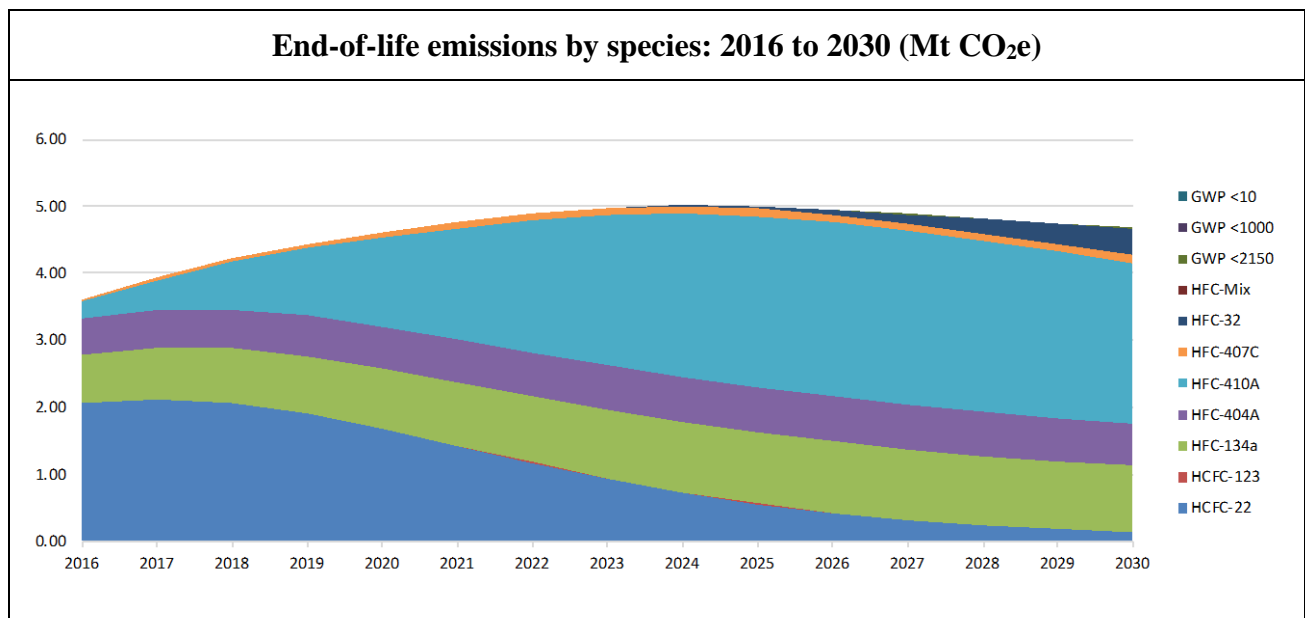


Figure 49: End-of-life emissions by refrigerant species from 2016 to 2030 in Mt CO₂e.

(Source: CHF3 RAC Stock model)

It should be noted that the peak EOL prediction, in CO₂e terms, of 5.02 million tonnes CO₂e in 2024, lags the model's prediction of peak CO₂e of the bank, at more than 102.4 million tonnes of CO₂e in 2019, by just 5 years. This is expected as a result of a mix of factors including the expected rapid decline of HCFC-22 from the EOL mix from around 2021, the effect of smaller charges gradually introduced into the major equipment classes from the early 2000s, flowing through to smaller volumes in EOL equipment in the 2020s, and the effect of the capping of growth of the HFC-134a bank, with the introduction of HCs into domestic refrigeration equipment in the mid-2000s.

Given the predominance in terms of total stock numbers of small split AC in the stock of equipment it is no surprise that the largest source of EOL emissions is from this equipment segment. EOL emissions from small split AC of 576 tonnes, or more than 28% of the total, are expected to rise steadily throughout the projection period by more than 80% to 1,050 tonnes by 2030, or more than 36% of the total EOL emissions at that time. However the changing refrigerants employed result in this segment's contribution to the CO₂e value of EOL

emissions to rise more slowly, increasing around 29% from 1.07 million tonnes CO₂e in 2016 to nearly 1.4 million tonnes CO₂e in 2030, and being roughly equal to 30% of all EOL emissions in CO₂e terms throughout the period.

Other segments of the stationary AC class are also significant contributors to EOL emissions throughout the period with stationary AC overall being responsible for more than 1,235 tonnes of EOL emissions, or more than 62% in 2016, rising to more than 1,950 tonnes in 2030, or more than 68% at that time. In CO₂e terms stationary AC is estimated to produce more than 2.25 million tonnes in 2016, or more than 62% at the time, rising to more than 3.12 million tonnes in 2030, or more than 66% at the time.

8.7.2 Refrigerant Reclaim Australia data

In 2016-17 Refrigerant Reclaim Australia (RRA) collected and destroyed 324 tonnes of waste refrigerant. RRA paid rebates on a further 172 tonnes that was reprocessed to ‘as-new’ specification by others. RRA takes back all recovered refrigerant presented to it by the market and to ensure the long-term viability of the recovery program it is necessary for RRA to carefully forecast returns, budget costs, and calculate the required funding. *Figure 50* provides an illustration of the CFCs, HCFCs and HFCs recovered from 2010 to 2016 and including the 172 tonnes of HCFC-22 that was reclaimed to new specification in 2016. Recovered HCFCs in the early years of the period illustrated are more likely to have been destroyed than recovered for reprocessing.

RRA estimates its recovery effectiveness between 50% and 70%, depending on the volume available for recovery. This is calculated on the estimated volume of refrigerant available for recovery being between 1,700 and 2,550 tonnes, while the range for retention and reuse is between 1,000 and 1,550 tonnes.

The volumetric range used by RRA is consistent with the CHF3 RAC Stock model that estimates EOL emissions totalled more than 1,990 tonnes of all types of refrigerants, equivalent to more than 3.6 million tonnes of CO₂ (CHF2 1,700 tonnes, 2.7 million tonnes CO₂e).

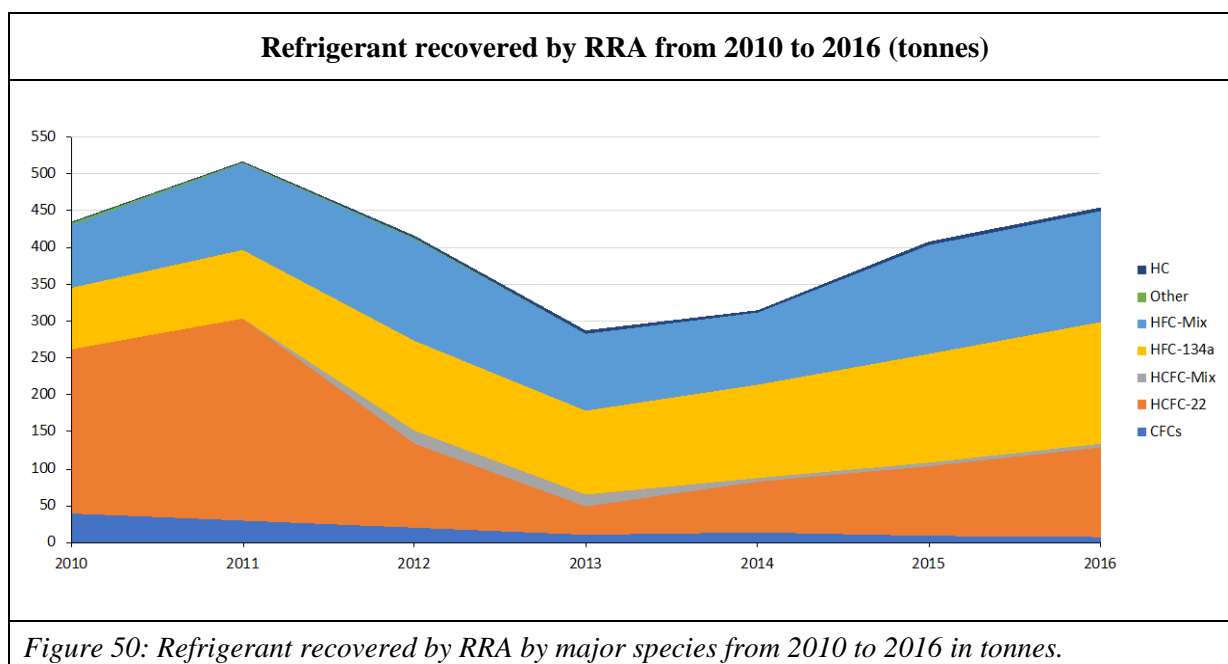


Figure 50: Refrigerant recovered by RRA by major species from 2010 to 2016 in tonnes.

Notes:

1. CFCs includes CFC-11, CFC-12 and CFC115.
2. HCFC-mix is HCFC-124.
3. HFC-mix comprises HFC-125, FHC-32, HFC-143A and HFC-23.
4. The HCFC volumes includes refrigerant reclaimed to new specification.

9 Energy and indirect emissions

9.1 National energy consumption

RAC services are a major consumer of electricity and, given the scale of the stock of equipment employed to deliver cooling services, electricity demand to fuel RAC services is a significant feature of the Australian energy economy.

Based on a 'bottom-up' calculation of electricity use by individual stationary equipment categories the CHF3 RAC Stock model estimates that RAC equipment consumed 61,000 GWh of electricity in 2016 (*CHF2 59,000 GWh*) costing more than \$12.62 billion.

Total RAC electricity consumption in 2016 was equal to slightly more than 23.6% of the 258,000 GWh of electricity production in Australia that year. This is very much in line with the 23.5% of total national electricity production consumed by RAC in 2012. However, at around 251,300 GWh, 2012 total national electricity production was reported as being slightly lower than 2016.⁶¹

Irrespective of the relatively small annual changes to electricity production in the two comparative years, overall electricity consumption by RAC technology increased by around 3.4% as compared to 2012.

The share of electricity consumption by major class of electricity consuming RAC equipment is illustrated in *Figure 51*.

⁶¹ *CHF2* calculated that electricity production, or 'sent-out' electricity in Australia in 2012 was 265,000 GWh, and that total electricity consumed by RAC in that year was equivalent to 22% of all electricity produced. Subsequently Australian energy statistics produced by the Department of Industry for the 2011-12 and 2012-13 financial years indicate that electricity production in calendar year 2012 was around 251,000 GWh, and thus total electricity consumed by RAC in 2012, at 23.5% of all electricity produced, was almost identical to the proportion of national electricity consumption by RAC in 2016 at 23.6%.

Electricity consumption by major class (GWh)

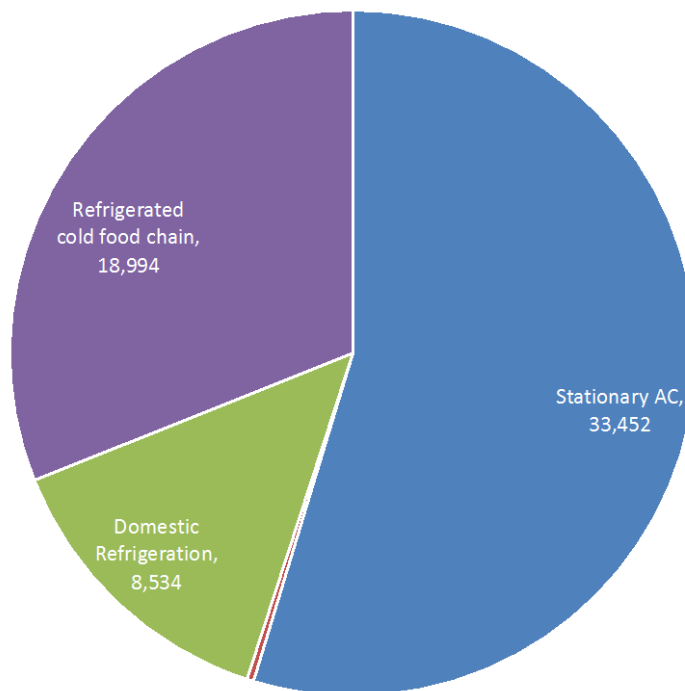


Figure 51: Electricity consumption by class in GWh in 2016.

(Sources: CHF3 RAC Stock model)

Note:

1. The small slice not visible in the above chart is Mobile AC for locomotive and passenger rail.

This break down of energy end use once again shows the dominance of stationary AC in the stock of equipment. CHF3 estimates 33,452 GWh of electricity was consumed in stationary AC applications with some 29% of that portion, or 9,788 GWh in residential applications and 71%, or 23,665 GWh providing air conditioning in commercial and business applications. By comparison, all electricity use in domestic refrigerators and freezers, at 8,534 GWh is now smaller than electricity used in residential AC. Commercial and industrial refrigeration was calculated as consuming around 18,994 GWh in 2016, or roughly 31% of all electricity consumed by RAC equipment in 2016. Total RAC electricity consumption equating to 61,174 GWh includes 193 GWh for air conditioning of locomotives and passenger rail.

Australian Energy Statistics 2017, prepared by the Department of the Environment and Energy (formerly produced by the Bureau of Resources and Energy Economics) provides the official source of energy statistics for Australia to support decision making and help understand how energy supply and use is changing (DoEE 2017b). This edition contains the latest data for 2015/16 financial year, summarised in *Table 26*.

When compared to total electricity consumption in Australia (as opposed to the total electricity production values used above) the numbers are even more notable. Australian electricity consumption, excluding conversion, transmission and distribution losses, was calculated to be approximately 227 GWh in 2015-16.

Table 26: Australian electricity consumption, by end use sector in 2015/16 FY.

End use sector	Electricity consumption (GWh) ⁽¹⁾	Proportion (%)
Residential	59.2	26%
Commercial and services	67.3	30%
Agriculture	1.8	1%
Food, beverages, textiles	6.8	3%
Storage (incl. related transport and services)	2.6	1%
Chemical	4.0	2%
Industrial ⁽²⁾	82.3	36%
Transport (road, rail, air and water)	3.4	2%
	227.4	100%

Notes:

1. The total energy consumed in each end-use sector is equal to total primary energy supply less energy consumed or lost in conversion, transmission and distribution.
2. Industrial includes mining, wood, paper, printing, iron, non-ferrous metals, construction and other industrial processes.

Assuming for the sake of the exercise that electricity consumption for calendar year 2016 was roughly in line with this financial year value, then the roughly 61 GWh consumed by RAC equipment in 2016 is equal to 26.8% of all electricity consumed in Australia, and on its own, as a class of technology, consumed more electricity than the entire residential sector in Australia.

The values above do not include energy used in mobile AC and transported refrigeration systems. The primary fuels used in MAC and in transport refrigeration services are liquid fuels, whereas the other MAC classes of equipment are powered by electricity (e.g. locomotives and passenger trains).

Total electricity consumed by the three stationary classes of RAC equipment, AC, domestic refrigeration and the stationary equipment in the refrigerated cold food chain, is equal to some 220 petajoules (PJ) of energy.

With the addition of the estimated 38 PJ consumed in liquid fuels providing mobile air conditioning and transport refrigeration, total energy consumed for the provision of RAC services in Australia in 2016 was approximately 258 PJ which, for instance, is only slightly less than twice the amount of total final energy consumption used in all Australian agriculture and construction combined in 2016. Or to provide another comparison of scale, is more than 80% of all final energy consumed in all commercial buildings and activities in Australia in 2016 (p16, DoEE 2017b).

