







# Cold Hard Facts 2019







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# **1** Executive summary

This edition of Cold Hard Facts updates the Cold Hard Facts 3 RAC Stock Model, adding data collected during 2017 and 2018.

The bank of high GWP<sup>1</sup> refrigerants in Australia increased by five per cent from 2016 to 2018, from around 50,800 tonnes in 2016 to an estimated 53,300 tonnes in 2018. Continued growth in the bank employed in stationary air conditioning, particularly in the smaller split systems and small commercial systems, contributed most to the overall growth of the bank.

Analysis of equipment imports confirmed a rapid transition to the use of HFC-32 in small air conditioning systems. In 2018, HFC-32 systems made up 53% of all pre-charged small air conditioning units imported, an increase from 39% in 2016 and up from effectively zero in 2012.

Sales of small single split system air conditioners in 2018 have seen annual sales soften for the first time since the Cold Hard Facts series began in 2006. The split system market experienced solid annual growth rates of around five per cent from 2012 to 2018. In 2017 a record number of 1,258,000 single split systems were sold in Australia. Sales reduced noticeably in 2018 with total sales around 1,158,000; a year-on-year decline of nearly eight per cent. Sales of multi-head systems, and sales of medium air conditioning systems all experienced continued growth through 2017 and 2018.

Hydrofluoro-olefin (HFO) refrigerants have begun to be employed in some stationary refrigeration and air conditioning equipment in Australia, but not in vehicles as was initially expected. Sales of vehicles employing HFOs were statistically irrelevant in 2018. In the stationary air conditioning sector, every major global chiller manufacturer now offers chiller models employing HFO-1234ze. Notably the HFO refrigerant of choice for large centrifugal chillers has become HFO-1233zd, which can provide meaningful financial benefits to equipment owners due to energy efficiency gains.

Leading supermarket chains continue active programs reducing leaks of high GWP (HFC) refrigerants and lead the way with concerted moves to HFC alternatives. The emergence of carbon dioxide ( $CO_2$ ) cascade and trans-critical systems in commercial refrigeration saw rapid growth of  $CO_2$  systems employed in the cold food chain, although from a low base. Innovation in the use of low-charge ammonia systems added to the highly energy efficient options for new build commercial refrigeration systems with a cooling capacity greater than 50 kWr.

Migration of new domestic refrigeration models to a hydrocarbon refrigerant is effectively complete with more than 99% of domestic refrigeration models surveyed on a retail shop floor found to be using hydrocarbons. Adoption of hydrocarbons in other parts of the cold food chain continued with the introduction of numerous small, self-contained commercial refrigeration models employing hydrocarbons.

These trends with CO<sub>2</sub>, ammonia and hydrocarbon refrigerants resulted in the share (in metric tonnes) of the HCFC and HFC refrigerant bank used in the refrigerated cold food chain falling again from 14% in 2016 to 13% in 2018, even though the absolute mass of HCFCs and HFCs employed in the cold food chain increased slightly to around 7,100 metric tonnes. The refrigerated cold food chain represents 21% of the bank in CO<sub>2</sub>e terms both in 2016 and 2018.

The portion of total electricity consumed by RAC in 2018 was around 24% of all Australian electricity generated.<sup>2</sup> Electricity price increases of more than 30% from 2016 to 2018 have placed significant emphasis

<sup>&</sup>lt;sup>1</sup> The global warming potential (GWP) of the refrigerant commonly used in the Australia are listed in Appendix A: Methodology – Taxonomy, data and assumptions.

<sup>&</sup>lt;sup>2</sup> Australian Energy Statistics, Electricity generation by fuel type, prepared by the Department of the Environment and Energy, March 2019 estimate the Australian electricity generation (i.e. sent out) by all fuel types (i.e. Non-renewable and renewable) was 261,405 GWh. This is 1% higher than 2016, estimated at 258,481 GWh.

on energy saving initiatives, particularly with large air conditioning systems in commercial buildings, and refrigeration equipment and plant in the supermarket and cold storage industries.<sup>3</sup>

# 2 Introduction

Welcome to Cold Hard Facts 2019, the fourth edition in the Cold Hard Facts series that began in 2006. Cold Hard Facts 2019 updates the findings of Cold Hard Facts 3 by incorporating industry data from 2017 and 2018.

The Cold Hard Fact series is underpinned by a techno-economic model of the refrigeration and air conditioning sector that has been developed over the course of completing dozens of research projects into the sector. The primary output of this model is to track changes in the make-up of the working bank of refrigerants in Australia, and to report mass flows of refrigerants through their life cycle from import, to utilisation, to disposal and destruction or loss to atmosphere. This work supports Australia in meeting its international commitments under the Montreal Protocol to phase out ozone depleting substances, and to phase down HFCs.

In providing this data to policy makers and industry participants, the RAC Stock Model, as it is known, also allows analysis and monitoring of trends in the industry across equipment sales, energy consumption, energy related greenhouse emissions, and changes in technology. It may also inform considerations on training and occupational health and safety requirements for the wide range of specialised skills required in the refrigeration and air conditioning workforce.

Since this research series began the refrigeration and air conditioning industry has become much more complex in terms of the technological options available to meet the growing requirements from users across the economy. The gradual phase down of HFCs under the Montreal Protocol is expected to further accelerate innovation and the diversification of refrigerants and refrigeration and air conditioning technology. The Cold Hard Facts series is intended to provide hard data for industry and policy makers in the sector to facilitate technological transition and assist in minimising market distortions or unintended policy outcomes.

The Cold Hard Facts series benefits from the participation of industry in the provision of market intelligence and response to surveys and questionnaires, as well as from government data collections. As new and unregulated refrigerants are introduced to the market (such as HFOs), some of the current import data collected on regulated refrigerants will capture a declining portion of refrigeration and air conditioning activity. New sources of data will have to be developed to track changes in the sector. Industry will need to be part of those collections to assist and maintain the validity and value of the series.

<sup>&</sup>lt;sup>3</sup> AEMO National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, Australian Energy Market Operator, published 2017. Residential, Commercial and Industrial national average prices have increased from 0.28, 0.16 and 0.13 c/kWh in 2016 to a projected 0.36, 0.24 and 0.21 c/kWh in 2018. Prices for 2018 used AEMO projected prices, as the AEMO 2018 Electricity Statement of Opportunities now only publishes the Price Index, not the actual prices.

# **3** Taxonomy of a 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.

Refer to Appendix A, Section 1.1: Taxonomy of a technology for further details.

# 4 The stock of equipment

# 4.1 The scale of events

The Expert Group RAC Age-Cohort Mass Balance Stock Model (RAC Stock Model) calculates that RAC services in all its forms were delivered by over 56 million individual pieces of equipment in Australia during 2018 (*CHF3 2016, 54 million*). The stock model also estimates that in the last few years Australians have spent around \$9.3 billion (*CHF3 2016, \$8.2 billion*) every year buying and installing new devices across all classes of RAC equipment.

In both 2017 and 2018, an estimated 2 million devices containing around 2,270 tonnes of residual refrigerant reached the end of their useful life. This included around 120 tonnes of refrigerant in domestic refrigerators and freezers, 1,480 tonnes in air conditioners, 430 tonnes in motor vehicles of all types, and 240 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.<sup>4</sup>

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 of some well-made commercial refrigerators and of some types of 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. 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 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, Australia will continue to employ tens of thousands of tonnes of older generations of refrigerants, that 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 more detail in the sections that follow.

<sup>&</sup>lt;sup>4</sup> Estimates of the average life of individual equipment categories are tabulated and explained in Appendix A: Methodology – Taxonomy, data and assumptions.

# 5 Main equipment classes

# 5.1 Stationary air conditioning

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, and to provide close temperature control in medical and scientific facilities, and in data processing centres.

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, contained in more than 14.4 million devices.

Stationary air conditioning consumed the largest portion of imported bulk refrigerants for service use in 2018, an estimated 1,350 tonnes of HFCs for service, charging new equipment, retrofitting existing equipment, and use by original equipment manufacturers (OEMs).

Stationary air conditioning consumes more electricity than all of the other classes of equipment in the RAC industry collectively.

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

This class includes stationary equipment such as heat pumps used for 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.

STAT	STATIONARY AIR CONDITIONING						
Item no	Segment	Application	Category code	Product category	Stock 2018		
1	Small Self- ained	Window/wall	AC1-1	Non-Ducted: Unitary 0-10 kWr	1,336 ,000		
2	AC1: AC: conta	Portable AC	AC1-2	Portable AC: 0-10 kWr	874,000		
3	Small Split	Single split: non- ducted	AC2-1	Single split system: Non-ducted: 1-phase	10 248 000		
4	AC2: AC:	Single split: non- ducted	AC2-2	Single split system: Non-ducted: 3-phase	10,248,000		
5	Ducted	Domestic & light commercial	AC3-1	Single split system: Ducted: 1-phase	2 125 000		
6	n AC: I mmerc	Domestic & light commercial	AC3-2	Single split system: Ducted: 3-phase	2,123,000		
7	Mediun light cc	Light commercial	AC3-3	RT Packaged systems	128,000		
8	AC3: ] &	Domestic & light commercial	AC3-4	Multi split	412,000		

Table 1: Stationary air conditioning taxonomy and stock in 2018.

STAT	STATIONARY AIR CONDITIONING						
Item no	Segment	Application	Category code	Product category	Stock 2018		
9		Light commercial	AC3-5	VRV/VRF split systems	126,000		
10	n AC: light ial	Light commercial	AC3-6	Close control	22,500		
11	Mediur ted & l mmerci	Light commercial	AC3-7	HW heat pump: commercial	2,200		
12	AC3: Duc co	Domestic & light commercial	AC3-8	Pool heat pump	42,700		
13	iillers	Chillers	AC4-1	<350 kWr	8,550		
14	AC: CI	Chillers	AC4-2	>350 & <500 kWr	4,100		
15	Large	Chillers	AC4-3	>500 & <1000 kWr	7,500		
16	AC4:	Chillers	AC4-4	>1000 kWr	3,450		
17	Other	HW Heat pump	AC5-1	HW heat pump: domestic	250,000		
18	AC5:	Heat pump clothes dryers	AC5-2	Heat pump clothes dryers	140,000		

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;<sup>5</sup>
- 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 for Stationary AC equipment used in this report are broadly consistent with the Australian Government regulatory impact statements (RIS) for split systems, close control air conditioning, chillers and hot water heat pumps (E3 2017a). However, there are some differences in sales inputs where pre-charged equipment import data provided more accurate estimates for changes in the stock in 2014, 2015 and 2016 than were reported in the regulatory impact statements. These changes lead to differences between CHF3 projections (published in CHF3 in 2018) and projections published in the regulatory impact statements and have flowed through to differences in the current model and report.

Australia has a declining stock of equipment charged with HCFCs (imports of which mostly ceased from 2010), and a large and growing stock of relatively new HFC charged equipment. The main HFCs employed in stationary AC since 2010 have been HFC-410A, HFC-407C and HFC-134a. However the more recently (~2013) commercialised HFC-32, with a lower GWP than the other species, has now become the fastest growing portion of the bank in the small AC product categories.

Table 2 provides a summary of the main metrics in stationary AC in 2018.

<sup>&</sup>lt;sup>5</sup> Hot water heat pumps for domestic and commercial applications, and swimming pools use refrigeration technology (i.e. vapour compression cycle) to remove heat from the air to heat water.

Metric	2018
Share of refrigerant bank	63%
Size of refrigerant bank	33,550 tonnes
Annual usage to replace leaks	1,350 tonnes
Refrigerant in pre-charged equipment imports 2018	2,722 tonnes
Estimated stock of equipment	> 15.7 million units
Annual electricity consumption	35,727 GWh <sup>(1)</sup>
Share of HVAC&R electricity consumption	56%
Annual GHG indirect emissions	28.58 Mt CO <sub>2</sub> e
Share of HVAC&R indirect emissions	53%
Annual GHG direct emissions (ODS)	0.48 million tonnes $CO_2e^{(2)}$
Annual GHG direct emissions (SGG)	1.88 million tonnes CO <sub>2</sub> e
Share of HVAC&R direct emissions	34%
Share of HVAC&R total emissions (direct and indirect, not including EOL)	51%

Table 2: Stationary air conditioning main metrics: 2018.