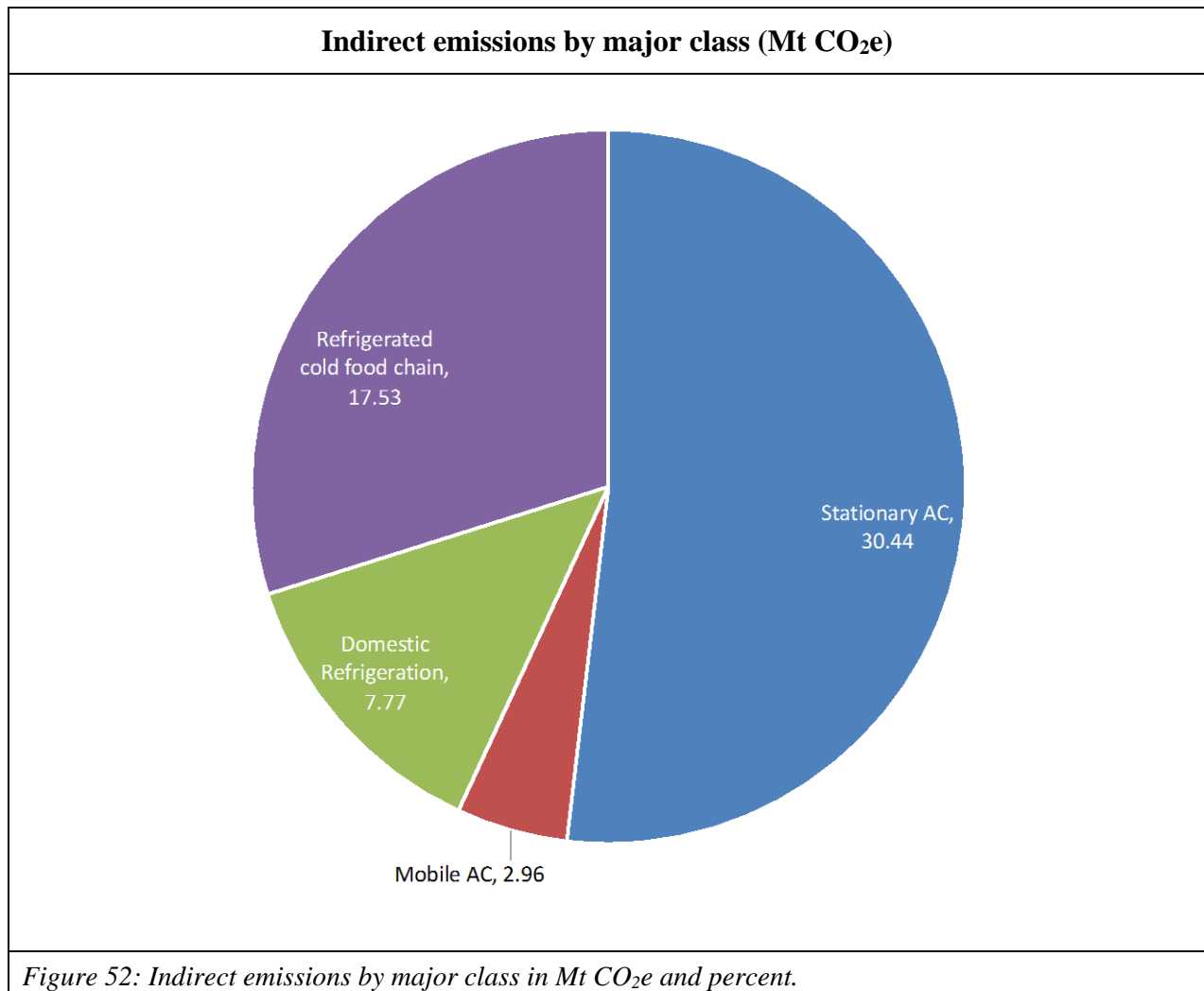
If the estimated \$1,567 million cost of liquid fuels (at an average price of \$1.25 per litre) consumed providing mobile AC and refrigerated transport is added to the cost of electricity consumed by stationary RAC in 2016, the total cost of energy used in cooling services in Australia in 2016 was roughly \$14.04 billion dollars.

9.2 Indirect emissions and total emissions

'Indirect' greenhouse gas emissions result from the consumption of energy (electricity or liquid fuels) in the delivery of a service.

The indirect emissions from energy consumed to deliver cooling services in Australia in 2016 is calculated as being more than 58.7 million tonnes of CO₂e in 2016 (*CHF2 57 Mt of CO₂e*).

The share of indirect greenhouse gas emissions produced by energy used to deliver refrigeration and air conditioning services is illustrated in *Figure 52*. Once again it can be seen that stationary AC dominates the analysis, producing more than 52% of energy related indirect greenhouse gas emissions from RAC.



(Source: CHF3 RAC Stock model)

Notes:

1. CHF3 uses the latest national estimate Scope 2 and 3 emissions factors to convert electricity consumption to indirect emissions. Refer consumption of purchased electricity by end users (Table 41, NGA Factor DoEE 2017) for a value of 0.81 kg CO₂e/kWh.

Combine the calculations of the global warming impact of refrigerant lost to air, as discussed in *Section 8*, with these estimates of energy related emissions and it is apparent that RAC equipment has a major role to play in the national greenhouse gas inventory.

Table 27: Direct and indirect emissions of RAC equipment in 2016 in Mt CO_{2e}.

	Direct emissions		Indirect emissions		Total emissions	
	Mt CO _{2e}	%	Mt CO _{2e}	%	Mt CO _{2e}	%
Stationary AC	2.19	34%	30.44	52%	32.63	50%
Mobile AC	1.25	20%	2.96 ⁽¹⁾	5%	4.21	6%
Domestic Refrigeration	0.05	1%	7.77	13%	7.82	12%
Refrigerated cold food chain	2.91	46%	17.53 ⁽¹⁾	30%	20.45	31%
	6.40	100%	58.70	100%	65.10	100%

Notes:

1. These values include emissions from consumption of liquid fuels (petrol and diesel).

Notably, while the wide variety of hard working equipment in the refrigerated cold food chain is the largest single contributor to direct emissions, the largest cause of energy related emissions is stationary AC, which when the direct emissions are added to indirect emissions, can be seen to have contributed 50% of all greenhouse emissions from RAC in 2016.

In something of an obvious ‘positive’ feedback loop, though with potentially very negative consequences, the demand for RAC services goes up strongly on hot days, significantly increasing demand for electricity.

Hot days and peak electrical demand combine to decrease the efficiency of the electrical distribution systems. The higher the temperature of the distribution system components, particularly the transmission lines, the greater the resistance to transmission and thus the greater the transmission losses incurred. These increased losses feedback directly into the average greenhouse gas emissions calculated for every kWh of electricity consumed, and into the total national emissions.

Rapid growth in installed air conditioning, starting in earnest around the turn of the century, has often been noted in the last decade as a major driver of new electricity demand and of peak electricity demand, requiring large investments in transmission and distribution infrastructure to ensure capacity to meet peak demand that occurs only relatively rarely throughout the year. This investment in electrical infrastructure has been one of the main reasons for consumer electricity price increases in Australia in recent years.

The total energy consumption for RAC systems calculated from the stock model is dependent on the estimated average annual hours of use of equipment in each category. Many of these estimates of hours of use have been informed by manufacturer’s data, estimates from previous studies into particular equipment categories, and from first-hand experience of some categories. However, even if adjusting annual hours of use to the lowest likely estimates for the equipment categories (in those categories where there is less certainty), the end result is a less than 10 per cent reduction in the estimates of total energy use.

In reality, given what we know about equipment in the field, it is possible that total estimated energy use, and thus the proportion of total national greenhouse gas emissions, is low. This is particularly relevant in the smaller equipment sizes where hundreds of thousands, and in some cases millions, of pieces of equipment are likely to be under serviced. Routine maintenance of air conditioning equipment (or lack of it) can have a profound effect on overall energy use in RAC equipment.

Maintenance of optimal refrigerant charge at the design specification of the compressor and condenser employed in a piece of equipment contributes to the most efficient transfer of heat. Cleaning of air filters and removing grime from heat exchange surfaces are very simple measures that have a direct impact on energy

efficiency in RAC equipment as well. Unfortunately, even such simple servicing of RAC equipment is often not done.

When incorporating EOL emissions estimates with direct emissions and energy related emissions, the significant role of RAC technology in Australian emissions is further underlined. The sum of direct emissions and EOL emissions in 2016 is calculated to be equivalent to just under 10.6 million tonnes of CO₂e. Approximately 68% or 7.2 million tonnes CO₂e of these emissions are calculated to be HFC emissions, with the balance being the effect of the GWP of HCFC emissions.

Recent analysis by CSIRO of atmospheric concentrations of the main species of ODS and SGGs, and their break down products, from air sampled at Cape Grim in Tasmania suggests a possible underestimation of at least the HFC portion of direct emissions and EOL. CSIRO’s analysis of atmospheric concentrations in 2015 indicated that HFC emissions from Australia were in the order of 11.5 million tonnes CO₂e, on their own, not including the HCFC included in the CHF3 RAC Stock model outputs in the table below. This discrepancy between the CHF3 RAC Stock model outputs and the Cape Grim data warrants further investigation, though may point to either an underestimate in leak rates along refrigerant supply lines, or in some product categories, or an underestimate of residual charge in some stocks of equipment.

When EOL emissions are added to the sum of energy related emissions and direct emissions, total RAC emissions for 2016 are calculated as equivalent to 68.71 million tonnes CO₂e, or 12.4% of the Australian National Greenhouse Gas Inventory (NGGI) in 2016.

Table 28: Total RAC Emissions (including end-of-life) in 2016 Mt CO₂e.

	Direct emissions		Indirect emissions		End-of-Life emissions		Total emissions	
	Mt CO ₂ e	%	Mt CO ₂ e	%	Mt CO ₂ e	%	Mt CO ₂ e	%
Stationary AC	2.19	34%	30.44	52%	2.25	62%	34.88	51%
Mobile AC	1.25	20%	2.96	5%	0.51	14%	4.72	7%
Domestic Refrigeration	0.05	1%	7.77	13%	0.16	4%	7.98	12%
Refrigerated cold food chain	2.91	46%	17.53	30%	0.69	19%	21.13	31%
Totals	6.40	100%	58.70	100%	3.61	100%	68.71	100%
	9.3%		85.4%		5.3%		100.0%	

10 Economics and employment

10.1 Structure of the industry

The vast majority of the physical inputs to the RAC industry in Australia are imported – most of the equipment, the components and all of the HFC and HCFC refrigerants. Despite the nearly total reliance on imported product, or at least on components, and refrigerants for those segments where an Australian manufacturing industry has survived, the RAC industry delivers a significant economic contribution to the nation.

The RAC industry is a significant employer, provides a range of essential services to the economy, mission critical value-adding to agricultural production and exports, and is a major energy consumer.

10.2 Supply lines

The supply lines for RAC goods and services are complex as this cross-cutting technology demands numerous specialised and niche services to deliver it into the wide range of end use industries that rely on it, from aviation, military and seaborne systems, to the mining sector, hospitals, laboratory systems and the commercial and retail sectors. However, the supply lines can be dissected into three major material supply chains:

- Bulk gas decanted into trading quantities for supply to manufacturers, installers and service companies;
- Imported pre-charged consumer appliances and equipment; and
- Locally manufactured equipment.

These three supply chains involve seven distinct commercial players prior to the end user:

- Importers;
- Manufacturers;
- Equipment distributors/suppliers;
- Refrigerant wholesalers;
- Specialist dealers of heating and cooling equipment (typically with their own showroom);
- White goods and household appliances retailers; and,
- Contracting businesses installing, repairing and servicing equipment, and sub-contractors.

Importers take delivery of ship borne ISO containers each carrying between 10 and 18 tonnes of refrigerant. These refrigerants are pumped into large vertical or horizontal storage tanks at the importer's yards. The larger tanks will generally be capable of holding between 20 and 70 tonnes of refrigerant, depending on the volumetric capacity and pressures of the refrigerant. Importers decant gas into tradeable quantities depending on purpose and market. There are four significant bulk import decanting facilities currently operating, three in Melbourne, and one in Sydney.

Gas is decanted at these sites into thousands of cylinders ranging in size from 10 kg, to 18 kg, and 60 kg, and also larger transportable tanks. Transportable tanks with a volumetric capacity of approximately 900 litres are commonly referred to as 'one tonners', and 'half tonners' for tanks with a 450 litres capacity. These transportable tanks can contain between 400 kilograms and 700 kilograms of product depending on the refrigerant involved.

More than 200 refrigerant wholesalers around the country provide the channel for the tens of thousands of small cylinders to be distributed, the majority going to contractors and service companies.

RAC equipment manufacturers decant from transportable tanks into smaller cylinders for use around their facility and for use when commissioning or servicing their own machinery. However, they will also decant directly from the larger storage into supply lines in their factories to charge equipment that they have manufactured, prior to dispatch from the factory floor.

Air conditioning distributors/suppliers import and distribute pre-charged equipment and do not themselves require large volumes of bottled refrigerant supplies from importers. They mostly purchase refrigerant from wholesalers for additional charges for larger systems (i.e. variable refrigerant volume split systems) and small volumes when directly undertaking service work.

Specialist dealers are unlikely to carry bottled gas supplies. Some dealers will be operating as contractors installing or servicing equipment for their customers, in which case they will have bottled gas demands as part of providing that service. Specialist dealers will likely get a range of product from different air conditioning distributors/suppliers and may also stock and sell equipment from local air conditioning manufacturers. If the specialist dealer does not operate as a contractor installing or servicing equipment they are likely to have close relationships with contractors whom they rely on to install and service equipment they have sold.

Retailers have no requirement for any bottled gas. Retailers sell pre-charged equipment supplied to them by air conditioning distributors/suppliers, or in some instances import directly. Retailers may also have relationships with contractors whom they recommend for installation and service of equipment they have sold.

Contracting businesses install, repair and service equipment, and often engage numerous individual sub-contractors. There are tens of thousands of individuals licensed to handle refrigerant and these contractors hold the majority of those licences. Contractors consume the majority of the small cylinders of refrigerant decanted by importers and distributed through refrigerant wholesalers.

Some of the businesses involved in these supply lines are the Australian arms of international companies of global scale. Daikin for instance, a supplier of various types of equipment, is a global company, as are competitors Fujitsu, Sanyo, Mitsubishi, LG, and other equipment manufacturers. Many of the Australian based businesses are relatively small, from the sole trader refrigeration mechanic contracting services to the medium sized wholesaler to the traders of ancillaries, components, specialised tools and refrigerant. The relatively rare Australian manufacturers of equipment, such as Actron Air, Temperzone, Advanced Refrigeration Technologies, and Stoddart Refrigeration in Queensland, and Williams Refrigeration and Smardt Chillers in Melbourne, have maintained and even grown their business because they produce the most energy efficient and advanced equipment in the market.

The wide variety of skills, qualifications and roles along the supply chain of the various parts of the industry can be viewed through the lens of the numerous professional associations that have developed to represent the interests of these groups in the wider industry, and to government. A list of the leading industry associations is included at the front of the document in *Acknowledgements*.

10.3 Indicators of value

There is no simple measure of total economic activity in this sector. However, there are a number of indicators that can be used to point to the overall size of the RAC industry and its economic activity.

The total stock of equipment of approximately 54 million devices (*CHF2>45 million*), is quite well understood. Imports of pre-charged equipment and Australian manufacturers; output provides very high quality data to model growth in this stock.

Using ranges of hours of operation of the various equipment categories in various climate zones, a calculation of the quantity of electricity that must be purchased to provide RAC services every year can be made.

The approximately 61,000 GWh of electricity purchased (*CHF2 59,000*) was more than one quarter of all the electricity consumed in Australia in 2016. Somewhat surprisingly the cost of the energy consumed in

2012 and in 2016 was effectively the same. Despite the increase in the stock of equipment in the model (some as a result of actual growth in equipment numbers and some as a result of better data revealing stocks unaccounted for in 2012) the value of all energy consumed in the sector in 2016 is estimated to have been worth slightly more than \$14 billion dollars, which is almost the exactly the same as the cost of energy consumed by RAC equipment in 2012.

In a large part this outcome can be attributed to falls in unit energy prices since 2012, at which time energy prices in Australia incorporated a fixed carbon price of \$23 per tonne of CO₂, and external factors meant liquid fuel prices were higher.

Estimated costs of energy consumption by class of equipment is set out *Table 29*.

Table 29: Estimated cost of energy spend in air conditioning and refrigeration services in 2012 and 2016 in millions.

	2012	2016
Stationary AC	\$7,456	\$7,349
Domestic refrigeration	\$2,058	\$2,325
Refrigerated cold food chain: stationary	\$2,811	\$2,771
Refrigerated cold food chain: mobile	\$99	\$174
Mobile AC	\$1,637	\$1,418
Total energy spend	\$14,061	\$14,037

Notes:

1. CHF3 applies three national average rates of 16c/kWh for commercial end-users, 28c/kWh for residential dwellings and 13c/kWh for industrial end-users such as cold storage facilities. The rates are as per the AEMO National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, Australian Energy Market Operator, published 2017 (AEMO 2017). It should be noted the AEMO 2017 rates were significantly higher (i.e. commercial 20c/kWh, industrial 17c/kWh and residential 31c/kWh) and 2018 (not yet published) are expected to include similar increases.
2. CHF2 applied three national average rates of 17c/kWh for commercial end-users, 27c/kWh for residential dwellings and 13c/kWh for industrial end-users. The AEMO prices for 2012 were 15c/kWh for commercial end-users, 28c/kWh for residential dwellings and 13c/kWh for industrial end-users (AEMO 2017).
3. Refrigerated cold food chain: mobile is fuel consumption attributed to road and marine refrigeration systems. For example, marine refrigeration assumes 75% of ancillary is for refrigeration (and excludes 25% for HVAC, lighting, services and plug loads) and excludes main engine fuel consumption (NPF 2013, CRC 2015).
4. Mobile AC energy spend is for the portion of fuel consumption attributed to the operation of mobile air conditioning units and equates to around 3.5% of total fuel consumption of registered vehicles. The in general terms the calculations assume 10% of fuel consumption is attributed to operating the vehicle air conditioner that operates 40% of the time in passenger vehicles and 50% of the time in commercial vehicles.
5. Mobile AC energy spend includes electricity consumption to operate air conditioners in locomotives and passenger trains.
6. Fuel prices used in CHF3 were petrol \$1.23 per litre and diesel \$1.26 per litre. Fuel prices were based on annual average retail petrol price in the five largest cities for FY 2016-17 published by the ACCC, Report on the Australian Petroleum Market (ACCC 2017).

Another useful measure of activity is the estimate of expenditure on new installed equipment in 2016 based on well documented imports, accurate national sales data, and conservative average installation costs. The estimated value of new equipment installed in 2016 by major equipment class is provided in *Table 30*.

Table 30: Estimated value of new installed equipment in 2012 and 2016 in millions.

	2012	2016
Stationary AC	\$3,350	\$4,856
Domestic refrigeration	\$1,201	\$1,423
Refrigerated cold food chain: stationary	\$728	\$798
Refrigerated cold food chain: mobile	\$54	\$128
Mobile AC	\$562	\$977
Total equipment spend	\$5,896	\$8,181

Notes:

1. The value of new installed equipment is estimated from the sum of individual calculations for each product category that multiply the 2016 sales quantity by a typical installed price. For example, a 5 to 6 kW wall hung split system retails for around \$1,500 and the installation price will cost around \$800 each including 4 hours labour and ancillaries (i.e. copper pipe, mounting brackets, capping, etc.).
2. Similarly, the price used for a domestic refrigerator was \$1,298 with no installation. The average price of a domestic refrigerator is based on Canstar Blue Fridge Reviews where they conclude “*Fridges can range anywhere from about \$400, all the way up to and over \$3,000 for the latest and greatest. Survey results indicate that the average spend on a fridge is \$1,298*”.

Increases seen in the cost of investment in all equipment categories can be partially attributed to inflationary cost increases between these 2012 and 2016 snapshots of investment, as well as an increase in demand for equipment.

The estimate of expenditure on stationary air conditioning systems is conservative and does not include the wide range of ancillary devices and mechanical services such as building management systems, pumps, etc., essential to the operation of large space cooling chiller systems.

This equipment is imported, or designed and manufactured, sold installed and serviced by more than 20,000 businesses, comprising contracting businesses, components and consumables suppliers, manufacturers, and other service providers including engineers and designers.

One useful measure of the number of businesses or contractors operating in this industry is the 18,144 Refrigerant Trading Authorities (RTAs) issued by the Australian Refrigerant Council (ARC) by the end of 2016 (*CHF2 17,048*). RTAs are required business authorisations for a business to buy, sell and store refrigerant. The main business types recorded in the licensing database are 49% automotive air conditioning, 43% stationary air conditioning and 5% domestic refrigeration. (*CHF2 47%, 46%, and 4% respectively*).

More recent data available shows growth in new RTAs issued during 2017 and could point to the strength of underlying business activity in the sector, as also evidenced by the growth in stock numbers in the preceding few years.

Table 31: Number of refrigerant trading authorities by industry sector, 2016 and 2017.

	Number RTA 31 December 2016	Number RTA 31 December 2017
Automotive Air Conditioning	8,875	9,222
Aviation	38	38
Awaiting Assessment	10	14
Domestic RAC	875	941
Manufacturer	42	43
Marine	75	77
Refrigerant Wholesaler	174	174
Restricted Automotive Parts Recycler	34	32
Restricted Metal Recycler	7	6
Restricted Non Fluorocarbon Refrigerants	3	2
Restricted Refrigerant Recoverer	34	33
Restricted Waste Management	10	12
Split Systems A/C Installation	2,894	3,080
Stationary RAC	4,959	4,905
Transport Refrigeration	111	107
Other	3	3
Total	18,144	18,689

Based on the detailed import records of refrigerant and using market data on wholesale and retail refrigerant prices, total expenditure on refrigerant can be estimated to be approximately \$161 million⁶² (*CHF2 \$533 million*). The significant reduction in annual refrigerant costs illustrates the effect of the equivalent carbon tax on refrigerant prices in 2012, as compared to 2016, two years post the removal of the tax.

The replacement value of the refrigerant bank in 2016 was estimated to be about \$2.7 billion (*CHF2 \$5.8 billion*), once again emphasising the impact of the equivalent carbon tax in 2012, as compared to the untaxed prices of refrigerants available to the market in 2016. This has been calculated on market prices after the introduction of the equivalent carbon tax.

⁶² Refrigerant prices are calculated from average sell prices to contractors in 2016 plus a mark-up to end users. All refrigerants had a 50% mark up from average contractor sales price to end users, except hydrocarbon had an 80% mark up as it is primarily sold into the automotive aftermarket sector.

All of this evidence points to a very large investment in the ownership, operation and maintenance of RAC equipment.

Using sources and methods first developed for CHF2 and refined for this study an estimate can also be made of the number people employed in this industry, developing and maintaining this substantial investment.

A review of the data available from the last census, and other collections of the Australian Bureau of Statistics (ABS), produced results that seemed to generally align with other data that the RAC industry itself could provide regarding the number of licences issued by the Australian Refrigeration Council for handling refrigerant.

The total number of refrigerant handling licences that are on issue are known, including the classes of licences held as set out in *Table 32*. The comparison of licences on issue at the end of 2016, with those on issue in 2012 is provided, in the table, although it is only the 2016 licences that are subsequently used in an estimation of total employment in the industry.

Table 32: Number of refrigerant handling licences by industry sector, 2012 and 2016.

	Number RHL 2012	Number RHL 2016
Automotive Air Conditioning	24,315	28,888
Aviation	122	188
Awaiting Assessment	-	361
Domestic RAC	387	346
Marine	241	169
Refrigerant Handler	267	158
Refrigerant Recoverer	231	307
Split Systems	7,443	11,683
Stationary RAC	20,975	24,076
Transport Refrigeration	121	118
Total	54,102	66,294

In a mix not dissimilar to the mix of RTAs, around 43% of RHLs are automotive air conditioning, almost 19% are split system installers and 36% are stationary refrigeration and air conditioning mechanics.

Once again, in *Table 33* below, more recent annual data confirms the continuing trend illustrated by the comparison of 2012 and 2016 licence numbers.

Table 33: Number of refrigerant handling licences by industry sector, 2016 and 2017.

	Number RHL 31 December 2016	Number RHL 31 December 2017
Automotive Air Conditioning	28,888	29,895
Aviation	188	242
Awaiting Assessment	361	438
Domestic RAC	346	353
Marine	169	153
Refrigerant Handler	158	140
Refrigerant Recoverer	307	306
Split Systems	11,683	12,878
Stationary RAC	24,076	24,965
Transport Refrigeration	118	121
Total	66,294	69,491

Using multipliers of employment developed for CHF2 and tested again for CHF3, the total number of Refrigerant Handling Licences can be used as a basis from which to project the direct employment in the RAC industry, as set out in *Table 34* below.

Table 34: Method for calculating total employment in the RAC industry in Australia in 2016.

Licence type	Number of RHLs	% of RHLs	Employment Multipliers ⁽¹⁾	Total Direct Employment	% of Direct Employment
Automotive AC	28,888	43.6%	2.40	69,331	31.7%
Aviation	188	0.3%	2.00	376	0.2%
Awaiting Assessment	361	0.5%	0.00	0	0.0%
Domestic RAC	346	0.5%	1.50	519	0.2%
Marine	169	0.3%	2.00	338	0.2%
Commercial refrigeration	7,223	10.9%	5.00	36,114	16.5%
Commercial AC ⁽²⁾	16,853	25.4%	5.00	84,266	38.6%
Split systems (up to 18kW _r)	11,683	17.6%	2.25	26,287	12.0%
Refrigerant handler	158	0.2%	2.00	316	0.1%
Refrigerant recoverer	307	0.5%	2.00	614	0.3%
Transport refrigeration	118	0.2%	3.00	354	0.2%
Total RHLs	66,294			218,515	100.0%
Industry services	66,294	X	0.05	3,315	
Refrigerated transport vehicles	38,284	X	2.00	76,569	
Total Employment in RAC Industry in Australia				298,398	

Notes:

1. Employment multipliers were derived for each class of licence type to provide full time employment numbers in that technology segment directly involved with selling or servicing the technology including the licence holder themselves, and people employed in administration and sales of parts, equipment and materials that directly support the employment of the licence holder.
2. Commercial AC includes RHLs permitted to install light commercial systems (typically >18 kW_r) for residential and commercial applications as space chillers. Assumed a 70%/30% split for commercial air conditioning /refrigeration.

3. Automotive air conditioning: Employed to inspect and service air conditioning in the Australian fleet of private motor vehicles, buses, trucks, trains and other unregistered mobile systems. A majority of these licence holders would most likely be primarily employed as auto mechanics servicing private motor vehicles and would hold the automotive air conditioning licence as a necessary 'ticket' for their employment. These 'part time' air conditioning maintenance jobs are however multiplied by administration staff that assist with the supply of parts associated with this large stock of equipment. Costs of importers engaged in delivering new and pre-charged equipment are picked up in spending on hardware.
4. Aviation: This small number of licence holders inspect, maintain and service air conditioning systems in the entire aviation fleet and are supported by skilled engineering, design and sales and administration personnel in this specialised area requiring designing, procuring, delivering, testing, recording and inspecting equipment installed.
5. Domestic RAC: Employed only in either the refurbishment of domestic refrigeration for resale or in the installation of domestic air conditioners, cost of transport, sales people, office administration for sales etc. covered by retail price of product. Installation requires labour from electrical trades for every install.
6. Marine: Licence holders dealing with largely customised systems that have been designed by engineers for each individual vessel, ranging from large pleasure craft to deep sea fishing vessels to passenger liners and large ships with refrigerated holds. Each licensee installs, inspects and maintains equipment designed by engineers and supplied by specialised procurement and sales staff, all supported by admin.
7. Commercial refrigeration: Employment multiplier in commercial refrigeration includes a significant number of employees, including system designers and engineers who design and deliver large supermarket and distribution centre systems, construction workers, smaller cool room contractors and manual labourers and other component suppliers. Other employees include electrical trades and plumbing trades involved in these sometimes very large construction and installation projects, and in regular maintenance and repairs, control system makers, programmers, administration and services, including data monitoring insurances, financial reporting etc. Additionally, the large commercial refrigeration units themselves, from the huge distribution stores at ports and rail heads, and other transport links, have full time employment on site dealing with daily maintenance, operation and use of these infrastructure scale facilities.
8. Commercial AC: Includes RHLs permitted to install light commercial systems (typically >18 kW_r) for residential and commercial applications as space chillers. Employment multiplier in light commercial HVAC includes a significant number of system designers and engineers who design and deliver large commercial building systems, ducting manufacturers and installers, fan manufacturers, and fabricators of other air handling components, construction workers, parts suppliers for extensive and routine repairs and maintenance work, electrical trades and plumbing trades involved in installations, control system makers, programmers and other services, including insurances, financial reporting etc.
9. Split systems <18kW_r: Employment multipliers in smaller split systems for residential and small commercial include electrical trades and other building trades, suppliers of consumables, sometimes required for installations and some ducting for a smaller proportion of these systems. All of these employment categories are involved in delivering and installing the more than 1 million of these units sold every year. The costs of importers, sales and administration support for sales are all covered in cost of hardware.
10. Refrigerant handler: Multiplier for refrigerant handling licence primarily in administration and sales in wholesale suppliers of gas.
11. Refrigerant recoverer: Refrigerant recovery may not be full time employment for some holders of these licences, however the process of recovery creates jobs in a 'reverse supply chain' for the return of gas for destruction or reuse via various chemical processes and testing to bring gas back to specification.
12. Transport refrigeration: The small number of licence holders in this class deal with an enormous fleet of refrigerated vehicles and shipping containers that are very hard working and consume relatively high volumes of parts and consumables. Some of the refrigerated transport fleet is certainly being serviced by licence holders in the commercial refrigeration category. However, it is also highly likely that a significant proportion of the transport refrigeration fleet is also being serviced by skilled tradesmen who are not licensed.
13. Refrigerated transport vehicles: Employment multiplier for each registered refrigerated freight truck includes an average of 1.25 truck drivers for each vehicle with the balance being store men and packers, logistics and freight forwarders and administrative and sales personnel associated with consigning freight and physically getting product on and off this significant fleet of refrigerated vehicles.

14. Industry services: Including curriculum development, training and education, industry associations, professional development, testing services, public administration, consulting and regulatory development, publishing, marketing, advertising, exhibition services and compliance services at 5 per cent of total licences.

Using the multipliers set out above it can be shown that the activity of this highly skilled and diverse licensed workforce produces totally national direct employment of nearly 298,400 jobs.

Separately from this body of employment, the refrigerated cold food chain is supplied with perishable foods via a fleet of 38,000 refrigerated vehicles (*CHF2* 28,900). Assuming that driving and keeping each of these vehicles on the road keeps two people employed full-time, it would equate to another 76,569 jobs.

The total labour force in Australia at the end of 2016 was 11.984 million (ABS 6202.0 2017). With total direct employment in RAC Industry in Australia in 2016 coming in at 298,398, (*CHF2*, 173,638⁶³) this means that in 2016 the RAC industry provided 2.5% of total employment in Australia (*CHF2* 1.5%).

A very interesting metric available for this edition of Cold Hard Facts, but not reported in 2012, is the average age of an RHL holder in 2017 was around 40 years. In future studies this metric could be used to evidence the success of industry efforts to secure younger tradespeople and apprentices to enter the industry.

Table 35: Average age of refrigerant handling licence holders by major sector 2017.

	Average age (Years)
Stationary Refrigeration and Air Conditioning	39
Split Systems Installation	39
Automotive Air Conditioning	40

(Source: Arctick 2017)

While this analysis could not be said to be exhaustive, the results are not unreasonable. In the research for *CHF1*, a survey of industry leaders and associations at that time arrived at a number of approximately 160,000 people employed across the industry in 2006, although that figure was essentially arrived at on the basis of informal survey and anecdotal evidence. Six years later in the research for *CHF2* the method developed and used above identified a total workforce of some 173,000.

Further, the proportions of employment (calculated in *Table 34*) relating directly to issued licences align quite well with the relative scale of the stock of equipment and bank of working gases in the broad classes of stationary air conditioning (looking at large systems and split systems combined), refrigerated cold food chain, and mobile air conditioning.

To calculate total wages paid in the industry both average annual earnings and a RAC industry ‘skilled labour’ earnings figure is used. Average annual earnings in Australia was \$78,832 in 2016 (*CHF2* \$69,992). However, the average hourly rate for RAC service technicians with greater than 5 years’ experience was \$41.20 in 2017, equating to \$85,696 based on a 40 hour week and 52 weeks with no overtime and bonuses (AMCA 2017).

⁶³ The multipliers used to calculate employment by type of RHL in 2012 used a multiplier of 1.0 for MAC as opposed to 2.4 used in *CHF3* 2016. The revision of this multiplier was based on a survey undertaken by the air conditioning and refrigeration equipment manufacturers of Australia (AREMA) sent to approximately 1,300 people who participated in Future Air MAC in 2016. There were 80 responses to the survey which equates to a response rate of around 6.2%. The main finding of the survey was the ratio between licensed tradespersons and total employment is 2.4 based on a total employment of 423 number from a licence pool of 176. At the same time multipliers for commercial AC and commercial refrigeration were revised up to 5.0. If the *CHF3* multipliers were used in 2012 then total estimated employment in the RAC industry in 2012 would have around 244,000.

Assuming that 15% of the licensed RAC workforce has less than 5 years experience, and assuming their income was on the national average (without overtime or bonuses) for 2016, and applying the value reported by AMCA for the income of the other 85% of the licensed workforce, gives a total annual wages spend on licensed technicians in the Australian RAC industry of \$5.61 billion. Using average wages for the balance of the workforce engaged in refrigerated transport and services results in another \$18.30 billion for a total 2016 wages cost of approximately \$23.91 billion (*CHF2 \$12.174 billion*).

It is too simplistic however to add the dollar values derived from the cost of new hardware, the cost of refrigerant, total energy cost and wages costs together to declare total economic activity in the RAC industry. The major uncertainty in these values is about the level of double counting. For instance, one can reasonably assume that some of the wages costs are in fact represented by the cost of new hardware supplied and installed, and the value of some refrigerant sales included in the costs of some maintenance and service.

Obviously there is a lot of skilled services and labour involved in the industry that is paid for separately from the cost of new hardware and refrigerant. These services and labour include the design and engineering involved in the construction of commercial buildings and new commercial refrigeration plants, plus the extensive labour involved in maintenance and refurbishment of the large stock of equipment.

However even offsetting 100% of the cost of new installed hardware and sales of refrigerant from calculated wages costs, leaves a *total discounted wages value* of \$15.73 billion (*CHF2 \$5.743 billion*). Using that figure as the value for wages not accounted for elsewhere, a summary of the main economic indicators that point to the size of the RAC industry has been compiled into *Table 36*.

Table 36: Total economic value of the RAC industry in Australia in millions of dollars in 2016.

	Equipment spend (installed)	Discounted wages cost	Refrigerant cost (end-user)	Energy spend (end-user)	Total spend including energy
Stationary AC	\$4,856	\$15,729	\$161	\$7,349	\$38,108
Domestic refrigeration	\$1,423			\$2,325	
Refrigerated cold food chain: stationary	\$798			\$2,771	
Refrigerated cold food chain: mobile	\$128			\$174	
Mobile AC	\$977			\$1,418	
Total	\$8,181			\$15,729	

Notes:

1. The discounted wages calculation deducts 100% of the annual expenditure on equipment and refrigerants from total wages calculated for the year of \$23.91 billion.
2. The refrigerant cost to end-user calculation assumed all refrigerants had a 50% mark up from average contractor sales price to end users, except hydrocarbon had an 80% mark up as it is primarily sold into the automotive aftermarket sector.