Notes:

1. The electricity consumption estimate does not take into account efficiency improvements in the fleet of equipment from 2016 to 2018 and is based on assumptions from CHF3.

2. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, as they managed through the Montreal Protocol.

# 5.1.1 Analysis of pre-charged equipment provides insights into the transitioning bank

Pre-charged equipment (PCE) imports reported under the Department of the Environment and Energy's import data, reveals that HFC-32 adoption has continued to grow very quickly in non-ducted split systems designed primarily for residential use.

Analysis of PCE imports shows that non-ducted single split systems make up the majority of equipment, and contain the bulk of the refrigerant mass<sup>6</sup>, of all stationary AC imported into Australia.

PCE data was dissected into multiple charge size categories to assess and track the rate of transition by technology type, particularly in small and medium AC, from HFC-410A to HFC-32.

*Table 3* below provides a guide of the technology types typically found in each of the charge size categories.

The tonnes of refrigerant and equipment numbers imported in equipment in 'Domestic use air conditioning' and 'Commercial use air conditioning' categories from 2014 to 2018 is provided in *Appendix B4.2: Stationary AC: Pre-charged equipment.* 

<sup>&</sup>lt;sup>6</sup> Based on actual refrigerant charge sizes.

Charge range	Most common stationary AC types
< 800 grams	Small AC: Self-contained Packaged room air conditioning units intended to be inserted through a hole in a wall or through a window generally referred to as 'window/wall' units. Dehumidifiers and portable air conditioning predominantly for domestic use.
$\geq$ 800 grams and < 2.6 kg	<ul> <li>Small AC: Split</li> <li>Non-ducted split systems covering a broad class of equipment that employs 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.</li> <li>Wall hung split systems with a nominal capacity of less than 10 kW dominates this charge range category.</li> </ul>
≥ 2.6 kg and < 4 kg ≥ 4 kg and < 6 kg ≥ 6 kg and < 12 kg ≥ 12 kg and < 20 kg	Medium AC 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. Ducted split systems with a nominal capacity from 10 to 18 kW are the most common type in the 2.6 kg to 6 kg charge size categories. Multi split systems and small variable refrigerant volume/flow (VRV/F) split systems up to 18 kW are typically have charges from 2.6 kg to 4 kg. Large VRV/F split systems (with multiple indoor units and nominal capacities ranging from 18 to 60 kW) which are emerging as the preferred technology for medium sized commercial buildings, schools and other multi-purpose buildings, typically have charges ranging from 6 kg to 12 kg. 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, typically have charges less than 12 kg. 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, are sold in small quantities relative to other Medium AC technology types, and typically have charges of 2 x 15 kg.
≥ 20 kg	Large AC Chillers for space cooling in large commercial buildings is the main application. Chillers that use scroll compressor technology typically use HFC- 410A, as well as HFC-407C. Chillers that use screw and centrifugal compressor technology typically use HFC-134a and have large charges up to several tonnes.

Table 3: Charge size category and most common stationary AC type.

Filtering out equipment with charges less than 800 grams, and greater than 2,600 grams, excludes the majority of the small portable AC and window wall units that are typically under 800 grams, and the majority of the larger ducted systems, which generally have charges larger than 2,600 grams. These larger units are most likely to be charged with HFC-410A.

Applying these filters highlights the rate of transition away from the much higher GWP HFC-410A, to HFC-32 in this size range, which is predominantly non-ducted single split systems.

*Figure 1* illustrates this trend, refer to *Appendix B4.2: Stationary AC: Pre-charged equipment* for tabulated data.



*Figure 1: Mass of refrigerant in pre-charge equipment imports of stationary AC from 2012 to 2018 (with a charge greater than 800 grams and less than or equal to 2.6 kg) by refrigerant type in tonnes.* 

(Source: DoEE 2019)

Notes:

1. 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.

Ducted and non-ducted air conditioners (excluding portable AC) up to 65 kW must satisfy Minimum Energy Performance Standards (MEPS) and be registered under the *Greenhouse and Energy Minimum Standards* (*GEMS*) *Act 2012*. The registration details include the refrigerant type.<sup>7</sup> As of the 1<sup>st</sup> of May 2019, the count of GEMS registered models operating on HFC-32 was:

- 639 non-ducted split systems registered (30% of all registered non-ducted single split systems);
- 33 window/wall models (33% of all registered window/wall); and,
- 87 single split ducted models (11% of all registered single split ducted).

<sup>&</sup>lt;sup>7</sup> www.energyrating.gov.au

Registrations are valid for 5 years. The ducted brands include Daikin, Panasonic, LG, Hitachi, Mitsubishi Electric and Toshiba with 38 models with a rated cooling capacity greater than 12 kWr and largest model 22 kWr.

The greater thermal efficiency of HFC-32 means that it has provided an avenue for manufacturers to achieve higher energy efficiencies with very minor equipment design changes. A much smaller HFC-32 charge can achieve the same cooling as a significantly larger charge of HFC-410A, giving designers more leeway to use smaller compressors requiring less electricity to deliver the same cooling services.

As such energy efficiency standards might be one of the important drivers of the transition to HFC-32, more than its lower GWP.

*Figure 2* suggests that the current rate of transition of smaller portable devices to HFC-32 is less conclusive than is apparent in the single split systems, and at the same time overall import volumes of portable devices are growing. Recent changes in energy efficiency requirements for some classes of small AC will potentially see a wider range of AC models employing HFC-32.<sup>8</sup>

However, the overall size of the bank in these small devices is an order of magnitude lower than the bank employed in single split systems.



Figure 2: Mass of Refrigerant in pre-charged equipment imports of stationary AC from 2012 to 2018 (with a charge size less than 800 grams) by refrigerant type in tonnes.

(Source: DoEE 2019)

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

<sup>&</sup>lt;sup>8</sup> The Federal Energy Minister signed a new Determination for air conditioners under the Greenhouse and Energy Minimum Standards (GEMS) Act 2012 in late March 2019. This follows the agreement of COAG Energy Ministers in December 2018 to further improve regulations on air conditioners: Specific changes include: applying MEPS to single duct portable air conditioners, increasing MEPS for air conditioners with a capacity greater than 65 kW, reducing MEPS for double duct portable air conditioners, and adopting the Seasonal Energy Efficiency Ratio (SEER) standard for rating air conditioner energy efficiency on the energy rating label.

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

By the end of 2018 there had been 2,705,000 air conditioning units containing HFC-32 imported in total, mostly split systems (~90%), containing a total of 2,298 tonnes of the refrigerant.

The average charge of HFC-410A models imported over the same period was 1,450 grams per unit compared to the average charge of HFC-32 models of only 1,155 grams, an average 20% reduction in charge size across the small AC market segment.

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 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  $CO_2e$  of the imports into this portion of the refrigerant bank when taking both charge size and GWP into account.

While HFC-32 is the current preferred refrigerant for new split systems other options are being explored. For example, Mitsubishi Heavy Industries has developed and showcased a demonstration unit wall hung split system (nominal capacity of 2.5 kW) operating on HFO/HFC blend R454C with a GWP of 148 that is intended for the European market. Chinese manufacturer Midea Group is considering HFO/HFC blend R466A with a GWP of 733. Honeywell is exploring a long-term replacement for R410A, HDR-147 with a GWP of around 399, and Daikin Industries announced it is exploring options to replace HFC-32 with a new refrigerant with a GWP less than 10.

#### Small AC: Hydrocarbons

Efforts to introduce HC charged small AC systems appear to have faded with the technology developing only limited manufacturing support.

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 portable AC, are unlikely to achieve any meaningful market share in the foreseeable future.

A market for small portable AC units charged with less than 150 grams of hydrocarbons (HCs) has been established during the last decade. For example, DeLonghi has been importing portable AC units in commercial volumes for more than 8 years with the total stock of HC charged portables now likely above ten thousand.

The announcement by the International Electrotechnical Commission (IEC) in May 2019 to increase maximum refrigerant charge for all flammable refrigerants (A2L, A2 & A3) to the smaller of 1.2 kg or 13 times the lower flammability limit (LFL) of the refrigerant increased the allowable charge of A3 flammable refrigerants (i.e. hydrocarbons) from 150 grams to approximately 500 grams<sup>9</sup> under IEC 60335-2-89 standard. This may have some impact in the future although global manufacturers are not at this point known to be investing in AC designs with larger HC charges. The revised standard is yet to be adopted in Australia but will be considered as part of the standards review process.

#### 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 2018, more than 1.2 million are estimated to be charged with HCFCs, representing a bank of some 800 tonnes of mostly HCFC-22 (down from an estimated 1.7 million units in operation in 2012). This stock of HCFC charged equipment is declining steadily as the equipment reaches the end of its useful life and it is predicted to be virtually non-existent by 2030.

The Small AC: Self-contained bank of HFCs is expected to grow to around 930 tonnes by 2030, comprising less than 2% of all HFCs in the total bank at that time.

<sup>&</sup>lt;sup>9</sup> R290 LFL of 0.038 x 13 = 0.494 kg and R600a LFL of 0.043 x 13 = 0.559 kg.

#### Hot water heat pumps

Just prior to 2010 hot water heat pump annual sales peaked at over 72,000 units per annum but have since steadily declined due to changes to the solar hot water rebate, which was a significant factor in early sales growth. The market has now stabilised at around 20,000 pieces sold per annum.

Over the last five years around 53 tonnes of HFC-134a was imported in hot water heat pumps involving almost 11,300 pieces per annum with an average charge of 950 grams.

 $CO_2$  and HC are not controlled substances under the OPSGGM Act and import of PCE and manufacturing of equipment containing these refrigerants do not need to be reported, therefore there is limited ability to analyse sales volumes of these types of units.

The Clean Energy Regulator<sup>10</sup> publishes small-scale renewable energy installation data for Air Source Heat Pumps. At the end of 2018 there were 251,129 domestic hot water air source heat pumps registered with the Clean Energy Regulator. The stock model calculates a stock of 250,000, which aligns with the Regulator's reported stock when assuming an average lifespan of 15 years and 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 around 20,000 pieces per annum until 2030.

#### Heat pump clothes dryers

A heat pump clothes dryer is a recently introduced product type that is extraordinarily energy efficient compared to conventional dryers that use electric heating elements. These 'condenser dryers' recycle heat in the process of extracting moisture, resulting in efficiency ratings of up to 6 stars (the best possible under the GEMS program in this product class). Whilst they are more expensive than conventional clothes dryers, they deliver 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.

All appliances available are charged with HFC-134a containing from 300 to 480 grams and an average charge of 470 grams. The total charge of HFC-134a imported over the five-year period in these appliances was around 65 tonnes.

## 5.1.2 Split systems sales softening but still strong

The overwhelming majority of split systems sales are 'single' split systems comprising one indoor unit attached to one outdoor unit.

The split system market has experienced solid compound annual growth rates of around 5.0% from 2012 to 2018. Single split systems sales, including wall-hung, cassette, consoles and ducted systems have grown rapidly from 2012 to 2018 with annual sales reported of 833,000 in 2012 rising to a record in 2017 of 1,258,000 units sold. For the first time in a decade sales declined in 2018 with sales of around 1,158,000, a year on year decline of nearly 8%.

There has been significant growth in single split ducted systems (included in the above numbers) increasing from around 110,000 in 2012 to 174,000 in 2018. Some of the growth has come from compact bulk head units below 10 kWr, comprising 32% of sales in 2018 versus 25% in 2012.

Multi head split system (excluding VRV/F) sales have grown, from around 23,000 in 2012 and 2013 to around 33,000 in 2018. As a result, the ratio of indoor units to outdoor units sold is slowly increasing from a ratio of 1.03 in 2012 to 1.05 in 2018.