If this calculation of expenditure of \$38 billion on the purchase and operation of RAC equipment is considered a valid indicator of the value of the industry, then this represents 2.3% of Australia's \$1.68 trillion GDP in 2016 (*CHF2 1.67% of national GDP of \$1.57 trillion*)⁶⁴.

Of course, this relatively simple method of calculating the value of the industry makes no attempt to put any value on the vast array of essential services provided by the industry from hospitals and laboratories, to data centres, shopping malls and high-rise offices, nor does it attempt to incorporate the enormous direct value add that the RAC industry provides to Australian agriculture and food exports. As such the real economic value of the RAC industry to Australia is very much an open question. But even counted as 2.3% of GDP, this is a major industry on the economic landscape.

When comparing the values derived using the same methods in 2012, with the 2016 values, as set out in *Table 37* below, some interesting observations can be drawn.

Table 37: Main economic indicators of RAC industry activity in 2012 and 2016.


Expenditure categories	Economic spend in 2012 (\$ Billion)	Economic spend in 2016 (\$ Billion)
New hardware costs installed	\$5.90	\$8.18
Annual refrigerant cost to end user	\$0.54	\$0.16
Energy costs to end users	\$14.06	\$14.04
Discounted wages cost	\$5.74	\$15.73
Total economic spend	\$26.24	\$38.11

The most notable observation when comparing these two snapshots of the industry is that, while the value of new equipment sales installed has increased by more than 38%, the discounted wages value for 2016 is significantly larger. This is the direct result of industry feedback suggesting that (and providing some reasonable evidence in support of the assertion) the employment multipliers used to generate the estimate of total employment in 2012 were too low, particularly in the large MAC sector, but also in the supply, installation, and operation of stationary AC and commercial refrigeration. The adoption of the higher employment multipliers had the effect of expanding the total workforce estimate by 39% in 2016 as compared to the estimate that would have been generated if the 2012 multipliers were applied. In the absence of more exacting workforce survey data, the authors are confident in the workforce estimate above.

While underlying energy costs are lower in 2016 than in 2012, the similarity in total energy costs, to run an increased stock of equipment, suggests that decades of government, industry and community focus on energy efficiency may be starting to show dividends in delivering increased energy services at lower cost to the economy.

The very significant change in the value of the refrigerant purchased in 2012 versus 2016 points to both the impact that the equivalent carbon tax had on the price of refrigerants (and to a lesser degree on the price of pre-charged equipment imports) in 2012, but also to the high global warming potential of most refrigerants and how the prices under a tax based on the GWP of refrigerants highlights the un-costed externality of most refrigerant GWPs.

⁶⁴ Australian Bureau of Statistics, catalogue 5206.0, *Australian National Accounts: National Income, Expenditure and Product, Dec 2017* released on 7 March 2018. Refer to Table 1, *Key National Accounts Aggregates, Gross domestic product: Chain volume measure seasonally adjusted (in Australian dollars)*.



The total industry expenditure for installed equipment to end users in 2016, excluding energy spend, is \$24.1 billion and \$38.1 billion including energy spend.

Further work in this area is recommended including an analysis of the value adding the RAC industry delivers across the many sectors of the Australian economy.

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Industry associations

Australian Institute of Refrigeration Air Conditioning and Heating (AIRAH)
Air Conditioning & Refrigeration Equipment Manufacturers Association of Australia (AREMA)
Air Conditioning and Mechanical Contractors' Association of Australia (AMCA)
Australian Refrigeration Association (ARA)
Australian Refrigeration Mechanics Association (ARMA)
Australian Refrigeration Council (ARCTick)
Refrigerated Warehouse and Transport Association
Refrigeration and Air Conditioning Contractors Association (RACCA)
Refrigerants Australia (RA)
Refrigerant Reclaim Australia (RRA)

Companies

Actrol Parts	GreenFreeze
Actron Air	Heatcraft Australia
A-Gas Australia	Highgate
Airfrig Australia	Hychill Australia
AJ Baker & Sons	ISECO Engineering Services (and Aldi)
Ashdown Ingram	IXOM (formerly Orica Chemicals)
Barry Brown & Sons	JAS Oceania
Bitzer Australia	Mitsubishi Electric
BOC Limited	Oxford Cold Storage
Burson	Repco
Carrier Transicold	Sigma Air (Knorr Bramsse)
Casco Refrigeration	Smardt Chillers
Coles	Swire Cold Storage
Cooldrive	Temperzone
Daikin Australia	Thermo King
Engas Australasia	Woolworths (Group Engineering)

References

A2EP 2017	Australian Alliance for Energy Productivity (A2EP), Food Cold Chain Optimisation: Improving energy productivity using real time food condition monitoring through the chain, May 2017.
AACS 2015	Australasian Association of Convenience Stores State of the Industry Report, 2015.
AB&C 2017	Australasian Bus & Coach (AB&C) bus and coach deliveries data from 1998 to 2017.
ABARES 2017	Agricultural commodity statistics, 2017, Department of Agriculture and Water Resource Economics and Sciences (ABARES), Published December 2017.
ABS 3101.0 2018	Australian Bureau of Statistics, catalogue 3101.0, Australian Demographic Statistics, March 2017.
ABS 5206.0 2017	Australian Bureau of Statistics, catalogue 5206.0, Australian National Accounts: National Income, Expenditure and Product, Dec 2017 released on 7 March 2018. For GDP refer to Table 1, Key National Accounts Aggregates, Column BB. Gross domestic product: Chain volume measure seasonally adjusted (in Australian dollars).
ABS 6202.0 2018	Australian Bureau of Statistics, catalogue 6202.0, Labour Force in Australia, January 2018.
ABS 6291.0 2017	Australian Bureau of Statistics, catalogue 6291.0, Labour Force, Australia, Detailed, Quarterly, Nov 2017.
ABS 8165.0 2017	Australian Bureau of Statistics, catalogue 8165.0, Counts of Australian Businesses, June 2017.
ABS 9208.0 2017	Australian Bureau of Statistics, catalogue 9208.0, Survey of Motor Vehicle Use, March 2017.
ABS 9309.0 2017	Australian Bureau of Statistics, catalogue 9309.0, Motor Vehicle Census, July 2017.
ABS 9314.0 2017	Australian Bureau of Statistics, catalogue 9314.0, Sales of New Motor Vehicles, Australia, December 2012 and Jan 2017.
ACCC 2017	Report on the Australian petroleum market, Australian Competition & Consumer Commission, June 2017.
AEMO 2017	AEMO National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, Australian Energy Market Operator, published 2017. http://forecasting.aemo.com.au/Electricity/AnnualConsumption/Operational
AIRAH 2017a	Australian Institute of Refrigeration, Air Conditioning and Heating Refrigeration Conference, May 2017. Presentation: Dario Ferlin, Woolworths sustainable innovations engineer.
AIRAH 2017b	Case study, 100 per cent natural flavor, Ecolibrium, August 2017, Volume 16.7, the Australian Institute of Refrigeration, Air Conditioning and Heating.
AIP 2017	Data available online for petrol and diesel prices in April 2013, Australian Institute of Petroleum, 2017.
AMCA 2017	Survey of Service Technician Hourly Rates, Australian Mechanical Contractors Association, 2017.
AMSA 2017	Registrar of Ships, Ship Inspection and Registration Division, Ship Safety Division, Australian Maritime Safety Authority, 2017.
ANSI/ASHRAE 34	ANSI/ASHRAE 34, Designation and Safety Classification of Refrigerant, which is published on the ASHRAE website.
ARctick 2017	License data provided by ARctick Australian Refrigeration Council by technician and business types.
BIC 2017	Review of Australian Bus Fleet, National Technical and Suppliers Summit, February 2017.
BITRE 2016	Bureau of Infrastructure, Transport and Regional Economics (BITRE) and Australasian Railway Association (ARA), Trainline 4 Statistical Report, 2016.
BREE 2017	Australian Energy Statistics, Bureau of Resources and Energy Economics, Canberra, 2017.
Coles 2017	Coles Supermarkets Australia, 2016 Year in Review, published 2017.

CRC 2015	Refrigeration from Catch to Market, A study of refrigeration technology options for the Northern Prawn Fishery and the Sydney Fish Markets; and A new refrigeration system reference design and demonstration prototype for fishing vessels by Expert Group for Seafood CRC, Fisheries Research and Development Corporation and the Northern Prawn Fisheries (NPF Industry Ltd).
CVIAA 2016	Caravan and Campervan Data Report 2016, Caravan Industry Association of Australia Ltd, Published October 2016.
DoEE 2018	National Inventory by Economic Sector 2016, Australia's National Greenhouse Accounts by Department of the Environment and Energy, National Inventory Team, February 2018.
DoEE 2017a	Data (i.e. bulk and pre-charged equipment import statistics by quantity, mass, species, licence holder, product category from 2006 to 2017) provided by the Department of the Environment and Energy, Ozone and Synthetic Gas Team, July 2017.
DoEE 2017b	Australian Energy Statistics 2017, Australian Energy Update, Energy Statistics and Analysis Section, Department of the Environment and Energy August 2017.
DoE 2016	HFC Demand in Australia and Projections to 2030 as compared to International Proposals for HFC Phase Down timetables prepared by Expert Group for the Department of the Environment, Ozone and Synthetic Gas Team, April 2016.
DoEE 2015a	Assessment of environmental impacts from the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 (the OPSGGM Act) prepared by Expert Group for the Australian Government, Department of Environment and Energy, Ozone and Synthetic Gas Team. Refer Attachment B: Environmental Impact Assessment, April 2015.
DoEE 2015b	Environmental Impacts of Refrigerant Gas in End-of-Life Vehicles in Australia, Expert Group for the Australian Government, Department of Environment and Energy, Ozone and Synthetic Gas Team, March 2015.
DoEE 2014	A study into HFC consumption in Australia in 2013, and an assessment of the capacity of Australian industry to transition in accordance with the North American Amendment proposal, under the Montreal Protocol, by Expert Group for the Australian Government, Department of Environment and Energy, Environmental Standards Branch, March 2015.
DoEE 2013	Cold Hard Facts 2, A study of the refrigeration and air conditioning industry in Australia and associated model, prepared by Expert Group for the Department of the Environment, Ozone and Synthetic Gas Team 2013.
DoEE 2008	ODS and SGGs in Australia: A study of end uses, emissions and opportunities for reclamation, prepared by Peter Brodribb and Michael McCann for Department of the Environment, Water, Heritage and the Arts, Ozone & Synthetic Gas Team, 2008.
DoEE, 2007	Cold Hard Facts, prepared by Energy Strategies in association with Expert Group for DEWHA and Refrigerants Australia, 2007.
E3 2017a	Decision and Consultation Regulation Impact Statement Air conditioners, Chillers and Close Control Air Conditioner: Energy Modelling & Cost Benefit Analysis prepared by EnergyConsult on behalf of the trans-Tasman Equipment Energy Efficiency (E3) programme, 2015 to 2017.
E3 2017b	Consultation Regulation Impact Statement - Fans in Australia and New Zealand, prepared by Sustainability Victoria (SV) and Expert Group on behalf of Equipment Energy Efficiency (E3) programme, April 2017.
E3 2016	Consultation Regulation Impact Statement, Refrigerated Display and Storage Cabinets in Australia and New Zealand, prepared by Expert Group for Energy Efficiency and Conservation Authority (ECCA) on behalf of Equipment Energy Efficiency (E3) programme, 2016.
E3 2015	Residential Energy Baseline Study: New Zealand, Department of Industry and Science, prepared by EnergyConsult on behalf of the trans-Tasman Equipment Energy Efficiency (E3) programme, August 2015.
E3 2009a	Draft Non-Domestic Energy Efficiency Strategy: In from the Cold, prepared by Mark Ellis, Peter Brodribb, Tony Fairclough, Rod King and Kevin Finn for DEWHA, October 2009.

FCAI 2017	VFACTS Extracts from National Reports, Federal Chamber of Automotive Industries, 2017.
ICF 2010	Identifying and Assessing Policy Options for Promoting the Recovery and Destruction of Ozone Depleting Substances (ODS) and Certain Fluorinated Greenhouse Gases (F-Gases) Banked In Products and Equipment, ICF International, May 2010.
IPCC 2007	IPCC Fourth Assessment Report: Climate Change 2007 (AR4), Physical Science Basis, Chapter2, prepared by the Intergovernmental Panel on Climate Change, 2007.
MC 2017	Metcash Ltd, Annual Report, 2017.
MfE 2017	Hydrofluorocarbon Consumption in New Zealand, prepared by Expert Group for the New Zealand Ministry for the Environment, October 2017.
NGA Factors DoEE 2017	National Greenhouse Accounts Factors July 2017, Department of the Environment and Energy.
NGERS	NGERS technical guidelines for the estimation of emissions by facilities in Australia, in the 2016-17 reporting year, Department of the Environment and Energy, and previous editions used in CHF2.
OPSGGM Act	Ozone Protection and Synthetic Greenhouse Gas Management Act 1959, including amendments.
QGDME 2017	Hydrocarbon Appliance Register, Queensland Government, Department of Mines and Energy, 2017.
TIC 2016	Truck Industry Council, Fleet Report, published March 2016.
WF 2017a	Wesfarmers, Annual Report 2017, and Coles Supermarkets Australia, 2016 Year in Review, published 2017.
WF 2017b	Wesfarmers, Sustainability Report 2016, Case Study: Natural refrigerants set the standard at Coles, August 2017.
WOW 2017a	Woolworths Limited, Annual Report 2017.
WOW 2017b	Woolworths Limited, Woolworths Group Corporate Responsibility Strategy 2020.

11 Appendix A: Methodology – Taxonomy, data and assumptions

11.1 Taxonomy of a technology

The data presented in this report has been derived from an extensive Excel workbook that has, at its core, a stock model of all RAC equipment employed in Australia. The central feature of the stock of equipment in this model is that it all employs vapor compression refrigeration systems in the delivery of an energy service, either cooling or heating, or both.

All electro-mechanical RAC equipment employing vapor compression refrigeration systems use just four essential technical elements:

- a compressor;
- a refrigerant (the thermal medium which is used to move heat from one place to another);
- an evaporator that uses the adiabatic effect to reduce the temperature of a space by evaporating the previously compressed refrigerant gas; and,
- a condenser or heat exchanger outside the refrigerated space that allows the evaporated then recompressed gas to cool, transferring the excess heat to the atmosphere (air cooled) or into water (water cooled).

These common electro-mechanical elements of RAC technology can be fabricated into equipment in a number of different ways, with the main components incorporated in quite different physical relationships to each other, to deliver heat exchange/cooling services. For instance, all of the four basic elements of vapor compression refrigeration are present in both a domestic refrigerator that is small enough for a single person can pick up, and into a system that has the capacity to regulate the temperature and humidity of an airport terminal, or the cockpit of a fighter aircraft, but obviously all in very different formats.

Because RAC technology and services, after 150 years of development, have become integrated into every sector of the modern economy, the number and variety of equipment formats that the RAC industry now supplies is highly varied.

To best manage the mass of data that must be captured and analysed in the stock model to understand the scale of the RAC industry and all of the applications and equipment formats that it delivers, the stock of RAC equipment has been divided and categorised into a taxonomy.

This taxonomy of a technology is made up of 4 broad classes, 14 segments and 59 product categories as set out in *Appendix: B1: CHF3 Taxonomy*.

The 4 classes of equipment encompass the four main applications for RAC technology, being stationary air conditioning, mobile air conditioning, domestic refrigeration, and the refrigerated cold food chain. These four classes are listed in order of the size of the refrigerant bank of refrigerant they employ, at least in the Australian context.

Starting with these four classes the taxonomy is built on a second and a third order classification in the following hierarchy:

1. Class
2. Segment
3. Product category

Each product category has a product code which uses an abbreviation of the name of the class to identify the class to which it belongs followed by a set of numbers identifying the segment number within the class and then the products position or order in the segment. The abbreviations used for each class are listed below:

- Stationary air conditioning – AC
- Mobile air conditioning – MAC

- Domestic refrigeration – DR
- Refrigerated cold food chain – RCFC

The second order nomenclature of each class or equipment is the segment which describes the general product formats and size of the RAC technology. For instance, the equipment segments in the stationary air conditioning class, include:

- AC1: Small AC: Self-contained
- AC2: Small AC: Non ducted
- AC3: Medium AC: Ducted & light commercial
- AC4: Large AC: Chillers
- AC5: Other

Finally the third order nomenclature of the taxonomy is the product category, which are simply numbered for their order in the Segment. Product Categories may distinguish products on the basis of the size of their refrigerant charge, their refrigerating capacity, or some other distinguishing feature that both limits or defines the application of the product, or determines the physical equipment format, the way in which the elements of the core technology of vapor compression refrigeration relate to each other (i.e. self-contained or remote condenser).

For instance the stationary air conditioning class includes ‘Single split: non-ducted’ (AC2-1 and AC2-2) and ‘Single split system: Ducted (AC3-1), describing the two most numerous equipment formats where the indoor evaporator is mounted separately from the outdoor condenser and the two are connected by piping through which the refrigerant is pumped back and forth between them. AC1-1 is ‘Window Wall: Non-ducted unitary <10kW_r, distinguishing this product category from the AC2 Segment because all of the elements of the vapor compression refrigeration system are integrated into a single device. Portable air conditioners are in the same segment as window wall units as they are also sealed unit (i.e. self-contained) and with similar refrigerating capacities.