<sup>&</sup>lt;sup>10</sup> http://www.cleanenergyregulator.gov.au/RET/Forms-and-resources/Postcode-data-for-small-scale-installations#Solar-waterheater-SWH-installations

## 5.1.3 Medium air conditioning

Medium AC typically have a charge size greater than 2.6 kg and less than 12 kg. Equipment types are described in *Table 3: Charge size category and most common stationary AC type*. PCE import data shows there was an average of approximately 248,000 medium AC pieces imported per annum over the last two years, containing an annual average of 1,138 tonnes of HFC, mostly HFC-410A. *Table 4* below provides a summary of PCE imports in this charge size over the last two years.

In 2017 there were 157,000 units imported with refrigerant charge greater than 2.6 kg and less than 4 kg, containing 507.5 tonnes of HFCs. The imports in 2018 in this charge size were 136,000 units, containing 475.6 tonnes of HFCs. Adoption of HFC-32 is in progress in this charge size with some 12,000 to 13,000 devices imported in both 2017 and 2018. No HFC-32 has been reported as yet in larger refrigerant charge categories, however industry sources confirm larger charges sizes are under development. Refer to *Appendix B4.2: Stationary AC: Pre-charged equipment* for tabulated data.

Table 4: Pre-charge	ged equipment	imports re	ported in	2017 and	2018 (cha	irge greater	• than 2.6 k	g and l	ess
than 12 kg).									

	20	17	2018		
	Refrigerant (Tonnes)	Units	Refrigerant (Tonnes)	Units	
$\geq$ 2.6 kg and < 4 kg	507.5	157,437	475.6	136,255	
$\geq$ 4 kg and < 6 kg	248.1	53,314	355.4	76,024	
$\geq$ 6 kg and < 12 kg	250.8	27,624	438.9	45,272	
	1,006.3	238,375	1,269.9	257,551	

Unlike in the smaller AC categories, Australian medium AC sales includes locally manufactured equipment. Leading Australian manufacturers include Actron Air, Temperzone and the recently acquired Brivis Climate Systems and Specialized Engineering, now divisions of Rinnai HVAC.

All three companies manufacture single split ducted systems, as well as roof top packaged systems and collectively consume 198 tonnes of HFC-410A in 2018. Local manufacturing of commercial hot water heat pumps is estimated to consume 2 to 3 tonnes of HFC-407C.

Australian manufacturers will soon have other refrigerant options to consider in the Medium AC segment, as the plans of global refrigerant manufacturers to adapt to the phase down of HFCs under the Montreal Protocol begin to deliver effective refrigerant alternatives for this segment.

Carrier, for instance, has announced plans to introduce a HFO/HFC blend into their European medium AC models from 2023. The 'mildly flammable' R454B refrigerant blend of 68.9% HFC-32 and 31.1% HFO-1234yf has a GWP of 466.

A non-flammable alternative, albeit with a GWP of 733, slightly higher than HFC-32 (GWP of 675), has also shown promising results in the larger charge sizes required in VRV equipment. Developed by Honeywell and trialled during 2018 by Toshiba Honeywell in Japan, R466A is a blend of 49% HFC-32 and 11.5% HFC-125 with CF3I, a flammability suppressant. According to Honeywell the test results show that the efficiency, cooling and heating capacity of VRF systems using R466A is 'very similar' to those using HFC-410A.

## 5.1.4 Large air conditioning - Chillers

Chillers for space cooling of large commercial buildings are the main application for Large AC. This equipment segment starts with equipment with a charge size of just larger than 12 kg and includes units with charge sizes as large as several tonnes of refrigerant.

There are estimated to be 25,100 chillers operating in Australia in 2018, containing in total approximately 4,200 tonnes of refrigerant. New chillers sales are expected grow at around 1% per annum, in line with construction activity in large commercial buildings.

Generally, chillers require larger refrigerant charges and the majority are charged with HFC-134a. PCE imports from 2014 to 2018 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 20 kg. Over the five-year period 2,117 units were imported with an average charge of 190 kg.

Industry sources report that large commercial equipment is increasingly being imported with a nitrogen charge or a small holding charge of refrigerant. This suggests there could be more local charging of chillers imported without a HFC charge in place in recent years. If it is assumed that the number of chillers imported was steady, local charging would have required more than 20 tonnes of HFCs in these large devices in each of 2017 and 2018.

*Table 5* below, reporting refrigerant types in pre-charged equipment in two charge size bins, illustrates the distribution of refrigerant preferences by equipment size.

Smaller chillers that use scroll compressor technology typically use HFC- 410A, as well as HFC-407C. Chillers that use screw and centrifugal compressor technology will more typically use HFC-134a and can have very large charges up to several tonnes.

	2017		2018	
	Refrigerant (Tonnes)	Units	Refrigerant (Tonnes)	Units
$\geq$ 12 kg and < 20 kg				
HFC-407C	0.9	58	0.0	3
HFC-410A	14.4	1,053	7.0	462
HFC-134a	0.0	0	0.0	0
Total	15.3	1,111	7.0	465
$\geq$ 20 kg				
HFC-407C	3.0	66	2.0	45
HFC-410A	18.8	413	20.6	501
HFC-134a	65.5	425	67.3	415
Total	87.3	904	90.0	961

Table 5: Pre-charged equipment imports reported in in 2017 and 2018 (charge greater than 12 kg).

Notes:

1. 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 the potential for 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.

- 2. Industry sources believe that at least some chiller manufacturers from China are shipping without refrigerant charge due to difficulties encountered with the dangerous goods transportation classification imposed on equipment with pressurised gas charges.
- 3. There was one chiller reported in 2018 containing 80 kg of HFO/HFC blend R513A.

To further complicate analysis of imports in these large equipment segments in the future, adoption of new refrigerants in large chillers is moving quickly. Recently commercialised HFO refrigerants are playing a key role in efforts to find low GWP alternatives to HFCs in large stationary AC equipment and, as HFOs are not required to be reported at point of import, it is increasingly likely that the market is starting to see some chillers imported pre-charged with HFOs.

So widespread has the adoption of HFO-1234ze become, that all of the global manufacturers of chillers (including local manufacturer Smardt) now offer HFO-1234ze options in their portfolio as an alternative to HFC-134a.

While primarily driven by the HFC phasedown timetable, and the fact that chillers generally have very long operational lives, it must also be pointed out that many of the HFC alternatives, and the new HFOs, also deliver improved energy efficiency, simply making the transition a matter of competitive and economic necessity.

For instance, the HFO refrigerant of choice for large centrifugal chiller manufacturers has become HFO-1233zd which provides meaningful financial benefits to equipment owners due to significant energy efficiency gains. The non-flammable safety classification of this 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 2018 operating on HFO-1233zd.

Some manufacturers 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. HFO/HFC blends are required to be reported at the point of import and the amount of refrigerant reported includes the total mass of HFCs and HFO.

To illustrate the rate of change and diversification of refrigerant types in this large equipment segment, at time of writing a selection of observations from the market are listed below:

- Daikin/McQuay are migrating the EU chiller range to HFC-32, requiring refrigerant charge sizes around one third for similar cooling capacity as the HFC-410A models in 80 kW up to 700 kW cooling capacity;
- Trane compressors designed to use HCFC-123 are now being designed to use HFO-514A (GWP of 2);
- HFO/HFC blend R452B is being offered in Clint chillers in the EU, an alternative to R410A and a rival to HFC-32. R452B is an A2L mildly flammable refrigerant with a GWP of 676;
- Kaltra a German manufacturer, is offering HFO/HFC blend R452B refrigerant as a lower-GWP alternative to HFC-410A in its chillers range in sizes from 50 kW-500 kW; and,
- Fluid Chillers Australia is offering HFC-407F and HFC-134a in air cooled models ranging from 11 kW to 216 kW and also in larger water cooled models.

As this trend accelerates new sources of data will be required for future editions of Cold Hard Facts to keep up with developments in this area as neither the bulk import of HFOs nor HFO pre-charged equipment is required to be reported.

## 5.1.5 Stationary air conditioning bank and projection

Overall the refrigerant bank in stationary air conditioning, across all segments from the very small selfcontained units to the largest chillers, is predicted to expand by nearly 33% between 2018 and 2030 to around 44,800 tonnes. The bank in Stationary AC is expected to represent more than 65% of the total refrigerant bank in 2030, an increase from 63% in 2018.



(Source: CHF 2019 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 21,700 metric tonnes in 2018 to a peak of more than 23,900 metric tonnes in 2022, before declining to around 18,200 metric tonnes in 2030; and,
- HFC-134a to grow from around 2,860 metric tonnes in 2018 to a peak of nearly 3,500 metric tonnes in 2025, before declining to around 3,200 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, rising from just 2,280 tonnes in 2018 to more than 18,300 tonnes in 2030, caps growth of the much higher GWP HFC-410A and helps cap the bank growth in CO<sub>2</sub>e value terms. The CO<sub>2</sub>e of the bank in stationary AC falls slightly over the 12 years of the projection period by approximately 8%, to some 57.9 million tonnes of CO<sub>2</sub>e, from the 2018 value of just more than 62.6 million tonnes CO<sub>2</sub>e.

The projection suggests the total  $CO_2e$  value of the stationary AC bank is still to peak at more than 64.7 million tonnes  $CO_2e$  in 2022 before slowly falling throughout the following decade.



(Source: CHF 2019 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 around 5,500 tonnes presently in use to 310 tonnes still employed by 2030.

Projections of Small AC, Medium AC and Large AC banks are available in tonnes and Mt CO<sub>2</sub>e in *Appendix* B3: Bank projections by class and segment.

# 5.1.6 Service rates and emissions projection

Stationary AC overall is expected to increase annual direct emissions of HCFCs and HFCs from around 1,245 tonnes in 2018 to more than 1,530 tonnes in 2030, increasing the overall share of direct emissions of stationary AC from the entire stock of equipment from 39% by mass now, to more than 50% by 2030.

The CO<sub>2</sub>e value of annual emissions from Stationary AC is expected to decline from around 2.4 million tonnes CO<sub>2</sub>e in 2018 to 2.2 million tonnes CO<sub>2</sub>e in 2030. This is largely due to the move to HFC-32 charges in small AC, the emergence of options in medium AC and the adoption of HFOs in larger classes of equipment such as chillers. Annual direct emissions from the small AC split system category are expected to remain relatively steady at 520 tonnes from 2018 to 2030 but with a decrease in the CO<sub>2</sub>e value of emissions from this segment from around 1.0 million tonnes CO<sub>2</sub>e in 2018 to nearly 0.52 million tonnes CO<sub>2</sub>e in 2030 as lower GWP refrigerants (primarily HFC-32) form the larger part of this bank.



<sup>(</sup>Source: CHF 2019 RAC Stock model)



(Source: CHF 2019 RAC Stock model)

# 5.2 Mobile air conditioning

Mobile air conditioning (MAC) includes equipment captured in two broad segments of the RAC Stock Model, 'small MAC' and 'large MAC'.

Small MAC includes air conditioning equipment in passenger vehicles, light commercial vehicles, trucks and commuter buses which together employed around 93% of the MAC bank in 2018. Large MAC includes equipment found in a diverse range of registered, unregistered and off-road vehicles, such as larger buses and coaches; locomotives, passenger trains and trams; recreational vehicles and caravans; boats and pleasure craft; aircraft systems; mobile cranes; combine harvesters; and road construction equipment.

These two segments and the twelve product categories in this class make up the second largest portion of the total bank of working refrigerants, containing approximately 21% of the bank in Australia, or around 11,200 tonnes in more than 19.0 million vehicles of all sorts (*CHF3 2016, 21%, 10,800 tonnes and 18.2 million vehicles*).

Metric	2018
Share of refrigerant bank	21%
Size of refrigerant bank	11,200 tonnes (1)
Annual usage to replace leaks (excludes re-use)	707 tonnes
Refrigerant in pre-charged equipment imports 2018	677 tonnes
Estimated stock of equipment	> 19.0 million units
Annual GHG indirect emissions	2.94 Mt CO <sub>2</sub> e
Share of HVAC&R indirect emissions	5%
Annual GHG direct emissions (ODS)	0.01 Mt CO <sub>2</sub> e <sup>(2)</sup>
Annual GHG direct emissions (SGG)	1.34 Mt CO <sub>2</sub> e
Share of HVAC&R direct emissions	19%
Share of HVAC&R total emissions (direct and indirect, not incl. EOL)	6%

*Table 6: Mobile air conditioning main metrics: 2018.* 

(Sources: AB&C 2019, ABS 9309.0 2019, ABS 9314.0 2018, AMSA 2019, BITRE 2018, BIC 2017, CVIAA 2019, DoEE 2019, FCAI 2019 and industry informants)

Notes:

- 1. An estimated 170 tonnes are refrigerants with a GWP<10.
- 2. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, as they managed through the Montreal Protocol.

# 5.2.1 Small mobile air conditioning

Stock numbers of small MAC are very robust as they align with registration data published by the Australian Bureau of Statistics (ABS). The RAC Stock model uses both sales (ABS 9314.0 2018 and FCAI 2019) and registration data (ABS 93090.0 2019) 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 CHF 2019 assumes 100% of vehicles manufactured after 2000 contain air conditioning.<sup>11</sup>

The increase in total stock in those four categories, from a total of 16.7 million vehicles in 2013 to more than 19.0 million vehicles in 2018, was a sizeable gain of nearly 14% in the five period.

Annual new vehicle sales containing small MAC have grown at a compound annual growth rate of 1.8% over the past 20 years from 807,669 in 1998, to 1,153,111 in 2018 (ABS 9314.0 2018 and FCAI 2019).

The majority of mobile air conditioning systems (94% based on units) 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, when it averaged around 1,100 grams per unit, at a time when MACs first started to become standard in most new vehicles.

*Table 7* below shows total new vehicle sales in Australia annually from 2012, and the number of vehicles manufactured in Australia during the period.

	2012	2013	2014	2015	2016	2017	2018
Vehicle sales	1,112,032	1,136,227	1,113,230	1,155,408	1,178,133	1,189,116	1,153,111
Vehicles locally manufactured	221,073	210,538	174,986	167,538	161,632	98,632	0

Table 7: New vehicles sales and local manufacture from 2012 to 2018.

(Source: ABS 9314.0 2018, FCAI 2019 and OICA 2019)

Notes:

1. New vehicle sales include all small MAC categories.

All significant passenger vehicle manufacturing in Australia ceased on October 20, 2017 with the closure of the Holden manufacturing plant in Adelaide. Toyota's Altona factory in Melbourne, 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 56 tonnes in the final year of Australian vehicle manufacturing in 2017. The effect of the end of all significant vehicle manufacturing means that since the year 2000 more than 300 tonnes of annual bulk HFC demand has been removed from the Australian economy. Import of HFCs in new vehicles has continued to rise however as sales of locally manufactured vehicles has been replaced by imported vehicles and the expected replacement of HFCs in MAC with HFOs has not occurred.

<sup>&</sup>lt;sup>11</sup> ABS Catalogue 93090 Motor Vehicle Census published July 2019, as of 31 January 2019, registrations for vehicles classified as Small MAC were 14,504,148 passenger vehicles; 3,313,418 light commercial vehicles; 648,438 trucks; and, 99,379 buses/coaches of which an estimated 73,800 are less than 4.5 GMT.

#### Trucks

While the taxonomy of the RAC Stock Model incorporates some 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/or operator comfort.

A fleet of more than 621,000 registered rigid body, articulated and non-freight trucks on the road in Australia in 2018 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 small construction and landscaping firms, 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 some kind of final customising or other work completed in Australia, including the incorporation of locally manufactured components, to make them 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.

#### Next generation of refrigerants making no impact on the Australian fleet in 2018

The most important event on the horizon for the MAC bank is the long-awaited introduction of the new generation of low GWP refrigerants, hydrofluoro-olefins, known as HFOs, developed with MAC in mind (HFO-1234yf, GWP of 1, IPCC Assessment Report 5).

As the use of this new generation refrigerant extends across a larger number of international manufacturers and new vehicle models, the CO<sub>2</sub>e value of the MAC bank in Australia is projected to fall by 34% from an estimated 16.0 million tonnes CO<sub>2</sub>e in 2018 to 10.5 million tonnes CO<sub>2</sub>e by 2030. However, it has to be noted that previous projections of the rate of HFO deployment in MAC have failed to materialise. Auto makers appear content to continue to supply models with older generations of refrigerants to any markets that permit HFCs, while making HFO charged models available where they are required to by law.

HFOs have been entering use in international vehicle markets since 2011, initially in Europe. 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.

Despite this low GWP option being employed by global manufacturers for several years now, interviews with Australian participants of the aftermarket survey confirmed that, while many were stocking HFO1234yf, none were selling any volumes worth noting.

The expectation has been that the first signs of HFO-1234yf in the market would be via the service departments of the main dealerships and smash repairers. A site visit to the largest Toyota Service Centre in Australia confirmed that no Toyota models imported to date contained HFO-1234yf, and discussions with Toyota head office engineering confirmed that no imports of HFO charged vehicle models were being planned.

Because HFOs are not a reportable substance, there are no records collected at the point of import that would explicitly reveal if new vehicles are entering the market pre-charged with HFOs. However, a comparison between PCE imports, plus local manufacturing less exports in 2017 and 2018, versus new vehicle sales in that year, found a statistical difference of just 1.8% over the last 2 years. This confirmed reports from industry that there is no statistically significant decline in PCE charged with HFCs. Further analysis of PCE imports by major brand (i.e. BMW, Mazda, Mercedes, Hyundai, Audi, Subaru) over the last 5 years show no statistical difference that would indicate switching to HFO-1234yf.

At this point in time the cost of the HFO refrigerant and components for HFO charged systems is higher than HFC-134a systems. However, the relative costs are starting to change as HFO charged MAC go into production for more vehicles for sale in markets where only HFOs meet regulatory requirements.

With the international agreement reached in 2016 under the Montreal Protocol to phase down HFC production and imports, it is expected that new vehicles from most leading manufacturers will be charged with HFO-1234yf by the mid-2020s, and a small portion (<0.5%) charged with CO<sub>2</sub>.

The move away from HFC-134a is now supported by regulations in the majority of leading 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 MAC charged with CO<sub>2</sub>.

The US Environmental Protection Agency and the Department of Transportation's National Highway Traffic Safety Administration have set standards to reduce greenhouse gases and improve fuel economy for cars and light trucks manufactured from 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.

It is only a matter of time before the Australia fleet starts to see HFO charged MAC in new vehicle sales. However because existing production lines for HFC charged MAC are clearly still profitable, global vehicle manufacturers are also likely to continue to manufacture and supply HFC charged systems, for as long as regulation allows.

## 5.2.2 Large mobile air conditioning

This segment comprises large buses and coaches dissected into two sizes, >4.5t and <12t GVM, 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 ABS as self-propelled motor vehicles containing an area primarily used for accommodation, which includes motor homes.

## Bus air conditioning

The fleet of buses and coaches with air conditioning is estimated to be greater than 42,700 with 25,400 buses with a GVM greater than 12 tonnes, and 17,300 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 (BIC 2017). 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 nationwide 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 around 1,300 per annum from 2012 to 2018 (AB&C 2019). 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, Sutrak, 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.

#### **Rail air conditioning**

The air conditioned rail fleet in Australia comprises 1,997 locomotives<sup>12</sup> and 5,816 passenger rail cars. Not all passenger rail cars are air conditioned, for instance in 2018 there were 1,619 passenger rail cars in Sydney of which 1,427 were air conditioned (BITRE 2019).

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 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 kWr 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.

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

#### **Recreational vehicles and caravans**

The Caravan Industry Association of Australia<sup>13</sup> reports that total caravan registrations have soared by 29% in the last five years to more than 612,000 in January 2018. Campervan registrations climbed 23% in the same period and has now grown to 69,753 registrations by January 2019 (ABS 93090 2019). 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 75% of caravans have air conditioning equating to a fleet of some 550,000 RVs and caravans with an average charge of 750 grams. The assumptions on the proportion of caravans fitted with air conditioning was based on a review of second-hand vehicles for sale and a physical survey conducted in 2018 on the Hume Highway in Victoria over a 5 hour period that counted 12 RVs and 53 caravans, identifying those that were fitted with AC.

Future editions of Cold Hard Facts will extend the survey model in this rapidly growing mobile AC segment.

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 2019).

# 5.2.3 Mobile air conditioning bank and projection

The vast majority of MAC enters the country pre-charged with HFC-134a in imported vehicles. While individual refrigerant charges are small, with more than 1.1 million new vehicles entering the economy

<sup>&</sup>lt;sup>12</sup> This excludes locomotives in storage, available for hire, or due for scrapping.

<sup>&</sup>lt;sup>13</sup> The Caravan and Campervan Data Report 2018 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 2019 and ABS 93090.0 2018).

annually for the past five years, the addition to the total bank of refrigerant in MAC is quite substantial, even after subtracting the number of vehicles reaching end-of-life each year. The majority of the MAC bank is HFC-134a (~93%). It is estimated that there are still more than 290,000 older vehicles in the fleet that were originally manufactured with MACs containing CFCs, the large majority of which are thought most likely to have been converted to HFC-134a or hydrocarbons at some stage in the last two decades.

Hydrocarbons, which are sometimes used as an aftermarket option in MAC in Australia, are estimated to be used in about 4% of the fleet, which equates to around 753,000 vehicles. Refer to *Appendix A: Section 11.2.5: Proportion of hydrocarbon in small MAC* for details on the calculation methodology and assumptions.

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.

The Expert Group predicts 2025 as the tipping point for HFO systems, which is reflected in *Figure 7* of the MAC bank projection below. The new sales mix projection for small MAC and large MAC from 2018 to 2030 can be found in *Appendix B2: New equipment sales mix by segment*, for new sales mix predictions to 2030. This estimated projection is based purely on market dynamics and cannot account for potential changes in policy settings that may impact on the timing or rate of introduction of HFO charged MAC.

The RAC Stock model predicts that there may be around 23.5 million vehicles with small MAC on Australian roads in 2030. It is expected that around 41% of those vehicles, or around 9.7 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.

By 2030 more than 5,400 tonnes of HFOs is predicted to be employed in the small MAC bank, mostly in private and small commercial vehicles, out of a total small MAC bank of approximately 11,900 tonnes at that time. Total volumes of HFC-134a in small MAC are forecast to decline 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 164 tonnes in 2018 to 198 tonnes in 2030. A small bank of around 60 tonnes of  $CO_2$  is also predicted to be in operation in small MAC by 2030.



<sup>(</sup>Source: CHF 2019 RAC Stock model)

## Large MAC Bank

The more complex and specialized segment, Large MAC, includes a range of applications for which high GWP HFCs are still needed to deliver the performance required for the application. 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 442 tonnes in 2018, rising to a peak of 535 tonnes in 2024 before starting to exhibit a
  gentle decline to around 453 tonnes in 2030;
- HFC-134a, from 226 tonnes in 2018 to 148 tonnes in 2030; and,
- HFC-410A, from 115 tonnes in 2018 to 176 tonnes in 2030.

The Large MAC bank is predicted to grow from around 805 tonnes in 2018 to approximately 1,026 tonnes in 2030, at that time comprising around 1.5% of the total bank of high GWP refrigerants.

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 534 tonnes in 2024. The larger charge sizes used in large buses and trains for public transport means the mild flammability of lower GWP refrigerants may be influencing refrigerant choice.

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 to effectively zero by 2030.

## 5.2.4 Service rates and emissions projection

#### Service Rates

Estimates of bulk refrigerant use for servicing the vehicle fleet in 2018 is 636 tonnes, or an estimated 18% of all bulk HCFCs and HFCs used in Australia in 2018. This refrigerant was used to replace leaked refrigerant from operating vehicles, equipment repairs and smash repairs.