Some numerous equipment types have two product categories, for instance:

- ‘Single split: Ducted single phase (AC3-1); and
- ‘Single split: Ducted three phase (AC3-2).

The two product categories AC3-1 and AC3-2 are distinguished by whether the equipment can be connected to single phase or three phase power. In this instance this distinction provides a direct correlation to the capacity of the compressors used and thus the refrigerating capacity range of the products in each product category.

Not all product category allocations may appear an obvious fit on first inspection. For instance in the light commercial segment (AC6) of stationary air conditioning there are five product categories including AC6-5 pool heat pump as the last product in the segment. This product has been classified in the selected light commercial segment because in terms of electrical capacity, functional design, refrigerant type, refrigerant charge size and energy service delivered, it is effectively similar to other products in the segment.

Due to the ubiquitous reach of RAC technology there are also some segments and product categories that include some ‘miscellaneous’ and ‘other’ descriptions, for instance in the mobile air conditioning class, in the large mobile air conditioning segment, several product categories are listed that include registered shipping and aircraft, locomotives and caravans. Obviously while the physical formats and even the refrigerants used are likely to be very different across these diverse applications, all of these product categories are defined by their end use in mobile systems.

The concept and framework of the taxonomy was developed in the early stages of researching and writing Cold Hard Facts 1 in 2006 and was then formalised and updated in 2013. Since that time additional data has come to light, and indeed some large populations of RAC equipment that were essentially not recognised in

2012, that has required some changes to be made to the taxonomy. The taxonomy below is the system of organising RAC technology that has been used in research and writing this report, Cold Hard Facts 3.

Refer to *Appendix B1: CHF3 Taxonomy*.

11.2 Data and assumptions

The data presented in this report has been derived from an extensive Excel workbook that has, at its core, a stock model of RAC equipment employed in Australia organised into a comprehensive taxonomy of equipment types, sizes and end-use applications. This model also reports annual usage, consumption and emissions of ODS and SGGs for non-refrigerating applications such as foam blowing, aerosols, and fire protection.

In this report the Expert Group RAC Age-Cohort Mass Balance Stock Model is referred to as the RAC Stock model.

11.2.1 Data underlying the stock model

The first version of the RAC Stock model was 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) (now the Department of the Environment and Energy) 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, collected from a number of importers, manufacturers and from published market research, constructed into the early years of the model and then released 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 the Environment and Energy data including bulk and pre-charged equipment import statistics by quantity, mass, species, licence holder, product category from 2006 to 2017 (DoE 2017a) ⁶⁵;
- Reviews of data included in regulatory impact statements and product profiles for air conditioning equipment (i.e. split systems, chillers, close control, portable, etc.) (E3 2017a), refrigeration display and storage cabinets (E3 2016), domestic refrigerators and freezers, non-domestic refrigeration (E3 2009), and other products such as high efficiency fans (E3 2017b) and 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, 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, upstream processors and end-users of natural refrigerants to establish aggregate industry measures;
- Market intelligence reports with monthly sales (\$ and quantity) of HCFCs and HFCs by species including refrigerant re-use;
- Market intelligence reports of refrigeration equipment sales (by type and capacity); and,
- 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, the main outputs, or the structure of the model.

The stock model has been further refined following more recent assignment including:

- Cold Hard Facts 2 prepared the Department of the Environment and Energy, 2013;
- A study into HFC consumption in Australia in 2013, and an assessment of the capacity of Australian industry to transition to nil and lower GWP alternatives way from HFCs, prepared for the Department of the Environment and Energy, April 2014;
- Environmental Impacts of Refrigerant Gas in End-of-Life Vehicles in Australia, prepared for the Department of the Environment and Energy, 2014;
- Assessment of environmental impacts from the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, prepared for the Department of the Environment and Energy, April 2015; and,
- Cold Hard Facts 3, prepared for the Department of the Environment and Energy (this report)..

11.2.2 Product category stock models

Detailed and quite high resolution and high confidence 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 population and annual equipment retirement estimates by refrigerant species.

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.

⁶⁵ Not all refrigerants are defined as controlled substances under the Ozone Protection and Synthetic Greenhouse Gas Management Act. All of the major classes of HCFCs and HFCs must be reported.

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. 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 $N_{2000}(1-p)$, where N_{2000} 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:

$$\Phi(2012-2000+0.5; \mu, \sigma) = \Phi(12.5; \mu, \sigma)$$

Where $\Phi(x; \mu, \sigma)$ 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 to predict the refrigerant mix of the bank and in retiring equipment. This methodology has been refined further for end-of-life vehicles with a survival curve which is a normal distribution with a mean retirement age of 18.6 years and a standard deviation of 6.2 years up to age 27, then uniform distribution out to age 64 years where it hits 100% of retirements. This curve simulates actual vehicle registrations in ABS Census of Motor Vehicles, 2014, TableBuilder.

11.2.3 Refrigerant charges and species

The size of the refrigerant charges and species used in various equipment classes are known from manufacturers' documentation and checks of equipment and appliances in the market. The size of refrigerant charges can also 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.

In some product categories the average charge size has been changed to reflect changing average refrigerating capacity, and due to the natural rate of improvement of the technology towards smaller charge sizes. For example, air conditioning systems on large buses and coaches greater than 12 tonnes GVM had an average charge of 9.0 kg prior to 2012. Following a detailed review of equipment models from major participants the average charge in 2016 has been revised down to 5.5 kg.

The average charge for the same type of equipment with roughly the same refrigerating capacity can be different by species. For example, the same capacity wall hung split air conditioning system contains an average charge of 1.7 kg of HCFC-22 as this is older technology, 1.45 kg of HFC-410A and 1.15 kg of HFC-32.

The refrigerant 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 refrigerant 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 refrigerant.

From 2006 to July 2012 the Department of the Environment and Energy 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 refrigerant charges in various products, and the dissection and transition of refrigerant species in products. The pre-charged equipment date collected by the Department since July 2012 has been aggregated into broader equipment categories that require greater interpretation to assess average charges and refrigerant types.

The average charge used in the table above is the average charge of the most common species found in that product category. Charges of other species used in the same product category may differ to some extent.

Refer to *Table 38: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan)* for most common substance, for average charges applied to all product categories in the taxonomy.

11.2.4 Small MAC refrigerant charges

The CHF3 RAC Stock model uses both ABS sales (ABS 9314.0 2017) and registration data (ABS 93090.0 2017) to calculate the current fleet of small MAC comprising passenger and light commercial vehicles, rigid trucks, articulated trucks, non-freight trucks. and small buses with a GVM less than 4.5 tonnes and assumes 100% of vehicles manufactured after 2000 contain air conditioning.

The RAC Stock model uses the polynomial in *Figure 53* to calculate average charge by year of manufacture for Small MAC.

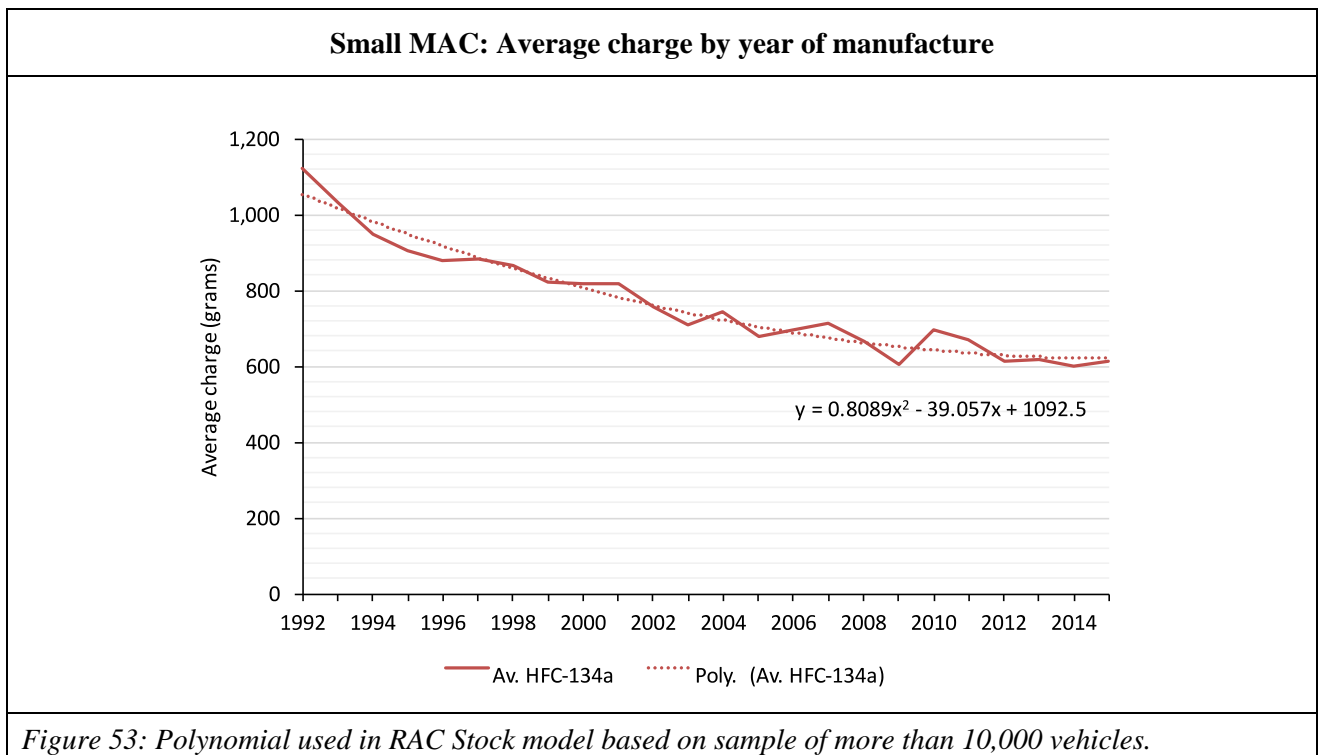


Figure 53: Polynomial used in RAC Stock model based on sample of more than 10,000 vehicles.

11.2.5 Proportion of hydrocarbon in small MAC

The estimated portion of the fleet containing hydrocarbon in 2012 has been revised down to 3.8%, and the 2016 estimate is at most 4.2%, which equates to around 743,000 vehicles. The CHF3 RAC Stock model estimates the number of vehicles charged with hydrocarbon based on the following method and assumptions:

Calculation method:

- The annual supply of hydrocarbon, less service usage equals volume available for conversions.
- The volume available for conversions, adds vehicles to the hydrocarbon fleet.
- The attrition rate retires vehicles from the hydrocarbon fleet.
- The number of hydrocarbon charged vehicles at the commencement of the following year is the starting fleet, plus conversion, less retirements.

Assumptions:

- Number of vehicles charged with HC in 2002 is 50,000.
- Average age of vehicle converted is greater than 10 years.
- Attrition rate of vehicles greater than 10 years old is 10%.
- Annual leak rate is 10%.
- Proportion HC charge to 134a based on mass is 30%.
- Growth in aggregate supply beyond 2016 is 2% per annum.

The annual aggregate supply of hydrocarbon to the automotive market was provided in confidence by all market participants.

11.2.6 Surveys of mobile air conditioner refrigerants

Refrigerant Reclaim Australia (RRA) has conducted more than 2,000 inspections of passenger and light commercial vehicles between 2013 to 2017 to analyse the refrigerants in mobile air conditioners.

The surveys were conducted across all major capital cities as well as regional areas to provide national coverage and dissect the refrigerant types found into the following categories HFC-134a (100% and >95%), HC (100%, >95% and HC mix), CFC-12, and empty. The surveys record the year of vehicle manufacture, which shows a sample that is consistent with the age range of the current fleet with the vehicles most frequently inspected being around 10 years old, and with a long tail of vehicles dating back to the 1970s.

The 2017 survey results found 86.0% of vehicles contained HFC-134a, 6.4% contained some HC, 0.2% contained CFC-12, and 7.5% were empty. The presence of CFC-12 found in the surveys has declined from 2.6% in 2013 to 0.2% in 2017. The proportion of vehicles that contained some portion of hydrocarbon varied from 3.7% to 6.5% over the five year survey period, however the number of vehicles that contained >95% HC ranged from 0.6% to 2.5%.

11.2.7 Leak rates and direct emissions

At various points in the report the 'leak rate' of refrigerant from a class, segment or product category is discussed.

The rates that different product categories actually leak over a period varies 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.

On occasion leak rates are discussed which refer only to the rate of loss of refrigerant from an individual type or even individual piece of working equipment over a period, or as an instantaneous observation. When the term leak is used it is not intended to capture the entirety of losses of refrigerant over the lifetime of the equipment.

Losses of refrigerant over the total life of a piece of equipment or even a class of equipment are referred to as 'direct emissions' when discussed in the context of greenhouse gas emissions – as compared to the 'indirect emissions' created by the consumption of electricity.

The annual leak rates referred to above are expressed as a percentage of the initial charge per annum, and defined as 'direct emissions' incorporating:

- Refrigerant that leaks from equipment, either from slow leaks in operation, or as a result of 'catastrophic' losses when a piece of equipment suffers some sort of breakdown or failure of containment and the entire charge is lost to air;
- Refrigerant that is lost through handling losses during installation and commissioning of equipment, and during servicing of equipment; and,
- Refrigerant that is lost along the supply chain for the species of gas that the class of equipment requires while gas is being transported, decanted or handled.

Direct emission rates applied in the model are listed against product categories in *Appendix: B1: CHF3 Taxonomy*.

The understanding of the equipment in the product categories has evolved over several years and partly as a result of having to prepare a series of research papers in this area. In the course of various projects all available data in this area was reviewed and a database of findings and observations of leak rates by other researchers was constructed.

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

- *A study into the HFC Consumption in Australia* prepared by the Expert Group for DSEWPaC, 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.
- *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 National Greenhouse and Energy Reporting (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 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.

- Other research used to inform 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 in the US and EU.

Direct emissions from product category, in any one year, are always going to be greater than or, at the very best, equal to the service usage for that product category in that year. This is a conclusion from other data and research that shows that in the majority of product categories, particularly those categories that encompass smaller privately owned equipment, service is rarely comprehensive across the stock and at least some part of the stock of equipment in any category at any time, is operating on less than the full technical capacity of the refrigerant charge. This is discussed further in *Section 11.2.9* below.

11.2.8 OEM, service usage and service rates

Bulk refrigerant is primarily imported for servicing and manufacturing RAC equipment. Other uses include, for instance, charging new commercial refrigeration equipment with remote condensers that have been manufactured or imported with a nitrogen charge and then charged on site. Smaller volumes of bulk refrigerant imports are used in non-RAC applications including foam blowing, aerosols, fire protection, as cleaning agents (solvents), and electricity distribution.

The volume of refrigerant 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 refrigerant purchased in any year for their production.

In CHF2 the annual usage of bulk imports of HFCs, after deducting refrigerant used in installation of new systems and by OEMs in Australia, was used as a proxy for effective leak rates of equipment. It was assumed that the balance of the refrigerant imported every year, and not used in new installations or by OEMs was therefore used maintaining and servicing the stock of equipment. It was further assumed that all product categories in the stock of equipment were maintained at close to an optimal charge, on average, over the effective life of the equipment.

Since CHF2 a number of pieces of research have demonstrated that stocks of operating equipment are not always maintained at optimal charges and that, as evidenced by reports from service technicians, and from surveys of the charge remaining in equipment that has reached the end of its useful life, some segments and product categories will operate for a significant portion of their operating life on sub-optimal charges.

This realisation has been built over a period during which a great deal of work was undertaken by the authors in the course of several projects to reconcile usage of declared bulk refrigerant imports into Australia, for all major refrigerant species, with all the possible end uses of the refrigerant.

Combined with supply chain and service company interviews, the analysis of bulk refrigerant imports, plus the expected losses from the stock of equipment is used to deduce the total volume of refrigerant applied to particular product categories to at least partially replace lost refrigerant across the stock of equipment in the Australian economy.

For example, a mobile air conditioning aftermarket survey was undertaken to assess HFC-134a usage for service, repairs and losses as the result of car crashes. The assessment concluded that the service usage rate for the last three years was less than 5% per annum of the MAC bank, versus the estimate of 10% leak rate, plus 1.5% applied for car crash losses in 2012. On this basis the service rate is around half of the leak rate, however the usage prior to 2012 was known to be much higher.

Assuming this under-servicing of the stock of equipment is consistently around 25% to 30% of annual losses, then the actual bank of refrigerant in the stock of MAC is about 82% of the capacity of that stock if it was

fully charged. The banks in other sectors, with less under-servicing, would be more full and the total bank is around 92% full.

These new insights into the industry and the operation and maintenance of the stock of equipment have led to the development of the concept of a 'service rate' for certain segments and product categories, where a discounted service rate (i.e. a service rate of less than 100%) leads to calculation of a 'partially charged bank', being less than the optimal or full bank.