This estimate of 2018 service refrigerant is a very robust value and is based on five consecutive years of surveying of market participants who supply more than 95% of this market. The survey results are summarised in the table below although these values do not take into account any aftermarket recovery and reuse.

2014	2015	2016	2017	2018
557,429	563,655	569,996	654,590	636,425

Table 8: Volumes of HFC-134a sold by calendar year (kilograms) based on aftermarket supplier survey.

Notes:

- 1. Excludes volumes supplied to major OEMs (i.e. Toyota, Holden, Ford) for the manufacture of vehicles up to October 2017 when manufacturing in of vehicles in Australia ceased.
- 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.

The Expert Group has conducted a number of studies in recent years that indicate underservicing in the MAC fleet. The degree of underservicing is indicated by the partial charge found in MAC in end-of-life vehicles (ELVs). Assuming an average vehicle life of 18.6 years, noting that service consumption of gas in 2018 was

equivalent to 5.3% of the total MAC bank in passenger vehicles, and noting the consistent observation that ELVs on average contain 67% of the original refrigerant charge, implies a leak rate across the fleet of MAC of just 7.1%.

This is significantly lower than the leak rate used in earlier studies of 11.8%, a value that has been an internationally accepted average leak rate for MAC. In the absence of any better data CHF 2019 has applied an average leak rate across the MAC fleet of 7.1% in 2018.

Assuming that servicing of the Australian fleet of MAC is consistently replacing around 75% (i.e. 5.3% divided by 7.1%) 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.

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.

## **Direct emissions projection**

While the vehicle fleet is expected to continue to grow substantially, small MAC is expected to reduce its contribution to annual direct GHG emissions by more than 30%, from a 2018 estimate of more than 1.2 million tonnes CO<sub>2</sub>e to around 850,000 tonnes CO<sub>2</sub>e in 2030, as a result of the expected adoption of HFOs by vehicle manufacturers and continuing improvements in containment of refrigerant in new vehicle MAC. This results in an overall decline in direct emissions from the overall MAC class of around 28%, even while losses from large MAC rise slightly from around 114,000 tonnes CO<sub>2</sub>e, then decline to 121,000 tonnes CO<sub>2</sub>e in 2030.



(Source: CHF3 RAC Stock model)

# 5.3 Refrigerated cold food chain

#### Introduction

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.

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 equipment classes.

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.

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:

- Cold 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 food product types moved along the cold food chain has also shaped the diverse formats employed.

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.

Using the product category codes in *Table 9* below it is estimated that:

- 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;
- All of the equipment in categories RCFC4-4, RCFC5-1 and RCFC5-2 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;
- 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; and,

• Less than 15% of equipment in RCFC1-5 is manufactured, or assembled and charged with refrigerant in Australia.

REFRIGERATED COLD FOOD CHAIN						
Item no	Segment	Application	Category code	Product category	Stock 2018	
31	RCFC1: Small Commercial Refrigeration	Self-contained	RCFC1-1	Refrigeration cabinets: self-contained	715,000	
32		Self-contained	RCFC1-2	Refrigeration beverage vending machines	137,500	
33		Self-contained	RCFC1-3	Beverage cooling (post mix)	54,000	
34		Self-contained	RCFC1-4	Ice makers	73,000	
35		Self-contained	RCFC1-5	Water dispensers (incl. bottle)	243,500	
36		Self-contained	RCFC1-6	Other self-contained refrigeration equipment	110,000	
37		Self-contained	RCFC1-7	Walk-in cold rooms: small: Slid-in/Drop-in	9,100	
38		Remote	RCFC1-8	Walk-in cold rooms: small: remote	212,000	
39	ration	Remote	RCFC2-1	Walk-in cold rooms: medium	20,500	
40		Remote	RCFC2-2	Walk-in cold rooms: large	21,300	
41	Refrige	Remote	RCFC2-3	Refrigeration cabinets: remote	13,500	
42	nercial	Remote	RCFC2-4	Beverage cooling (beer)	9,300	
43	Medium Comn	Remote	RCFC2-5	Milk vat refrigeration (direct expansion)	5,100	
44		Remote	RCFC2-6	Packaged liquid chillers (incl. milk vat)	12,600	
45	RCFC2:	Remote	RCFC2-7	Process, and mfg. refrigeration (<40 kWr)	21,000	
46		Remote	RCFC2-8	Other remote equipment	51,000	

# Table 9: Refrigerated cold food chain taxonomy.

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REFRIGERATED COLD FOOD CHAIN							
Item no	Segment	Application	Category code	Product category	Stock 2018		
47	RCFC3: Supermarket	Supermarkets	RCFC3-1	Supermarket refrigeration: small	2,397		
48		Supermarkets	RCFC3-2	Supermarket refrigeration: medium	1,306		
49		Supermarkets	RCFC3-3	Supermarket refrigeration: large	470		
50	RCFC4: Transport refrigeration	Transport refrigeration	RCFC4-1	Mobile refrigeration: road: trailer - inter- modal	12,000		
51		Transport refrigeration	RCFC4-2	Mobile refrigeration: road: diesel drive	8,400		
52		Transport refrigeration	RCFC4-3	Mobile refrigeration: road: off engine	24,700		
53		Transport refrigeration	RCFC4-4	Mobile refrigeration: marine	400		
54	RCFC5: Process and industrial	Industrial refrigeration	RCFC5-1	Cold storage and distribution	15.5 Million m <sup>3</sup>		
55		Industrial refrigeration	RCFC5-2	Process and mfg. (>=40 kWr)	-		
Total RCFC					>1,758,000		

(Sources: AACS 2018, AMSA 2019, DoEE 2019a, DoEE 2013, MC 2018, CG 2019, WOW 2019a, WOW 2017b, and industry informants)

Notes

- 1. Stock values are rounded to the nearest hundred.
- 2. Total numbers of stock in the cold food chain includes the count of supermarkets which accounts for 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 13% of the bank of refrigerant in Australia, or around 7,100 tonnes (*CHF3 2016, 14%, 6,900 tonnes*).

The refrigerated cold food chain has more than 1.7 million installations and pieces of equipment that in 2018 used an estimated 1,340 tonnes of HCFCs and HFCs to charge new equipment and replace leaked refrigerant. This represents around 37% of all HCFCs and HFCs used in Australia in 2018.

There have been several developments in this class since 2016 including;

- Rapid growth of HC refrigerants in smaller self-contained equipment (~25,000 devices imported in 2018) and the decline of sales of CO<sub>2</sub> pre-charged equipment migrating to HC;
- Continuing 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 cold rooms identified in the market place and a concerted effort underway by industry body AIRAH to improve standards of installation and operation in this strongly growing segment;<sup>14</sup>
- Continuing increases in small refrigerated transport units as home delivery of fresh foods, food services and catering businesses and prepared meals delivery business continue to grow.

Metric	2018		
Share of refrigerant bank	13%		
Size of high GWP refrigerant bank	7,100 tonnes		
Annual usage of high GWP refrigerants	1,340 tonnes <sup>(1)</sup>		
High GWP refrigerants in pre-charged equipment imports	61 tonnes		
Estimated stock of equipment	1.7 million devices		
Annual electricity consumption	19,600 GWh		
Share of HVAC&R electricity consumption	31%		
Annual GHG indirect emissions	15.93 Mt CO <sub>2</sub> e		
Share of HVAC&R indirect emissions	29%		
Annual GHG direct emissions (ODS)	0.01 Mt CO <sub>2</sub> e <sup>(2)</sup>		
Annual GHG direct emissions (SGG)	2.99 Mt CO <sub>2</sub> e		
Share of HVAC&R direct emissions	46%		
Share of HVAC&R total emissions (direct and indirect, not incl. EOL)	31%		

Table 10: Refrigerated cold food chain main metrics: 2018.

(Sources: AACS 2018, AMSA 2019, DoEE 2019a, DoEE 2013, MC 2018, CG 2019, WOW 2019a, WOW 2017b, and industry informants)

Notes:

1. Annual usage of high GWP refrigerants includes charging new equipment, replacing leaked refrigerant and repairs.

2. Emissions of ODS are not counted as part of the GHGs reported under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, as they managed through the Montreal Protocol.

<sup>&</sup>lt;sup>14</sup> The Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH) is due to publish a Best Practice Guide for Energy Efficient Walk-in Cold Rooms in late 2019.
#### Leak rates slashed in supermarkets

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 that CHF1 was published in 2006 the larger players in the industry were acknowledging that leak rates were unacceptably high in this sector and concerted programs at improved containment had commenced. By 2011, with the imminent imposition of the 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 life cycle refrigerant containment, generally involving leak prevention, proactive maintenance programs, system redesign, and installation of automatic leak detection systems.

In some instances, the results have been outstanding with leak rates in some major supermarkets dropping from as high as 25% per annum in the early 2000s to around 6% per annum in 2018 in some applications.

#### Much larger stocks of cold rooms identified

The term walk-in cold rooms (WICs) is used to describe an enclosed storage space that is refrigerated, either to temperatures above zero degrees Celsius (cool rooms) or to zero degrees Celsius and below (freezers).

Greater transparency achieved in the last few years by research into the supply lines for components that go into construction of cold rooms, led to a significant increase in the stock of walk-in cool rooms and walk-in freezers in the RAC Stock model in 2016, particularly in 'small cold rooms'.

WICs 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 while smaller WICs 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 which 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 reduce energy consumption by 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 Good Practice Guideline for WICs that is expected to be released by the end of 2019.

Total stocks of small cold rooms are estimated at more than 221,000 in 2018 (*CHF3: 2016, 219,000*). There is an estimated stock of 41,800 medium and large WICs in 2018.

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 cold room.

The RAC Stock model estimates that around 80% of sales of remote condensing units are for equipment being used in WICs. However, the growth in the stock of small WICs is considerably less than annual equipment sales indicate. This is because this hard-working equipment has a relatively short operational life of only 12 years and, depending on the working environment, this can be much shorter.

As such many of the equipment sales are being used to either replace the refrigeration equipment servicing cold 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 cold 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 cold rooms, they are potentially subject to impact damage from cartons and pallets of food.

### 5.3.1 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.

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 (sometimes twin circuits).

These equipment categories are employed in large numbers in both the front of store and back rooms of supermarkets, 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' (RDCs) and is fitted with either glass doors, transparent lids (in the case of horizontal display cases) or are open (at least during trading hours) as is the case with many of the 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 (improving efficiency).

The main product categories include:

- RCFC1-1: 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 cold 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 cold rooms, but with a remote condensing unit. These very small walk-in cold rooms are the only category in the RCFC1 segment that use a remote condensing unit.

Self-contained equipment has lower leak rates and smaller refrigerant charges than remote condensing unit systems.

The refrigerant employed in commercial refrigeration is often selected based on the two main temperature ranges used for the conservation of 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 frozen at 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 (the rate at which temperatures need to be reduced for instance in blast freezing or snap freeze processes).

#### 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 4% 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 25,000 units out of almost 140,000 total sales of self-contained units in 2018 (including beverage vending machines, post mix drink vending machines, ice makers and water coolers). 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 CO<sub>2</sub>, as compared to the older equipment charged with HFC-404A and more recently 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 RDCs charged with  $CO_2$  were introduced to the market in recent years. However, it is thought to be unlikely that  $CO_2$  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 hydrocarbon<sup>15</sup>. Increasing this charge size limit 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 cold 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.

The announcement by the International Electrotechnical Commission (IEC) in May 2019 to increase maximum refrigerant charge for all flammable refrigerants (A2L, A2 & A3) to the smaller of 1.2 kg or 13 times the lower flammability limit (LFL) of the refrigerant increased the allowable charge of A3 flammable refrigerants (i.e. hydrocarbons) from 150 grams to approximately 500 grams<sup>16</sup> under IEC 60335-2-89 standard. This will increase design innovation in HC charged commercial refrigeration which should soon flow on to increased options in the Australian market.

HCs and  $CO_2$  are expected to make up more than 41% of the bank in this segment by 2030. This is partly driven by developments in standards both here and overseas, and corporate commitments in the Australian supermarket sector to employ low GWP refrigerants (as seen for instance at both Coles and Woolworths), and supported by equipment manufacturers ready to roll-out product charged with natural refrigerants.