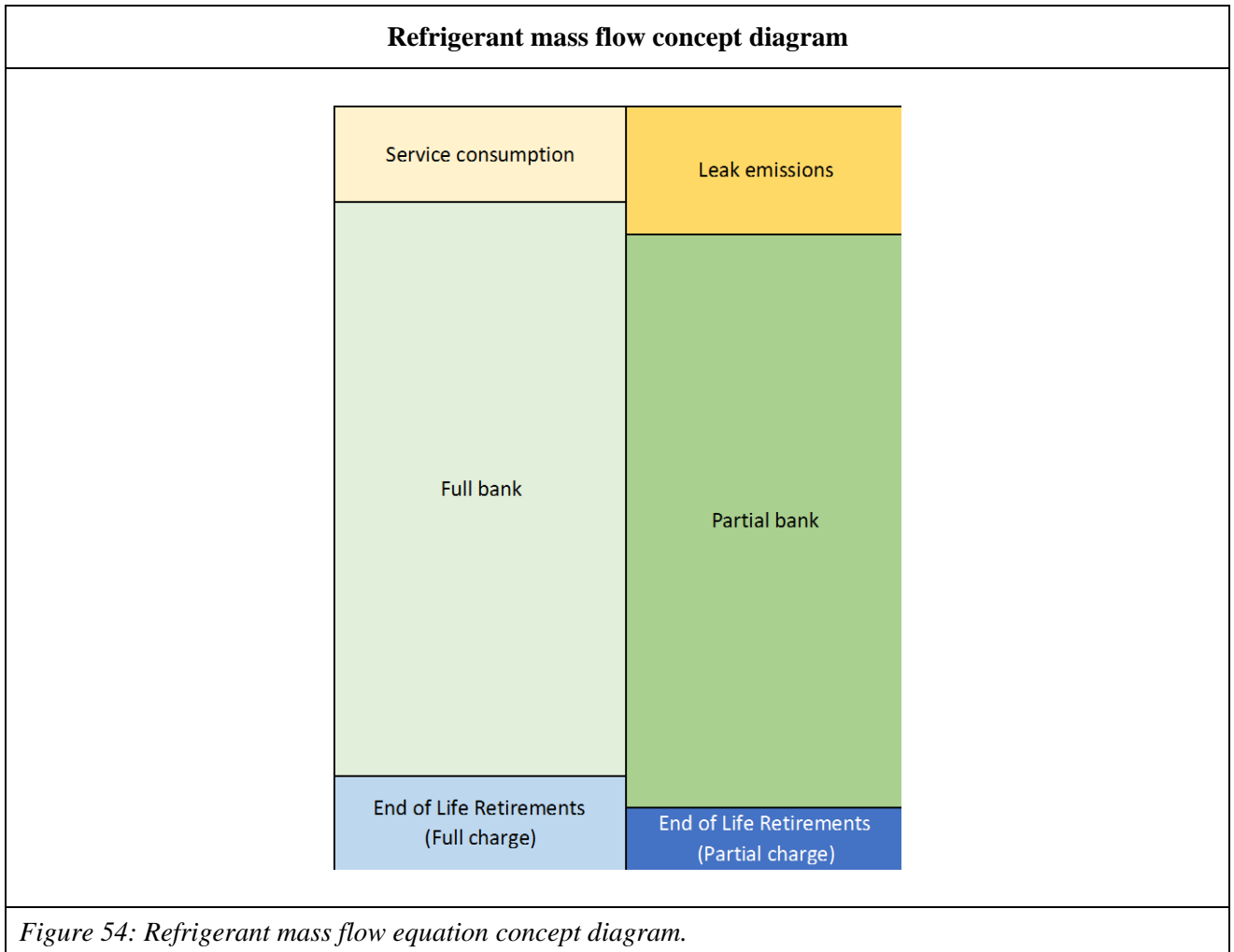
The main segments where under-servicing is thought to be significant includes small MAC and whitegoods (i.e. domestic refrigeration, portable AC, window/wall AC and wall hung split systems) particularly where the device is cheaper to replace than service. Notably these two segments are dominated by private ownership.

11.2.9 Calculating the full bank and partially charged bank

External references and field experience are used as a starting point for leak rates applied to product categories. Service rates are as set out in the section above. A 'full bank' is the product of a known stock of equipment multiplied by the average original charge rates in the various cohorts of equipment that make up a product category, derived largely from manufacturers' specifications. Residual charges in end-of-life equipment are estimated based on various surveys and published sources.

Using this data, a mass balance equation is used to calculate the actual refrigerant bank, referred to as the 'partial bank', in a product category and thus in the stock of equipment.

Figure 54 below illustrates the mass balance concept and relationship between the full bank, service usage and total possible end-of-life residual charges on one side of the equation, and the partial bank, direct emissions and actual end-of-life retirements from the partial bank on the other.



The conceptual model of the partial bank can be validated by applying the same data and mass balance equations in a segment or product category for which all data required can be found.

For example, aftermarket surveys covering all major market participants determined that service usage for small MAC was found to be around 5% of the MAC full bank in 2014, 2015 and 2016.

The average end-of-life charge in small MAC is known from surveys of ELVs to be 67% of the original charge. A life cycle charge profile for small MAC was developed that assumes vehicles retain 100% of the original charge from years one to five during the typical warranty period, then follows a linear decline from 100% in year five to 67% of original charge at retirement.

Therefore, the annual leaks can be calculated from the mass balance equations in kilograms or tonnes, then converted to a percentage based on the original charge in the full bank. In small MAC this analysis yields an annual average leak rate of the equipment of 6.8% in 2016.

The leak rate in the model depends on the assumptions, for example the theoretical rate of small AC: Split AC is 3.6% based on a 2% service rate, average lifespan of 12 years and EOL residual of 80%, and has a theoretical leak rate of 2.8% based on an EOL residual of 90%.

Figure 55 provides a graph of the mass balance elements for small MAC from 2016 to 2030. The full and partial bank axis is on the right in tonnes, and the annual flows axis is on the left. This modelling approach provides regulators with reconciled usage which is important from a Montreal Protocol perspective, and annual emissions (leak and end-of-life minus recoveries), essential for domestic emission reduction policy and understanding Kyoto Protocol elements.

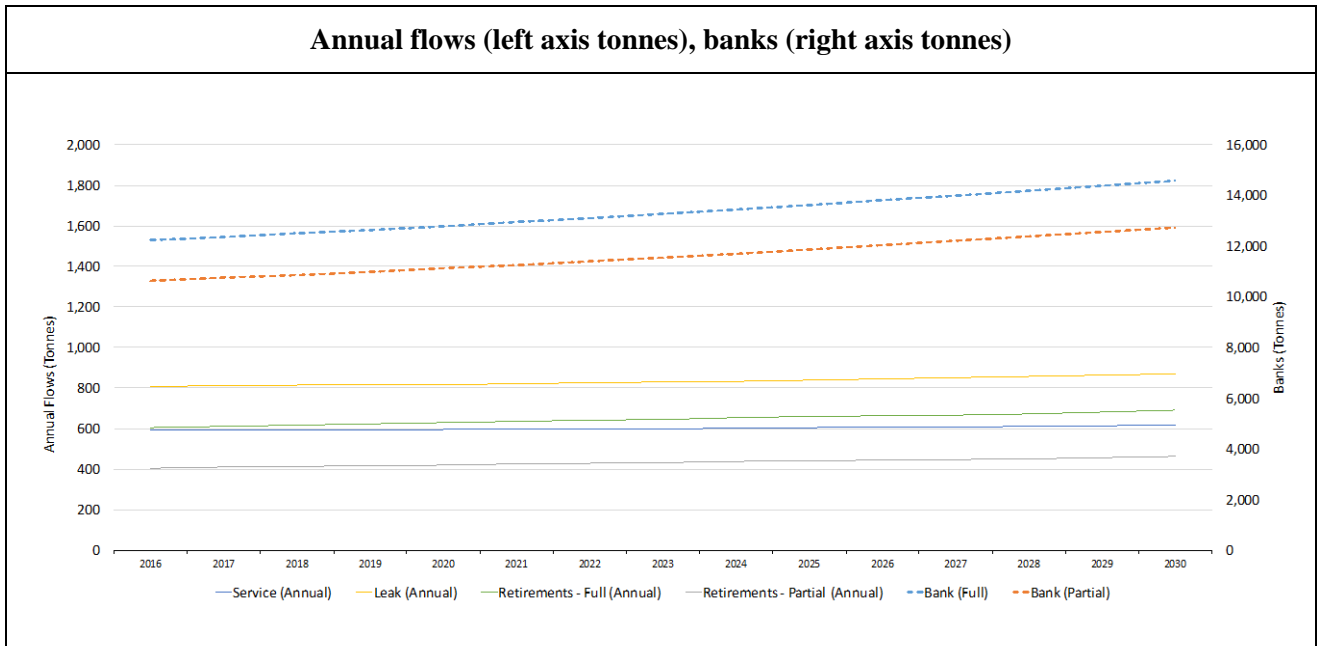


Figure 55: Small MAC Mass balance elements, annual flows and banks from 2016 to 2030 in tonnes.

Refer to Table 38: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan) for most common substance, for equipment service usage rates for each product category in the taxonomy.

11.2.10 The bank of refrigerant

In simple terms the bank of refrigerant is calculated by using average charges of refrigerant in each product category to calculate the total ‘full bank’ of refrigerant by product category and segment, and by species.

Leak rates are used to assess the volume of refrigerant required for servicing equipment segments in any year. This service demand is reconciled against the known volumes imported and sold to deduce a service rate for each product category. The full bank multiplied by the service rate results in a calculation of the ‘partially charged bank’, generally referred to in this report simply as ‘the bank’, or the ‘refrigerant bank’.

In generating a ‘partially charged bank’ for any product category, the RAC Stock model also takes account of the changing charge size of the various vintages of equipment in some product categories.

Starting with the bank in 2016, projections of the changing composition of the bank out to 2030 were prepared by combining the outputs from the model that projects the future sales mix of equipment by species employed.

11.2.11 Bank by product category

A ‘full bank’ and ‘partially charged bank’ of refrigerant can be calculated for each product category with varying degrees of confidence depending on some of the characteristics of the product category, particularly the estimated leak rates and service rates of the different categories.

The ‘full bank’, or fully charged bank, is calculated based on the number of devices in the product category multiplied by the average original charge of that type of equipment when it is initially installed/purchased.

The ‘partially charged bank’ will, in practice, be less than the fully charged bank as the charge in individual pieces of equipment in the category declines over time until the equipment retires. How much less the actual bank is than the full bank at any time is determined by both the level of leaks from the equipment in that

particular product category, off-set by the normal level of servicing of the stock in that product category. Both leak rates and service rates differ across the entire stock of equipment.

The stock of equipment in each product category is made up of equipment cohorts based on date of manufacture, ranging from new equipment that is fully charged, through to aging equipment eventually reaching end-of-life with only a residual charge of refrigerant remaining. For example, the residual charge of a small mobile air conditioner at end-of-life is estimated to be just two thirds of the original charge, and the average age of vehicles in the fleet is around 10 years (DoEE 2015b).

The table below provides a summary of the refrigerant charges, end-of-life charges, leak rates, service rates and average equipment life span that are applied in the stock model. These metrics are applied to produce a number of outputs of the RAC Stock model, and ultimately define the bank of refrigerant.

Table 38: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan) for most common substances.

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2016	EOL ⁶⁶	Tech Rec ⁶⁷	Service rate (2016)	Theoretical leak rate (2016)	
Small AC: Sealed							
Non-ducted: unitary 0-10 kW _r	0.75	0.65	85%	90%	2.0%	2.5%	12.0
Portable AC: 0-10 kW _r	0.6	0.55			0.0%		8.0
HW heat pump: domestic	0.9	0.9			2.0%		15.0
Heat pump clothes dryers	0.46	0.46			2.0%		16.5
Small AC: Split							
Single split: non-ducted ⁽¹⁾	1.7 (HCFC-22)	1.15 (HFC-32)	80%	90%	2.0%	3.5%	12.0
Medium AC							
Split system: ducted	4.7	4.7	80%	90%	2.0%	2.7%	16.0
RT Packaged systems	12.2	15.0			2.0%		20.0
Multi split	3.0	3.0			2.0%		20.0
VRV/VRF split systems	11.0	9.0			2.0%		20.0
Close control	30.0	30.0			2.0%		12.5
HW heat pump: commercial	110.0	110.0			2.0%		20.0
Pool heat pump	2.8	2.8			2.0%		17.5
Large AC							
<350 kW _r	40.0	40.0	85%	95%	4.0%	4.5%	20.0
>350 & <500 kW _r	60.0	60.0			4.0%		25.0
>500 & <1000 kW _r	210.0	210.0			4.0%		25.0
>1000 kW _r ⁽²⁾	670.0	670.0			4.0%		25.0

⁶⁶ The EOL factor is used to calculate the residual EOL charge at end-of-life. The end-of-life factors are generally consistent with others cited internationally (e.g. ICF 2010) and in good practice guides by the IPCC.

⁶⁷ The calculated EOL charge in each segment has a maximum technical recovery factor that is uniformly set at 90%, except for air conditioning chillers, supermarket systems and commercial refrigeration with remote condensing units where the technical recovery rates are set to 95%.

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2016	EOL ⁶⁶	Tech Rec ⁶⁷	Service rate (2016)	Theoretical leak rate (2016)	
Small MAC							
Passenger and LC Vehicle	0.629	0.622	67%	90%	4.8%	6.7%	18.6
Large MAC							
Registered buses (>12 GMT)	9.0	5.5	80% ⁽³⁾	90%	9.8%	10.8%	20.0
Registered buses (>4.5 & <12 GMT)	4.0	3.0			9.8%		20.0
Un-registered: passenger rail	15.0	15.0			9.8%		30.0
Un-registered: Locomotive	4.0	4.0			9.8%		30.0
RV and caravan	0.75	0.75	85%		2.0%		15.0
Un-registered: off-road, defence and other (boat, etc.)	2.75	2.75	80%		9.8%		15.0
Registered marine and pleasure craft	2.25	2.25			2.0%		15.0
Refrigeration							
Refrigeration cabinets: self-cont.	0.5	0.5	85%	90%	6.0%	7.2%	11.5
Refrigeration beverage vending machines	0.25	0.25			6.0%		12.0
Beverage cooling (post mix)	0.7	0.7			6.0%		8.0
Ice makers	1.0	1.0			6.0%		11.0
Water dispensers (incl. bottle)	0.05	0.05			6.0%		8.0
Other self-cont. refrigeration equipment	0.5	0.5			6.0%		12.0
Walk-in cool rooms: mini: Slid-in/Drop-in	0.75	0.75			6.0%		12.0
Walk-in cool rooms: small: Slid-in/Drop-in	1.4	1.4			6.0%		12.0

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2016	EOL ⁶⁶	Tech Rec ⁶⁷	Service rate (2016)	Theoretical leak rate (2016)	
Walk-in cool rooms: mini: remote	1.0	1.0	80%	95%	14.5%	15.7%	12.0
Walk-in cool rooms: small: remote	5.0	5.0			14.5%		12.0
Walk-in cool rooms: medium	17.0	17.0			14.5%		12.0
Walk-in cool rooms: large	23.0	23.0			14.5%		15.0
Walk-in cool rooms: warehouse	30.0	30.0			14.5%		20.0
Refrigeration cabinets: remote	10.0	10.0			14.5%		15.0
Beverage cooling (beer)	40.0	40.0	80%	95%	14.5%	15.7%	15.0
Milk vat refrigeration	40.0	40.0			14.5%		30.0
Packaged liquid chillers (incl. Milk vat)	40.0	40.0			14.5%		20.0
Process and mfg. (<40 kW _r)	40.0	40.0			14.5%		20.0
Supermarket refrigeration: small	500.0	500.0	100% ⁽⁴⁾	95%	11.8%	11.8%	15.0 ⁽⁵⁾
Supermarket refrigeration: medium	900.0	900.0			11.8%		15.0
Supermarket refrigeration: large	1,100.0	1,100.0			11.8%		15.0
Mobile refrigeration: road: trailer - inter-modal	10.0	6.5	90%	95%	15.0%	15.7%	12.5
Mobile refrigeration: road: diesel drive	7.0	4.0			15.0%		12.5
Mobile refrigeration: road: off engine	4.0	2.2			15.0%		10.0

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2016	EOL ⁶⁶	Tech Rec ⁶⁷	Service rate (2016)	Theoretical leak rate (2016)	
Mobile refrig: marine	130.0	130.0	90%	95%	15.0%		25.0
Domestic refrig.							
Refrigerators and freezers ⁽⁶⁾	0.140	0.133	90%	90%	1.0%	1.7%	16.5
Portable refrig.	0.055	0.055	95%	0%	1.0%		12.0
Vehicle refrig.	0.035	0.035	95%		1.0%		12.0

Notes:

1. Charge for HFC-410A single split system is 1.45 kg.
2. The HCFC-123 charge is different with capacity range >500 & <1000 kW_r = 180 kgs, and >1000 kW_r = 670 kg as they are generally large capacity models.
3. Large MAC EOL percent adjusted to be consistent with commercial AC.
4. Supermarket refrigeration adjusted to 100%, consistent with high service levels, recovery and re-use.
5. Supermarket lifespan relates to average plantroom refurbishment lifespan.
6. Refrigerators and freezers average charge for HC is 0.55 grams. Portable and vehicle refrigeration rarely use HC.