<sup>&</sup>lt;sup>15</sup> Refer AS/NZS ISO 5149: 2016 Refrigerating systems and heat pumps. - Safety and environmental requirements for further details on refrigerant charge limits.

<sup>&</sup>lt;sup>16</sup> R290 LFL of 0.038 x 13 = 0.494 kg and R600a LFL of 0.043 x 13 = 0.559 kg.

# 5.3.2 Medium commercial refrigeration

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

Much of the medium sized equipment in the refrigerated cold food chain is built using 'remote condensing units'. 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.

Remote condensing units typically range from 1 kWr to 20 kWr 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.

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 cold rooms, beverage cooling (e.g. beer and soft drinks), milk vat refrigeration on dairy farms and chilling and freezing applications in industry.

The equipment categories in this segment include:

- RCFC 2-1 and RCFC2-2: (CHF 2 RCFC 1-5 and RCFC 1-6) medium and large walk-in cold 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 <40kWr (new category split out from CHF2).

Some older walk-in cold rooms, beer coolers and milk vats are still charged with HCFC-22 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 cold rooms and freezers for more than a decade, maintains its dominance of the bank in RCFC2 with more than 2,700 tonnes in 2018. HFC-134a is the alternative refrigerant employed in the segment, increasing from around 600 tonnes in 2012 to over 1,000 tonnes in 2018, particularly among walk-in cold rooms. HFC-134a is expected to grow steadily in these applications to more than 1,300 tonnes in 2030 as HFC-404A declines over the same period to around 1,230 tonnes.

HC charged systems have started to appear in the market for this segment with the entry of HC charged packaged liquid chillers. HC systems are expected to achieve less penetration in this segment, achieving less than 0.5% of the remote condenser bank by 2030.  $CO_2$  systems are projected to grow from a relatively few installations to an estimated 117 tonnes in 2030, representing just 2.8% of the bank in this segment at that time.

Walk-in cold rooms of all sizes are often working in very difficult conditions and are prone to refrigerant leakage with an estimated annual average leak rate of around 15% per annum.

## 5.3.3 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 m<sup>2</sup>;
- 2. Medium Supermarkets with floor areas between 1,500 m<sup>2</sup> and 2,750 m<sup>2</sup>; and,
- 3. Small Supermarkets with floor areas between 400  $m^2$  and 1,500  $m^2$ .

Mini-marts, convenience stores and liquor outlets with floor areas smaller than 400 m<sup>2</sup> 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 they employ will all be either self-contained equipment and/or remote condensing units (i.e. walk in cold rooms) which is captured in other categories of equipment. *Table 11* shows the dissection of large, medium and small supermarkets as well as mini-marts by brand.

Brand	Stores	Av. Trading floor (m <sup>2</sup> )	Trading floor $(m^2)^{(4)}$					
			Large	Medium	n Small	Extra small		
			≥ 2,750	≥1,500 & < 2,750	<1,500 & ≥400	< 400		
Coles	808	2,298	202	404	202	0		
Woolworths (Safeway) <sup>(1)</sup>	1,029	2,605	257	515	257	0		
Aldi (2)	524	1,060	0	0	524	0		
IGA	1,674	800	0	335	1,172	167		
Foodworks	530	~800	0	53	212	265		
Costco	11	~5,000	11	0	0	0		
SPAR	150	-	0	0	30	120		
	4,726		470	1,306	2,397	<b>552</b> <sup>(3)</sup>		

Table 11: Supermarket fleet by brand and size at end of 2018.

(Sources: CG 2019, WOW 2019a, MC 2018 and industry sources)

Notes:

- 1. Woolworths has more than 544 stores with attached liquor.
- 2. The count of stores is as of the end of 2018, except IGA is April 2018. The mix of small, medium and large is estimated based on total fleet m<sup>2</sup> and other factors.
- 3. There are a further 6,343 convenience and petrol stores as at the end of 2017 including 7 Eleven, AA Holdings, Apco, BP, 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 2018).
- 4. The average trading floor and allocations of sizes are estimates only and are calculated based on a combination of published information and data from industry sources.

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.

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 cold 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, ice cream, 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 kWr, 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 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.

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 and trans-critical  $CO_2$  only systems that can encompass air conditioning loads and other refrigeration loads such as attached liquor outlets.

There are at least 4,174 supermarkets (trading floor >400 m<sup>2</sup>) which together contain around 2,100 tonnes of high GWP HFCs and 120 tonnes of HCFCs, or about 4% of the bank (*CHF3 2016, 3,200 tonnes and 4%*). 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% by mass of the larger 2018 bank, so has the relative share of direct emissions from supermarkets fallen to an estimated 6% in 2018 based on CO<sub>2</sub>e.

The leading supermarket operators have also achieved real absolute reductions in direct emissions in the course of the last decade, as a result of long term programs of improved maintenance, leak reduction and improved containment, equipment redesign and a concerted shift towards lower GWP refrigerants. These increasingly common programs of improved refrigerant management are generally accompanied by, or part of, overarching energy efficiency programs, which have also been producing tremendously positive results for supermarket owners.

A trend in refrigerant retrofitting, which was first reported in CHF2, has also persisted. 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  $CO_2$  in a secondary refrigerant circuit.

The first  $HFC/CO_2$  cascade refrigeration system was installed in Australia in 2005 by Coles and other varieties were trialled including an ammonia/CO<sub>2</sub> 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, with  $CO_2$  as the secondary refrigerant with  $CO_2$  charges ranging from more than 400 kg to as little as 25 kg of  $CO_2$ . 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 HFC replacements are proven and released to the market.

For some time, efficient operation of  $CO_2$  systems has been restricted in warmer climatic zones due to the low critical temperature of  $CO_2$  refrigerant (e.g. critical temperature of  $CO_2$  is  $31.1^{\circ}C$  versus  $101^{\circ}C$  for HFC-134a). This characteristic of  $CO_2$  refrigerants has been a technical barrier for use of trans-critical  $CO_2$  systems in higher ambient temperature regions in Australia, with the early  $CO_2$  trans-critical systems only found to perform efficiently in BCA climate zones 6 and 7. Early designs for trans-critical  $CO_2$  systems incurred an energy penalty in the hotter months in warmer climate zones, as compared to HFC charged systems.

However, a new generation of  $CO_2$  trans-critical technology is rapidly evolving with a mix of technology enhancements 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  $CO_2$ . The current count on  $CO_2$  trans-critical systems is more than 35 with significant growth over the next five years. For example, Aldi recently announced a target of 100  $CO_2$  trans-critical systems by 2025.

CO<sub>2</sub> trans-critical are now well established in major supermarket groups and are starting to be employed by smaller independent supermarket operators. Supermarket contractor AJ Baker has installed CO<sub>2</sub> trans-critical systems across 20 sites with eight in Perth, three in Brisbane, three in Sydney and six others in climate zones 5 and 6 as of March 2019.<sup>17</sup> The key lessons have been that system gas cooler outlet temperature control is imperative for energy efficient operation in higher ambient temperature zones, and that adiabatic coolers can deliver energy savings not previously possible in hotter months.

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 CO<sub>2</sub>-only trans-critical systems, have all contributed to reduce demand for bulk refrigerant in supermarkets.

As a result of these trends 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  $CO_2$ . The model predicts around 35% of refrigeration systems in supermarkets will still be operating on high GWP refrigerants however this could be a conservative estimate if prices of high GWP refrigerant increase compared to alternatives. The balance of refrigerants comprises lower GWP blends and HFOs with a smaller footprint of HC (<1%) in 2030.

Coles and Woolworths, which control the majority of food retail in Australia (estimated at around 65% of the trading floor), 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).

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 declared their intention of achieving HFC free refrigeration services, across the many thousands of stores in the smaller end of the industry cost pressures and low margins will mean older equipment is likely to be employed for much longer, which has implications for both the use of older high GWP refrigerants, and for leak rates.

<sup>&</sup>lt;sup>17</sup> AIRAH Refrigeration Conference 2019: Trans critical CO<sub>2</sub> in Australian supermarkets – continued success, Mike Baker, AJ Baker & Sons Pty Ltd.

An example of industry change is a recent smaller independent store refurbishment reported in RAC industry media in 2019. The contractor, MB Refrigeration, replaced around 50 kg of CFC-12, 500 kg of HCFC-22, 400 kg of HFC-404A and 100 kg of HFC-134a. In this case all of the refrigeration and HVAC requirements in the store are now provided by an integrated trans-critical CO<sub>2</sub> system.

# 5.3.4 Transport refrigeration

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 260 tonnes of refrigerant comprising less than 0.5 % of the refrigerant bank (*CHF3 2016, 0.5% and ~245 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 (*CHF3 2016, 1.6%,* ~55-60 tonnes) of annual HFC and HCFC refrigerant bulk imports, the majority is used for 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 trailer/intermodal and diesel drive units are imported fully charged, tested and ready to be fitted. Offengine 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 starting to migrate to HFO/HFC blend R452A (GWP of 2141). The HFC phase down in the EU is the main driver of this trend to a lower GWP refrigerant.

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.

Woolworths and Coles now provide home delivered groceries that can be ordered on line and scheduled for delivery to your door. 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.

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. Whilst CO<sub>2</sub> refrigerant closed cycle models are available, Australian suppliers are not promoting this option due to the extreme operating pressures and poor energy efficiency when used outside of very moderate climates.

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.

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.

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.

In aggregate marine refrigeration is estimated to comprise around 0.1% (~55 tonnes) (*CHF3 2016, 0.1%, also 55 tonnes*) of the refrigerant bank. The leak rates have reduced from between 25% and 30% per annum<sup>18</sup> in 2012 to around 15% per annum in 2018, the main driver being price.

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 electromechanical systems.

## 5.3.5 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.

<sup>&</sup>lt;sup>18</sup> Industry source: Austral Fisheries, leak rates greater than 30% per annum can be experienced on old open drive equipment.

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 more than 95% of applications, based on total refrigerant bank in the category, using ammonia. There are some instances where ammonia refrigeration systems have been installed in cold storage facilities using the existing steel pipes from the previous HCFC-22 system. Some facilities with large HCFC-22 refrigerant charges (~6 tonnes) have been re-configured 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 kWr to more than 1,000 kWr. 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 ammonia<sup>19</sup> systems are found include cold storage facilities (typically 5,000 to 250,000 m<sup>3</sup>), 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 2018 there was an estimated 15.5 million  $m^3$  of cold storage space operating in Australia and the very large majority of these facilities (>95%) operate on ammonia systems. Assuming a benchmark obtained from industry sources of 29 kg per 1,000  $m^3$  of storage space, this equates to around 445 tonnes of ammonia in cold stores.<sup>20</sup>

Some examples of construction activity of ammonia systems in the cold storage industry since 2016 include:

- A consolidation and expansion of the Ingham's Food Processing and Cold Storage Facility in Lytton to around 114,000 m<sup>3</sup> in 2017.
- PFD Food Services constructed a new facility with 8,500 m<sup>2</sup> of freezer and 5,500 m<sup>2</sup> of chiller capacity in 2018.
- In late 2018 Link Logistics opened a new facility with 1,000 m<sup>2</sup> of freezer and 900 m<sup>2</sup> of chiller capacity in the commercial precinct of Hobart Airport to allow local producers to transport their fresh produce directly to export destinations. This system was a CO<sub>2</sub> only trans-critical system due to location and the requirement for low toxicity, non-flammability and energy savings.
- Costco Australia constructed a new distribution centre with capacity to service up to 30 stores nationally
  plus online. Costco propose to close the existing distribution centre in Wetherill Park when the new
  warehouse comes on line in 2019.
- Expansion of the Woolworths, Adelaide Regional Distribution Centre on the Gepps Cross site by 94,000 m<sup>2</sup> planned to be complete by mid-2020.
- In May 2018 Woolworths announced the construction of a new dedicated Melbourne Fresh Distribution Centre to be located in Truganina, Victoria designed to replace current operations at Mulgrave in late 2020.
- Numerous Bidfoods sites have been upgraded or are under construction including a new 7,500 m<sup>2</sup> Cold Storage and Distribution Centre in Cairns. These are low charge ammonia systems.