11.2.12 Hydrocarbons and equivalent refrigerant charge

The equivalent refrigerant charge shows changing market share. Instead of showing this through the proportion of devices, it shows it through the proportion of refrigerant a particular piece of equipment or device would have used had newer low GWP technology, such as hydrocarbon, not replaced it.

The equivalent refrigerant charge is a tool used in this report to help visually compare different equipment types on the basis of the work that the refrigerants carry out. This has assisted in illustrating how different sectors are transitioning to new equipment – either at a particular point in time, or the rate of those transitions over time.

It does not ignore or replace the ‘actual’ charge; it is an alternative measure used to help represent the rate of transition of the number of devices and the energy services they provide.

The model assesses the charge size and bank based on equivalent refrigerant charge and actual refrigerant charge. The equivalent charge size relates to the amount of high GWP HFC that will be displaced, not the actual charge of the lower GWP refrigerant which can be up to 70% less (e.g. hydrocarbon).

The equivalent charge provides a comparative representation of the rate of transition of the number of devices, and the energy services they provide whereas the actual refrigerant charges in aggregate can provide insights into the scale of the bank and skills required to service different refrigerant classes.

11.2.13 Leak rate improvements over time

When considering average economy wide leak rates it is important to recognise that they generally improve over time. As older equipment retires and is replaced with new designs that employ improved containment, leak rates of new equipment are nearly universally found to be lower, with the effect that the average leak rates across a product category reduces over time.

The evolution of wall-hung and ducted split air conditioning equipment demonstrates this evolution in improved design and manufacturing capability. For instance, the older generation equipment from the 1990s and the 2000s, containing HCFC-22, has leak rates in the order of 8% per annum, versus current generation models with leak rates of around 3% per annum and less.

In addition, as field practices improve, and as the cost of refrigerant increases, leak rates decline and can do so very rapidly. This was amply demonstrated by the market response to the rapid rise in the price of HCFC-22 to wholesale prices of around \$100 per kg that has now stabilised at this level.

The Australian supermarket industry is another 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 National Greenhouse and Energy Reporting Act 2007. Current market intelligence and reconciling usage shows leak rates of HFC-404A less than half this within the main supermarket chains. Supermarkets, and other segments of the industry that employ equipment that is maintained by engineers, have improved leak rates substantially since the introduction of the equivalent carbon tax in 2012. Even though this tax was only in place for two years, it appears to have substantially changed behavior in several sectors of the industry.

11.2.14 Losses at end-of-life and recoverable refrigerant

Refrigerant recovery is compulsory under the OPSGGM Act and the associated Regulations. Refrigerant Reclaim Australia (RRA), a not-for-profit organisation, is authorised by the Australian Competition and Consumer Commission (ACCC) to work with industry to recover, reclaim and destroy ozone depleting and synthetic greenhouse gases.

The EOL charge and therefore the potential end-of-life emissions are calculated by multiplying the average refrigerant charge by the EOL factor - the proportion of original charge remaining at end of life for each segment or equipment category, if available at that level. The EOL factors used were generally consistent with those used by the IPCC and ICF International in a variety of technical papers (ICF 2010).

The EOL charge multiplied by the technically recoverable factor (recovery efficiency/recycling factor) equates to the recoverable refrigerant, the amount that is available for either reclamation or destruction. Between 30 June 2007 and 30 June 2012 an average of about 500 tonnes of waste HCFCs and HFCs was collected and destroyed annually in Australia via the RRA scheme. The balance that is not destroyed, re-used nor reclaimed is considered a direct emission.

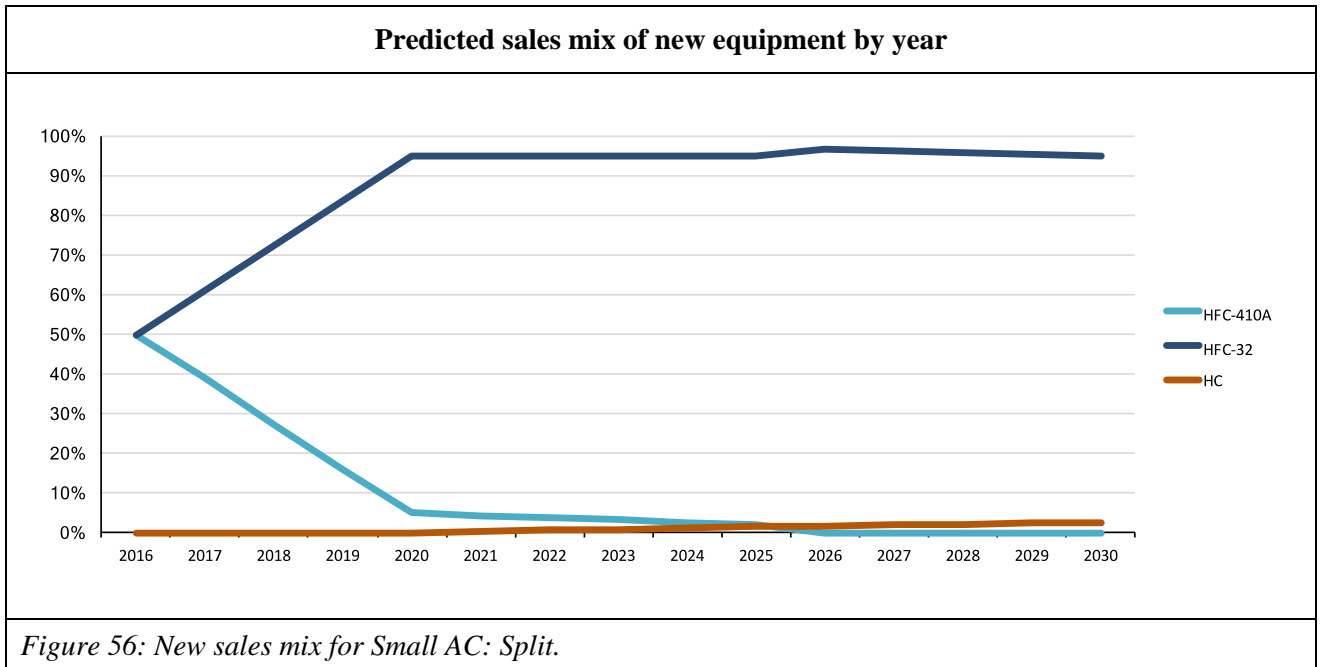
For some products direct emissions include losses calculated for appliances and equipment reaching the end of the products useful life. The assumption for some products, such as domestic refrigerators and portable air conditioners, is that all of the remaining charge of refrigerant is lost to air and none is recovered.

11.2.15 New sales mix projections

Projections of new sales mix by species are based on linear projections of sales by species in periods from 2016 to 2020, 2020 to 2025, and 2025 to 2030.

In some broad product categories there are a variety of equipment types and the proportion of a particular species is a mass weighted calculation based on average charges and sales in that year. The dominant substance is typically used as the residual portion and therefore is not linear. An example of the new sales mix projection for small AC: Split is provided in *Figure 56*. The assessment of the new sales mix proportion for this product category in 2016 was based on a review of pre-charged imports that found 42.4% of single split systems contained HFC-32 and the balance HFC-410A.

The new equipment sales mix charts and data tables by year for each segment in the taxonomy is provided in *Appendix B2: New equipment sales mix by segment*.



11.2.16 GWPs and refrigerant compositions

Global Warming Potential

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

Australia’s original legally binding emissions obligations under the Kyoto Protocol (1997 to 2013) were 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 1989* (the OPSGGM Act), cited GWPs from AR2.

Revised GWP values were reported in the Fourth Assessment Report (AR4) in 2007. The 2nd Kyoto Protocol commitment period is based on AR4 values. The Australian Government adopted AR4 from July 2017.

This report uses one hundred year GWP values from the Fourth Assessment Report (AR4 GWP-100). A new class of substances that are mentioned in this report are 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 (HFO-1234yf AR4-100 GWP of 5 and HFO-1234ze AR4-100 GWP of 5). While the Fifth Assessment Report includes HFC-1234yf and HFC-ze, the AR5 GWP-100 values have not been used. The AR5-100 GWPs of HFO-1234yf and HFO-1234ze have been revised down to 1.

Table 39 below lists both AR2 and AR4 GWP values as a reference for readers, and *Table 40* provides details of the refrigerant mass composition of common blends used in Australia that are used to calculate the GWPs of the blends from the IPCC reports.

Table 39: GWP factors of main refrigerant 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-448A	-	1387
HFC-449A	-	1397
HFC-452A	-	2141
HFC-507A	3300	3985
HFC-513A	-	631
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

Common substances	AR2 GWP-100 Year	AR4 GWP-100 Year
CO ₂ (R744)	-	1
Ammonia (R717)	-	0
HFO-1234yf ⁽⁵⁾	-	5
HFO-1234ze(E)	-	5
HFO-1233zd	-	5
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 throughout the report 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 the manufacturers 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.
6. *Table 40* provides the refrigerant mass composition of common blends used in Australia.

Table 40: ASHRAE Refrigerant designation and refrigerant mass composition of common blends used in Australia.

ASHRAE Refrigerant designation	Refrigerant composition (Mass %)
Refrigerant blends: Zeotropes	
R404A	R125/143a/134a (44.0/52.0/4.0)
R406A	R22/600a/142b (55.0/4.0/41.0)
R407C	R32/125/134a (23.0/25.0/52.0)
R407F	R32/125/134a (30.0/30.0/40.0)
R408A	R125/143a/22 (7.0/46.0/47.0)
R409A	R22/124/142b (60.0/25.0/15.0)
R409B	R22/124/142b (65.0/25.0/10.0)
R410A	R32/125 (50.0/50.0)
R422D	R125/R134A/R600A (65.1/31.5/3.4)
R427A	R32/R125/R143a/R134a (15.0/25.0/10.0/50.0)
R436A	R290/600a (56.0/44.0)
R438A	R125/R32/R134A/R600/R601a (45.0/5.0/45.0/4.0/1.0)
R436B	R290/600a (52.0/48.0)
R448A	R1234yf/R1234ze/R32/R125/R134a (20.0/7.0/26.0/26.0/21.0)
R449A	R1234yf/R32/R125/R134a (25.3/24.3/24.7/25.7)
R452A	R1234yf/R32/R125 (30.0/11.0/59.0)
Refrigerant blends: Azeotropes	
R507A	R125/143a (50.0/50.0)
R513A	R1234yf/R134a (56.0/44.0)

- The contents of this table are from ANSI/ASHRAE 34-2013, Designation and Safety Classification of Refrigerant, published on the ASHRAE website.

11.2.17 Energy consumption calculations and comparisons

The electrical consumption of products is estimated to allow a calculation of energy related emissions produced by each product, equipment category and segment.

CHF3 electricity consumption calculations have been compared to the most relevant recent studies commissioned by the Equipment Energy Efficiency (E3) program of the Department of the Environment and Energy.

Domestic refrigeration

CHF3 RAC Stock model estimates a total stock of greater than 19.2 million domestic refrigeration devices in Australia (including domestic freezers and small portable refrigerators).

The number of these devices that are used in residences is however less than that total stock of equipment. Deducting from this population of 19.2 million devices an estimated 888,000 portable refrigerators, that are run from vehicles, in caravans on and battery power of various sorts, and deducting a further estimated 5% of devices that are assumed to be used in business premises, such as restaurants and takeaway shops, and in office kitchens, and the CHF3 RAC Stock model arrives at an installed base of 17.41 million domestic refrigerators and freezers in residential buildings in Australia in 2016.

This is a value that aligns very well with the results of the Residential Baseline Study 2015 (E3 2015) which estimated an installed base of 17.68 million refrigerators and freezers in Australian homes in 2016.

The CHF3 RAC Stock model calculates the 17.59 million domestic refrigerators and freezers consumed 8,534 GWh in 2016 compared to 29.59 PJ (8,219 GWh) published in the Residential Baseline Study for 2016.

Hot water heat pumps

The CHF3 RAC Stock model estimates a stock of greater than 206,000 hot water heat pumps, a value that aligns with those published by the Clean Energy Regulator⁶⁸ of 210,649 devices registered at the end of 2016. The stock model assumes an average lifespan of 15 years, however reduces total stock at a slightly accelerated rate to account for older models that are more likely to have been retired since early 2000s.

As a result the CHF3 RAC Stock model estimates the stock of hot water heat pumps at 206,000 units that consumed 186 GWh in 2016 compared to the Residential Baseline Study that estimated 196,378 devices consuming 0.633 PJ (176 GWh) in 2015.

Stationary air conditioning

CHF3 stock numbers and energy use in stationary AC are based on slightly different equipment definitions and a larger number of categories than were used in the AC RIS prepared for DoEE in 2016. However by combining some of the categories used in CHF3, a comparison of the stocks used in both studies has been made below.

⁶⁸ <http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations#Solar-water-heater-SWH-installations>

Table 41: Comparisons of stock and electricity consumption values: CHF2 vs AC RIS: 2016 vs CHF3: 2016.

	CHF2: 2012		AC RIS: 2016		CHF3: 2016	
	Stock	Energy consumption (GWh)	Stock	Energy consumption (GWh)	Stock	Energy consumption (GWh)
Non-Ducted: Unitary	1,915,000	1,967	1,637,196	764	1,591,808	1,166
Portable AC	606,000	534	789,897	176	826,561	309
Single split system: non-ducted	7,145,000	7,542	7,864,553	5,652	9,238,148	7,972
Single split & packaged: ducted	1,304,000	13,472	1,741,133	6,294	2,025,821	9,254
Multi split	276,000	2,041	264,496	320	331,165	516
VRV/VRF split systems			86,204	626	93,547	617
Heat pumps ⁽¹⁾	269,000	308	-	-	310,120	507
Close control	11,500	1,478	20,449	1,553	20,872	1,544
Chillers	28,500	6,335	20,664	6,144	24,914	7,676
Chiller ancillaries	-	3,167	-	-	-	3,838
Total	11,555,000	36,845	-	-	14,462,956	33,452

Notes:

1. "Decision and Consultation Regulation Impact Statement Air conditioners, Chillers and Close Control Air Conditioner: Energy Modelling & Cost Benefit Analysis" prepared by EnergyConsult on behalf of the trans-Tasman Equipment Energy Efficiency (E3) programme, 2015 to 2017 (E3 2017a).
2. Domestic and commercial hot water heat pumps; swimming pool heat pumps; and heat pump clothes dryers.
3. The energy consumption calculations for stationary AC includes fan energy for equipment where the fan is incorporated into the equipment, which includes all residential and light commercial AC equipment. Large AC such as space chillers have separate ventilation systems and ancillaries including pumps and motors. An allowance of 50% for ancillary equipment is included in the calculation for both air cooled and water cooled chillers.
4. No allowance is made for fan energy for residential, commercial and industrial ventilation that includes a diverse range of applications such as domestic exhaust fans, kitchen exhaust fans for residences and commercial kitchens, carpark ventilation systems to monitor and control carbon monoxide levels, and ventilation systems for industrial processes.
5. CHF3 and the AC RIS 2015 use similar average capacities and efficiencies (i.e. AEER and ACOP) in the energy consumption calculations.

Residential AC electricity use calculations

The CHF2 calculation of residential AC electricity use was based on 500 full load hours of cooling and heating combined and used average COP and EER efficiencies by equipment class without any discounting factors.

The AC RIS 2015 residential calculation was based a 2012 ABS survey of general operating hours of heating and cooling equipment by state, which calculated an average of 979 operating hours for a non-ducted single split system stock mix and 932 operating hours for a ducted equipment stock mix. A product adjustment factor of 0.75 was applied to non-ducted single split systems and heating hours discounted by a factor of 0.56 based on a stock weighted average.

Finally, the AC RIS incorporated part load calculations for a range of part load operating bins and efficiencies, which discounts the equivalent full load hours by varying amounts, depending on the efficiencies and variability of the technology type, before applying an occupancy factor of 0.9 to account for unoccupied dwellings (i.e. holiday homes). The result is that the AC RIS calculated electricity consumption on the basis of equipment being used for 250 full load hours for window wall units, 360 hours for non-ducted single split systems, and 450 hours for ducted single split systems.

The CHF3 residential calculation makes the same assumptions as the AC RIS 2015 except applies a part load to full load factor of 0.75 resulting in 454 full load hours, before applying an occupancy factor of 0.9 and a field efficiency factor of 0.9 for non-ducted single split systems and 0.85 for ducted systems that accounts for sub-optimal performance in the field versus rated efficiencies.

Business electricity use calculations

The CHF2 calculation of business electricity use was based on 1,255 full load hours (cooling plus heating) based on the assumption there were 251 working days (excluding weekends and statutory holidays), and the system operated 10 hours per day (i.e. 2,510 operating hours per annum) on full load 50% of the time.

The actual operating hours of businesses can vary significantly depending on the type of business. For example many large supermarkets can be open from 7.00 am to 12.00 pm and only close for Christmas day, equating to more than 6,000 operating hours per annum. Smaller retail stores are often open weekdays plus half a day on the weekend and one night to 9.00 pm weekdays equating to around 2,800 operating hours per annum.

Many businesses have their air conditioning systems pre-programmed to operate around 10 hours per day to take into account occupants arriving early and leaving later. Some medium to large commercial, office and education buildings may have an air conditioning button that occupants can push to provide temporary conditioning outside normal working hours.