<sup>&</sup>lt;sup>19</sup>Ammonia used in refrigeration systems is anhydrous ammonia meaning it does not contain water, the chemical symbol is NH<sub>3</sub> and the ASHRAE refrigerant number is R717.

<sup>&</sup>lt;sup>20</sup> Industry participants of the Refrigerated Warehouse and Transport Association.

 Hilton Food Group is constructing a 45,000 m<sup>2</sup> meat processing and distribution facility that is anticipated to be fully operational in 2020.

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 150 meat/poultry processing facilities in Australia that employ more than 20 people.<sup>21</sup>

A survey of suppliers of bulk ammonia estimated 643 tonnes were delivered to customers in 2018. The recent survey confirms a five-year average of 698 tonnes supplied per annum from 2014 to 2018. 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 5,000 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.

## 5.3.6 The refrigerated cold food chain bank and projections

The refrigerated cold food chain employs a diverse bank to suit the wide range of temperature conditions (typically from  $-25^{\circ}$ C to  $+7^{\circ}$ C) and outputs required.

Employing about 13% of the total bank, or about 7,100 tonnes of refrigerant in 2018, 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.



<sup>&</sup>lt;sup>21</sup> ABS 8165.0 Counts of Australian Businesses, as of June 2018 and includes codes 1111 Meat Processing and 1112 Poultry Processing. There were 52 business with more than 200 employees and 96 businesses with more than 20 and less than 200 employees. There were a further 710 businesses that were classified as non-employing or with less than 20 employees that are unlikely to have sufficient scale for an ammonia plant.



(Source: CHF 2019 RAC Stock model)

### Small commercial refrigeration

Small commercial refrigeration, predominately comprising self-contained equipment, is estimated to contain around 7% of the RCFC bank in 2018, or around 490 tonnes of HCFCs and HFCs, and around 20 tonnes of HCs. 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 2018 more than 90% of this small segment was charged with either HFC-134a (221 tonnes) or HFC-404A (260 tonnes). By the end of the projection period the bank of HFC-134a is expected to decline by more than 30% to just 155 tonnes and HFC-404A is expected to decline by nearly 85% to just 45 tonnes.



Figure 11: Refrigerant bank (actual) by species from 2018 to 2030 in tonnes.

(Source: CHF 2019 RAC Stock model)

HCs are expected to grow to around 120 tonnes in 2030. Refrigeration display cases and storage cabinets have already experienced a rapid transition to HC with more than 25,000 devices imported in 2018 with a charge less than or equal to 150 grams of HC per refrigeration circuit. HCs (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 expected to be employed 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 by 2025 has to be prepared to deal with any one of seven possible different refrigerants, including small charges of highly flammable HC, mildly flammable A2L refrigerants and high pressure CO<sub>2</sub> equipment. Only a few years ago a technician would expect to work on a commercial refrigeration contract with just two main Class A1 non-flammable refrigerants (HFC-134a and HFC-404A).

#### Medium commercial refrigeration

The developing diversity of the bank is even more acute in the broad segment of remote equipment, 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 systems are very hard working, almost always have some 'bespoke'/situational design considerations, 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  $-25^{\circ}$ C and lower for blast freezing, or medium temperature refrigeration services (zero to  $+7^{\circ}$ C).

Employing a total bank of more than 4,140 tonnes in 2018, representing 58% of the RCFC bank, 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 62% of the highest GWP refrigerant in the bank, HFC-404A, which illustrates some of the technical challenges facing this sector during the HFC phase down.



(Source: CHF 2019 RAC Stock model)

Banks of these high GWP refrigerants in this segment are estimated as follows:

- HFC-134a of around 1,010 tonnes in 2018 to grow steadily to 1,330 tonnes in 2030;
- HFC-404A of more than 2,700 tonnes in 2018 to fall steadily by more than 54% to around 1,230 tonnes by 2030;
- HFC-410A of around 43 tonnes in 2018 rising steadily to the end of the projection period at 116 tonnes;
- HFC-407C to rise slowly from around 110 tonnes in 2018 to 122 at the end of the projection period;
- A small bank of emerging HFO/HFC blends including R448a and R449a in the <2150 GWP bin is predicted to grow to more than 720 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 500 tonnes by 2030.

Low GWP refrigerants are also predicted to grow into a small portion of this complex bank with HC, CO<sub>2</sub> 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 2018 and is expected to grow to some 12 tonnes;
- CO<sub>2</sub> systems are predicted to grow from zero at the start of the period to a bank of more than 115 tonnes by 2030; and,
- Ammonia systems in low temperature remote applications of more than 40 kWr are expected to grow from zero to more than 22 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 165 tonnes presently in use to just 5 tonnes by 2030.

#### Supermarkets

Supermarket refrigeration systems were estimated to employ around 2,400 tonnes of refrigerant in 2018, at that time comprising more than 33% 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.



(Source: CHF 2019 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 2018 bank of around 1,415 tonnes, climbing to around 1,455 tonnes in 2020 before falling steadily to less than 610 tonnes by 2030.

HFC-134a, starting with a bank of around 580 tonnes in 2018 is expected to climb to around 870 tonnes in 2025 before declining steadily to around 480 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.

Refrigerants in the <2150 GWP bin including HFC-407F and emerging HFO/HFC blends R448a and R449a are predicted to grow steadily from a 2018 estimate of some 70 tonnes to a bank of around 480 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 320 tonnes by 2030.

Two stage HFC-134a/CO<sub>2</sub> cascade systems, and CO<sub>2</sub> only trans-critical systems will see large CO<sub>2</sub> charged centralised refrigeration systems build a bank of CO<sub>2</sub> from around 210 tonnes in 2018 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 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.

This bank is projected to grow steadily to around 290 tonnes by 2030, with limited options currently available to move to lower GWP refrigerants. The CO<sub>2</sub>e value of this small bank is expected to decline slightly from around 775,000 tonnes CO<sub>2</sub>e in 2016 to around 700,000 tonnes in 2030.



(Source: CHF 2019 RAC Stock model)

The RCFC Transport bank, while small, illustrates some of the technical challenges facing the wider RAC industry in the HFC phase down. 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  $CO_2$  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-452A (GWP of 2141) on larger systems and HFC-134a on smaller systems.

### 5.3.7 Service rates and emissions projections

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.

Annual direct emissions of HCFCs and HFCs in the RCFC class is predicted to remain steady in volume terms at around 1,020 tonnes per annum from 2018 to 2030.

Supermarkets are projected to cut their direct emissions by more than half from a 2018 estimate of more than 750,000 tonnes  $CO_2e$  to around 360,000 tonnes  $CO_2e$  by 2030. The adoption of lower GWP refrigerants across the class helps lead the entire RCFC class to reduce the  $CO_2e$  value of annual losses by almost 40% from a 2018 estimate of 3.1 million tonnes  $CO_2e$  to a 2030 estimate of around 1.9 million tonnes  $CO_2e$ .

While only comprising 13% of the total bank in 2018, the RCFC class is the second highest contributor to direct emissions of all RAC equipment. The RCFC class is forecast to contribute 37% on a CO<sub>2</sub>e basis to total emissions in 2030 down from 45% of direct CO<sub>2</sub>e emissions in 2018.



(Source: CHF 2019 RAC Stock model)



<sup>(</sup>Source: CHF 2019 RAC Stock model)

# 5.4 Domestic refrigeration

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.

Domestic refrigeration in Australia (including domestic freezers and small portable refrigerators) is estimated to contain approximately 1,700 tonnes of HFC-134a and 475 tonnes of HC refrigerant in a total stock of greater than 19.7 million devices<sup>22</sup>, equal to approximately 3% of the total refrigerant bank.

The main metrics of the stock of domestic equipment are provided below in Table 12.

Metric	2018		
Share of refrigerant bank	3%		
Size of high GWP refrigerant bank	1,700 tonnes		
Annual service rate of high GWP refrigerants	4.3 tonnes		
High GWP refrigerants in pre-charged equipment imports	9.9 tonnes		
Estimated stock of equipment	19.7 million appliances <sup>(1)</sup>		
Proportion stock HFC charged (by mass)	78%		
Proportion stock HFC charged (by units)	65% <sup>(2)</sup>		
Annual electricity consumption	8,738 GWh		
Share of HVAC&R electricity consumption	14%		
Annual GHG indirect emissions	6.99 Mt CO <sub>2</sub> e		
Annual GHG (SGG) direct emissions	0.05 Mt CO <sub>2</sub> e		
Share of HVAC&R direct emissions	0.8%		
Share of HVAC&R total emissions (direct and indirect, not incl. EOL)	7%		

Table 12: Domestic refrigeration main metrics: 2018.

(Sources: DoEE 2019a, E3 2015 and industry informants) Notes:

<sup>&</sup>lt;sup>22</sup> Deducting from this population of 19.7 million devices an estimated 980,000 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 CHF RAC Stock model predicts an installed base of 17.82 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 18.06 million refrigerators and freezers in Australian homes in 2018.

- 1. Including portable and automotive refrigeration.
- 2. An estimated 35% of domestic refrigerators are charged with HC based on units.

New sales of domestic refrigerators and freezers in 2015 (the latest year for which data is available) amounted to slightly more than 1.1 million devices (excluding portable and automotive refrigeration). This is very consistent with the average new sales of 1.1 million devices that have been reported every year for the decade prior to 2015.

All new domestic refrigerators and freezers are now imported to Australia as pre-charged equipment. There is no manufacturing of any equipment in this class remaining in Australia. Only a decade ago the majority of domestic demand was supplied by domestic manufacturing.

Typical storage volumes of domestic equipment 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 an in-built 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 hydrofluorocarbon refrigerant charges ranging from less than 50 grams to more than 200 grams<sup>23</sup>, or with charges around 60% smaller if charged with hydrocarbons.

With an estimated 950,000 domestic devices reaching the end of their useful life every year this stock of equipment is expected to continue to grow at just over 1% 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 (or 55 grams of HC), is estimated to have lost slightly less than 18 tonnes of refrigerant in 2018 from leaks from operating equipment, or approximately 0.6% of all direct emissions of high GWP refrigerant in 2018. These direct emissions are only from the operating stock, and do not include refrigerant lost from equipment that has reached the end of its useful life.

The majority of the bank of refrigerant in the stock of domestic equipment is still HFC-134a, more than 65% based on units (and 78% based on volume), however this dominance of HFC-134a in the bank of refrigerant in domestic devices is declining rapidly as the use of hydrocarbons for new domestic devices becomes effectively universal across all manufactures.

Some very old products manufactured prior to the mid-1990s contain CFC-12<sup>24</sup>, and while these units are still occasionally found, it is expected that this small part of the stock is rapidly dwindling, containing less than a few tens of tonnes of CFCs in aggregate.

There was around 10 tonnes of high GWP HFC refrigerant imported in pre-charged domestic refrigerators in 2018, most of which was employed in the smaller portable and automotive style refrigerators, all of which are still charged with a synthetic refrigerant. However, this quite small addition to the bank of high GWP refrigerants from domestic refrigerator and freezer imports further underlines the shift of the global manufacturing base of domestic equipment to the use of HCs.

#### Growth of hydrocarbon charged domestic refrigerators

The growth of hydrocarbon charged domestic refrigerators and freezers in the stock has accelerated dramatically since 2012, with an estimated 6.8 million devices (~35% of the stock) containing hydrocarbon HC-600a in 2018.

<sup>&</sup>lt;sup>23</sup> The average charge of a domestic refrigerator is 140 grams of HFC-134a and 55 grams of HC.

<sup>&</sup>lt;sup>24</sup> This older stock of equipment is just one of the sources of the 2 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.

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. A similar survey was conducted in February 2019 found just one model out of 107 inspected (<1%).