The AC RIS 2015 calculation of electricity use in businesses was based on 2,062 operating hours and undertakes part load calculations for a range of part load bins and efficiencies by technology type. When compared to a full load calculation the resulting hours of use in the RIS equates to around 955 full load hours for window wall units, 1,275 full load hours for non-ducted single split system, and, 1,870 full load hours for ducted single split systems.

CHF3 has assumed 251 working days on average (i.e. excludes weekends and statutory holidays), and equipment operating 10 hours per day (i.e. 2,510 operating hours per annum) on full load 40% of the time equating to 1,004 full load hours per annum for all residential style and light commercial equipment types that are installed in business premises.

Both the AC RIS process and CHF stock model would benefit from actual operating data from a variety of types of residences and businesses, which coupled with data on AC equipment efficiency in the field, would enable a much more accurate assessment of the part and full load operating hours of air conditioning equipment in commercial premises.

Close Control AC

CHF3 assumes that 81% of close control equipment is operating 8,760 hours per year, based on the assumption that 20% of systems have no back up, 40% of systems are 1 operating system to 1 back up, 25% of systems have 5 units operating with one back up, and 15% of large systems with 10 or more units have one back up. A part load to full load factor of 0.75 is then applied equating to 81% of the installed base operating 6,570 full load hours per annum (or 5,322 hours per piece of equipment across the fleet).

Proportion of residential and commercial

To allow calculation of indirect emissions as a result of electricity consumption in various product categories, an estimate of annual hours of use of the equipment types is used. Estimates of hours of use vary depending on whether the equipment is employed in a residential or a commercial setting. There are many smaller equipment types that are used in both residential and commercial settings. The table below lists the estimated percentage of 'commercial use' of the stock, applied to the product categories where this is the case.

As well as being used in the calculation of indirect emissions these ratios are also used in calculated annual expenditure on electricity as different national average electricity tariffs apply for residential and commercial users..

Table 42: Estimated air conditioning proportion of use in commercial applications.

Product category	Commercial (%)
1Ph Non ducted split 0-4kW	5%
1Ph Non ducted split 4-6kW	15%
1Ph Non ducted split 6-10kW	20%
1Ph Non ducted split >10kW	30%
3Ph Non ducted split 0-20kW	95%
1Ph Ducted	20%
3Ph Ducted 0-20kW	80%
3Ph Ducted 20-40kW	95%
3Ph Ducted >40kW	100%
1Ph Non ducted unitary 0-10kW	30%
1Ph Non ducted unitary >10kW	100%
Portable AC 0-10kW	5%
3Ph Non ducted 20-40kW	100%
3Ph Non ducted >40kW	100%
Chillers	100%
Multi Splits	20%

Product category	Commercial (%)
VRV/VRF split systems	75%
Close control air conditioning	100%
HW heat pump: commercial	100%

11.2.18 Energy related greenhouse emissions

The total hours each product is operated per annum is multiplied by the electricity demand of each product, and by a national average greenhouse intensity factor for electricity, to arrive at an estimate of indirect, energy related greenhouse gas emissions.

In CHF2 the NGERs state based indirect (scope 2) emission factors from consumption of purchased electricity from a grid for the 2012-13 reporting year was used to calculate a national weighted average based on population using data from ABS 3101.0, Australian Demographic Statistics, June 2012 (ABS 3101.0 2017). The calculated national average for CHF2 in 2012 was 0.914 kg CO₂e/kWh.

In CHF3 the latest national estimate Scope 2 and 3 emissions factors - consumption of purchased electricity by end users (Table 41, NGA Factors DoEE 2017) was used, a value of 0.81 kg CO₂e/kWh.

Fuel combustion emissions for petrol and diesel used by transport refrigeration and mobile air conditioning were calculated using the relevant energy content emission factors for post 2004 vehicles.

Table 43: Fuel combustion emission factors-fuels used for transport energy purposes for post-2004 vehicles.

Fuel type	Energy content factor (GJ/kL)	Emission factors (kg CO ₂ e/GJ)		
		CO ₂	CH ₄	N ₂ O
Gasoline (petrol)	34.2	67.4	0.02	0.2
Diesel oil	38.6	69.9	0.01	0.6

(Source: Table 4, NGA Factors DoEE 2017)

11.2.19 Annual expenditure

The number of pieces of any product being imported, manufactured, sold, installed, and commissioned in any year is known from the stock model. The average cost to the end-user of that product is known from surveys of the market and interviews with suppliers. These two factors allow the calculation of total expenditure on RAC equipment in any year.

The quantity of refrigerants that are imported every year is known from the Department of the Environment and Energy's bulk import data. The uses to which that refrigerant is put is deduced from the data underlying the calculation of the bank of refrigerants. The cost to the end-users of that refrigerant is known from market surveys and information from wholesalers (i.e. list prices and discounts) and service contractors (i.e. mark-ups to end-users). These factors allow the calculation of total annual expenditure by end-users on refrigerant.

The quantity of electricity consumed in RAC equipment is calculated and an average per kWh price applied to provide an estimate of annual expenditure by equipment and appliance owners on electricity consumed in

the equipment. Three national average rates were used, one for commercial end-users of 16c/kWh, industrial end-users of 13c/kWh and 28c/kWh for residential. A rate of 13c/kWh was used for large commercial end-users such as cold storage facilities. The rates are as per the AEMO National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, Australian Energy Market Operator for 2016 that was published in 2017. It should be noted the AEMO rates published for 2017 were significantly higher (i.e. commercial 20c/kWh, industrial 17c/kWh and residential 31c/kWh) and actual rates at the end of 2017 were higher again.

The assumptions made about the proportion of different classes of air conditioning equipment found in commercial applications are tabulated in *Table 42: Estimated air conditioning proportion of use in commercial applications*. These estimates are based on information provided by major importers and manufacturers, and on first-hand experience of the market for air conditioning equipment in Australia, where some large ducted systems are used in the residential sector, and many small units are found being employed in commercial and retail applications.

The proportion of equipment used in commercial applications influences the result of the calculation of the energy spend because of the different hours of use of commercial equipment versus residential equipment, and because of the different electricity prices applied to commercial equipment.

All domestic refrigeration equipment used the residential tariff. Devices in the refrigerated cold food chain used the commercial rate.

11.3 RAC Stock model outputs and projections

The main outputs and projections of the model are:

- **Annual refrigerant use** of all RAC technology and of classes, segments and some product categories;
- **Indirect emissions** as a result of energy use by RAC technology owned by commercial enterprises and privately;
- **The bank** of refrigerant employed in the entire stock of equipment, and in various classes, segments and product categories of the stock;
- **Direct emissions** by product category in most cases, by segment and class, and as an economy wide average from the entire Bank;
- **Projections for predicted sales mix** of new equipment by the type of refrigerant in that equipment; and,
- **End-of-life emissions** from the entire stock of equipment and from some classes and segments of the stock.

As a result of all of the above the RAC Stock model can also be used to generate projections of the working banks of refrigerant by class, and, in some cases by equipment segment. The model also produces projections of annual service use by refrigerant type from 2016 to 2030. Projections are calculated in metric tonnes and in millions of tonnes CO₂e. This enables the model to be used to estimate and analyse the future refrigerant bank in an economy as compared to the bank required under international agreements to phase down HFCs and an overall reduction in greenhouse gas emissions.

An example is shown below of the small MAC bank in tonnes and millions of tonnes of CO₂e based on the equivalent bank.

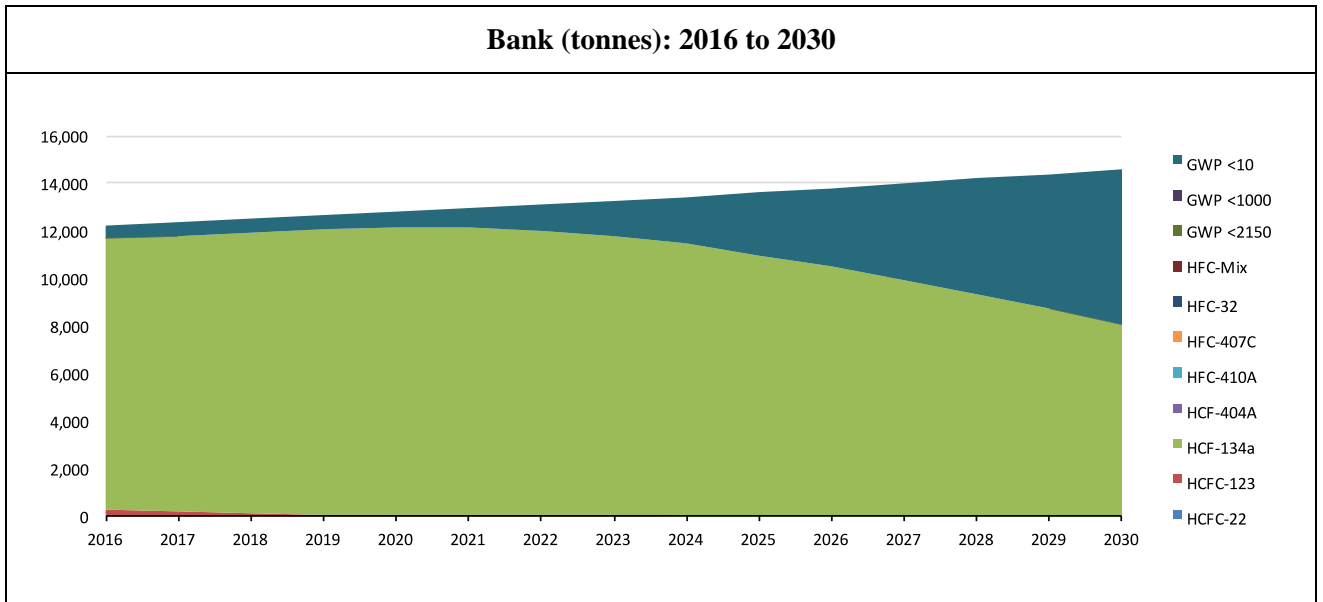


Figure 57: Mobile AC refrigerant bank in tonnes from 2016 to 2030.

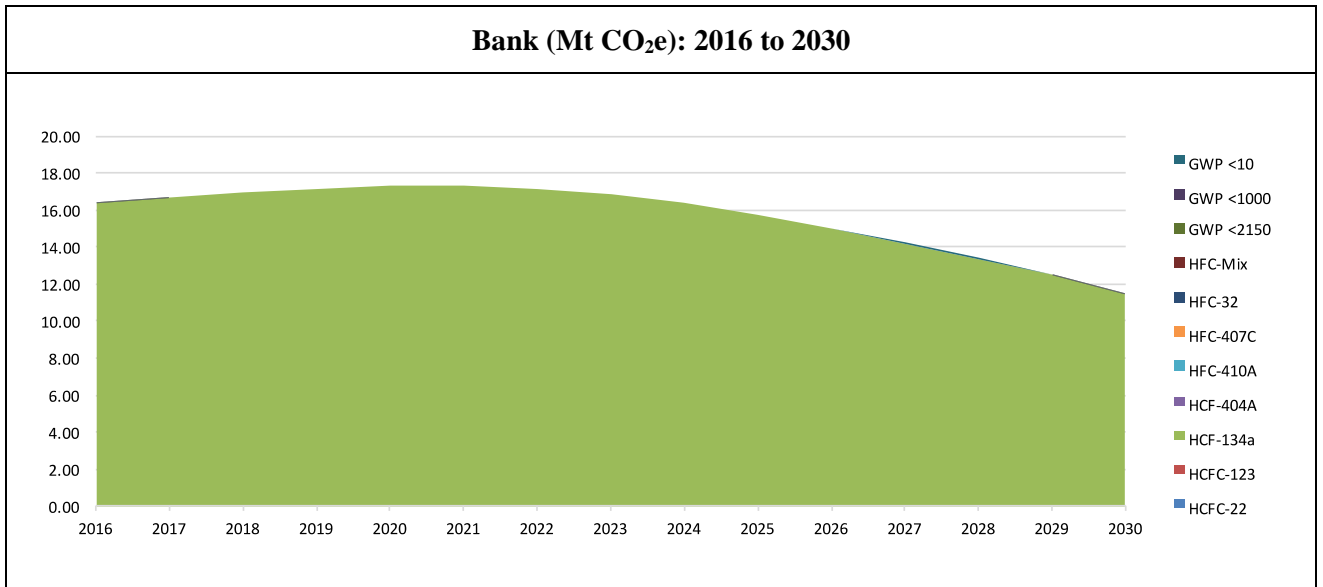


Figure 58: Mobile AC refrigerant bank in Mt CO₂e from 2016 to 2030.

Charts and tables illustrating projected changes of the various banks are published in *Appendix B3: Bank projections by class and segment*.

11.4 HVAC&R Supply chain business types and end use applications

Understanding the types of businesses in the HVAC&R supply chain and end use applications is important when defining the industry boundaries in terms of business and employment counts. *Table 44* below provides a list of businesses that are considered part of the HVAC&R industry. A list of end use applications is provided on the following page. Equipment and services suppliers to these end use applications are generally considered part of the industry sector.

Table 44: Types of businesses in the HVAC&R supply chain.

Types of businesses in the HVAC&R industry
Wholesalers (major and independents: full HVAC&R range, air conditioning, auto air, etc.)
Contractors (installation, service and maintenance)
Equipment manufacturers
Equipment suppliers (air conditioning, evaporative coolers, heating, hot water heat pumps, hydronic, commercial refrigeration, domestic refrigeration)
Component suppliers (compressors, fans, coils, chilled beams, refrigerant, etc.)
Cool room suppliers (panel and contractors)
Controls and instrumentation suppliers (IS, software, electronics, data logging, VSDs, sensing/measuring, temp/humidity/air flow/air quality, etc.)
Filtration and environmental services (supply and cleaning)
Air movement (ducts, sheet metal, fittings, registers, dampers, diffusers, accessories)
Fans and ventilation
Mechanical services engineers
Consulting and design engineers
Commissioning engineers
Energy efficiency and specialist (i.e. natural refrigerants) engineers
Facilities maintenance
Accessory suppliers (insulation, pipes, fittings, pumps, valves, lighting, tools, chemicals, oils, corrosion protection, etc.)
Cooling tower specialist
Rental companies (air conditioning equipment for events and breakdowns)
Business services (insurance brokers, etc.)
Technical services (equipment testing, scientific, calibration, etc.)

End use applications

The following is a list of some of the important industrial and commercial applications where RAC systems are found across the Australian economy. This list does not include the common and populous applications of domestic refrigeration and residential air conditioning with which readers would be familiar. This provides an insight into the wide applications of RAC systems that the Taxonomy does not reveal, based as that is on the format and capacity of the enabling technology employed in the applications listed below.

If there was any question about the central and essential energy service role that RAC technology plays in the Australian economy, simply read the following list and imagine how the environments and processes listed would be without being serviced by RAC systems.

Stationary air conditioning systems

Non-residential buildings ventilation and air conditioning systems:

- Commercial and government office accommodation
- Education (all generally also including some larger format refrigeration) such as schools, universities and TAFEs
- Community buildings
- Hospitals and health facilities including mortuaries
- Hotels and accommodation
- Industrial
- Convention centres, retail malls and food courts
- Entertainment, restaurants, swimming pools, gyms
- Transport hubs, underground train stations, airports

Close Control facilities:

- Computing, server farms and UPS
- Telecommunications switching, PABX and UPS
- Museums, galleries, archives and specialised storage
- Pharmaceutical
- Labs and testing

Mobile air conditioning systems

Air conditioned and refrigerated transport:

- Light commercial
- Buses
- Recreational vehicles, mobile homes and caravans
- Mining & construction
- Trains
- Agricultural (including tractors, harvesters)
- Refrigerated trucks & trailers (cold food chain)

Aviation:

- Commercial passenger airlines

- Military aviation
- Private and charter aircraft

Maritime systems:

- Fishing fleet
- Specialised sea freight
- Passenger liners
- Luxury boats and private charter
- Defence field systems and emergency services

Refrigerated cold food chain, industrial and process systems

Commercial refrigeration:

- On farm cool rooms (horticulture, vegetables, wine grapes)
- Aquaculture & wild caught seafood
- Food transport and distribution centres
- Retail display
- Supermarkets
- Pharmaceuticals

Process chillers & industrial refrigeration:


- Brewing and wine making
- Dairy industry
- Milk harvesting and storage
- Milk processing
- Cheese industry
- Food processing (confectionary, frozen foods, drinks, fruit juice, chilled water as additive)
- Ice making

Industrial chiller applications:

- Plastics/die cooling
- Electronic plating
- Printing machines & associated equipment
- Dry cleaning
- Construction
- Laser cutting equipment
- Chilling of water for industrial processes

Other large chiller deep freeze applications:

- Water cooling for medical or chemical equipment such as SEM, MRI and X-Ray units
- Petro-chemical/gas & chemical
- Medical/pharmaceutical/serum/plasma

- 
- Co-generation/tri-generation
 - Mining and tunnels
 - Liquefaction and cryogenics

Power generation industry:

- Mobile plant

Other applications:

- Water coolers
- Heat pump pool heaters