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 183,500 units in 2018 of which 138,000 were portable refrigerators with a charge of less than or equal to 65 grams of HFC-134a (DoEE 2019). The majority of portable refrigerators have not transitioned to HC.

*Figure 17* 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 market for smaller portable refrigerators is apparent in this chart.

Most suppliers and service agents no longer undertake on-site repairs of domestic refrigerators. Some suppliers have central repair centres to undertake major repairs, however this sector is largely now a replacement market.

The service rate of domestic refrigerators in the RAC stock model has been reduced to 0.25% per annum equating to around 4 tonnes per annum.



(Sources: DoEE 2019a)

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 to HC charges in the larger formats is obvious, smaller portable and automotive devices are still universally being imported with HFC charges. These smaller format devices require charges of less than 65 grams of HFC-134a. Approximately 132,000 portable and passenger vehicle refrigerators have been imported each year on average between 2012 and 2018; major suppliers include Dometic Group (Waeco

brand) and Engel Australia. Evercool, Norcoast and OzeFridge manufacture small quantities of portable 12V refrigerators in Australia.





<sup>(</sup>Source: CHF 2019 RAC Stock model)

The estimated 950,000 domestic and portable devices that reached the end of their useful life during 2018 are expected to contain as much as 130 tonnes of residual charge of HFC-134a. That quantity of HFCs is the equivalent of 178,750 tonnes of CO<sub>2</sub>e. Due to the small charge sizes, despite the rare subsidised recovery programs operating at some local government scrap metal collection points, it is expected a significant portion of this refrigerant will be released to the atmosphere.

All domestic refrigeration and freezers in the economy are estimated to contain around 2,150 tonnes of refrigerants in 2018, or about 3% of the total bank of HCFCs and HFCs, of which 78% is HFC-134a, with the balance 22% (475 tonnes) being hydrocarbons.

This is projected to change relatively quickly by 2030 with a larger stock of domestic devices expected to be operating on a total bank more than 40% smaller at around 1,230 tonnes, of which more than 81% is hydrocarbons and the balance a rapidly declining bank of just 184 tonnes of HFC-134a.

While domestic refrigeration has been a smaller and declining portion of the bank since the mid-90s, this class is a good example of how quickly the composition of the bank can change, when the technological and market circumstances align.

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.

As a result, coupled with improved containment, the move to HCs means that the contribution of domestic refrigeration to annual direct emissions of SGGs is predicted to decline rapidly towards zero in the projection period.



(Source: CHF 2019 RAC Stock model)

# 6 The refrigerant bank

The common denominator of all vapour compression air conditioning and refrigeration is that it 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 significantly. Originally starting with common compounds 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 it, from small benchtop drink merchandisers with less than 30 grams of HCs, to large chillers with 1,500 kilograms of HFCs cooling enormous structures like airport terminals.

Having successfully implemented an international phase out of ozone depleting refrigerants, a process that is now well advanced, international governments and the refrigerants industry have now agreed to a phase down of HFC refrigerant production, 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 models)

Notes:

1. The band provides sensitivity analysis with the 2006 value (+20%, -5%), 2012 plus (+10%, -5%), 2016 and 2018 values (+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 of HCFCs and HFCs in Australia in 2018 is estimated at approximately 53,300 tonnes (CHF3 2016, 50,800 tonnes). This is an increase of 5% as compared to the bank in 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 strong sales of small and medium domestic and commercial air conditioning systems (<25 kW). 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.

A growing community-wide dependency on AC 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 item in the majority of buildings.

During the same period Australia's increasing food exports 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.

Setting aside the apparent softening in growth in the most recent period, using the starting point of 33,185 tonnes in 2006, the bank has grown in total by more than 60% in the 12 years from 2006 to 2018, equivalent to a compound annual growth rate of 3.9% over the period.

# 6.1 Constituents of the bank, GWP and CO<sub>2</sub>e

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

- HFCs (hydrofluorocarbons) (47,500 tonnes or 88% 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 that had been 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, most HFCs in common use have high 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 gradually from 2019 towards a 2036 target of 15% of recent levels of production;
- HCFCs (hydrochlorofluorocarbons) and CFC (chlorofluorocarbons) (5,800 tonnes or 11% 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 production 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 CO<sub>2</sub>, 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 applications<sup>25</sup>. The bank of natural refrigerants that has displaced HFCs and HCFCs in commercial refrigeration and mobile applications between 2012 and 2018 is estimated at 900 tonnes. There is a further estimated 5,000 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. These ammonia refrigerants are not included in the estimate of the bank in 2018 as illustrated in *Figure 20* above.

<sup>&</sup>lt;sup>25</sup> 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'.

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 provide, while also having very low GWPs (GWP of HFO-1234yf and HFO-1234ze is 5 and 1, respectively – IPCC Assessment Report 5). HFOs are entering into service internationally, initially in new motor vehicles, and chiller manufacturers are also offering some models that employ HFOs due in part to the energy efficiency gains they deliver. In 2018 there was no significant volume of HFOs<sup>26</sup> in use in equipment in Australia although they are expected to grow their share of the bank quite rapidly.

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.



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

The effect of the boom in adoption of small and medium AC, and the shift away from HCFCs, can be seen the slow decline of HCFC-22, once the largest single component of the bank, and the rapid growth of HFC-410A between 2006 and 2018.

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 10 million HFC-410A charged pieces of equipment in the course of the last decade, containing a bank of 21,900 tonnes of HFC-410A, representing 41% of the entire bank.

This 780% growth in HFC-410A from just 9% of the bank (2,800 tonnes) in 2006 to 41% of the bank in 2018 (21,900 tonnes) 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.

<sup>&</sup>lt;sup>26</sup> 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 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).

HCFC-22 as a proportion of the total bank has declined from 37% in 2006 to 10.5% in 2018.

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 7,200 tonnes from that high point, or more than 56%, in the last 8 years.

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

The sharp drop in the HCFC bank should continue as a result of the large numbers of HCFC charged air conditioning units that were installed between 10 and 25 years ago, that are now reaching the end of their useful life and being retired.

Despite the ban on import and manufacture of HCFC charged equipment, small quantities of HCFC precharged 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. Expert Group data suggests that the long tail of HCFC-22 bulk imports until the end of 2029 will not be sufficient to meet the expected demand to service and repair the remaining installed HCFC charged equipment, requiring recycling of much of the remaining bank of HCFC-22 as older equipment is retired.

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.

The market reaction to the phase out and limited supply of HCFCs provides insight into the trends that should emerge with HFCs, 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 to HCFCs were 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 now becoming more complicated by the amount of unreported HCFC-22 reuse, the cost of maintaining older equipment and changing market prices for recycled HCFC-22.

After HFC-410A, HFC-134a is the second most abundant refrigerant in the 2018 bank, growing steadily at around 3% per annum up to 2016, at which point it constituted some 32% of the bank, a proportion it has maintained by 2018.

HFC-404A which saw steady growth in overall tonnes between 2012 and 2016, increasing by more than 1,100 tonnes, or 25%, to reach 4,547 tonnes and 9% of the total bank in 2016, has only maintained this proportion of the total bank into 2018 with now an estimated 4,560 tonnes.

HFC-407C also grew in volume by more than 25% from 2012, reaching some 1,336 tonnes in 2016, having grown steadily from around 700 tonnes in 2006, increasing its proportion to 2.8% 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 21* above was produced. The tabulated data of the bank by species notably shows the emergence in 2016 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 overall GWP intensity of the refrigerant bank as it becomes the most common refrigerant employed in the extensive stock of small AC.

	2006 (4)		2012		2016		2018		
	Tonnes	Share	Tonnes	Share	Tonnes	Share	Tonnes	Share	
HCFC-22	11,280	37%	11,227	26%	8,283	16%	5,605	110/	
HCFC Mix	1,000	3%	201	0%	217	0%	199	11%	
HFC-134a	11,389	37%	13,432	31%	16,343	32%	16,803	31.5%	
HFC-404A	3,412	11%	3,306	8%	4,547	9%	4,560	9%	
HFC-407C	711	2%	1,017	2%	1,336	2.6%	1,492	2.8%	
HFC-410A	2,783	9%	14,341	33%	18,660	37%	21,893	41%	
HFC-32	0	0%	0	0%	1,035	2.0%	2,286	4.3%	
GWP<2150	0	0%	0	0%	336	0.7%	432	0.8%	
GWP <1000	0	0%	0	0%	0	0%	31	0.1%	
Total HCFCs and HFCs	30,575	100%	43,524	100%	50,756	100%	53,301	100%	
GWP<10	100	-	799	-	737	-	902	-	

Table 13: Refrigerant bank 2006, 2012, 2016 and 2018 by mass in tonnes and share in percent.

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 40 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<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. This value is the published CHF2 bank of HFC-404A. Based on CHF3 methodology the bank of HFC-404A in 2012 would be higher. Since CHF2 the number of walk-in cold rooms has been revised upward and 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 were revised upward.
- 5. The GWP<10 substances listed in the above table represents applications that have transitioned from HCFCs and HFCs to low or zero GWP refrigerants. The actual bank of refrigerants with a GWP<10 is much larger as it includes large ammonia plants that used ammonia prior to 2006.

# 7 Refrigerant imports and usage

There are two means by which the bank of working gas in Australia grows:

- Via imports of equipment pre-charged with a refrigerant gas, referred to as PCE imports; and,
- Via imports of bulk gas, where the bulk gas imported is not used to service existing stocks of equipment, replacing gas lost to air, but rather is consumed charging new equipment manufactured in Australia, or charging new equipment imported without a refrigerant charge.

This section analyses PCE and bulk gas imports, and then examines the market dynamics for bulk gas as it is broken down into smaller lots and distributed (sold) into the supply lines for servicing the stock of existing equipment and charging new equipment.

Natural refrigerants, ammonia,  $CO_2$  and hydrocarbons are not classified as scheduled substances under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* and are discussed separately in *Section 8*. Hydrofluoro-olefin (HFO) refrigerants are not classified as scheduled substances, however ingredients used in HFO blends are briefly discussed at the end of this section (*Section 7.4 Hydrofluoro-olefin refrigerants*).

# 7.1 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 increases in and changes in the overall composition of the refrigerant bank.

PCE imports can have an impact on the bank for decades ahead with some equipment expected to have working life greater than 20 years.

Pre-charged equipment imports of all sorts has been the major source of growth in the refrigerant bank for the last five years, introducing an average of about 3,330 tonnes of new refrigerant per annum since 2014.

In 2018 there were more than 4.8 million devices pre-charged with HFCs imported to Australia containing, in aggregate, around 3,690 tonnes of refrigerant<sup>27</sup> (*CHF3 2016, 4.7 million devices containing some 3,127 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 than 1.4 million stationary air conditioning devices imported in 2018, accounting for more than 2,586 tonnes of refrigerant, or 70% of imported refrigerant contained in PCE that year. More than 1.3 million of these stationary AC were classed as 'residential' devices that added more than 2,035 tonnes of refrigerant to the bank.

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

Mobile AC systems were the second largest category of PCE, containing 18% of HFCs imported in equipment in 2018, and adding some 677 tonnes to the bank, followed by commercial, domestic and mobile refrigeration systems that added 61 tonnes of HFCs to the bank.

<sup>&</sup>lt;sup>27</sup> A ban on imports of equipment containing HCFCs was implemented in July 2010.



(Source: DoEE 2019)

A breakdown of the major categories of pre-charged equipment imports reported from 2013 to 2018 is presented in *Table 14*. This demonstrates the relative scale of stationary air conditioning imports, as compared to other categories.

	2013	2014	2015	2016	2017	2018
Residential use air- conditioning	1,005,503	1,066,378	1,168,421	1,159,087	1,472,853	1,364,751
Commercial use air- conditioning	77,024	67,660	114,803	99,169	106,738	113,718
Motor vehicle, watercraft or aircraft air-conditioning	986,923	919,906	995,687	924,854	1,070,029	1,041,795
Domestic use refrigeration	444,590	319,614	256,664	257,985	220,451	183,527
Commercial use refrigeration	110,446	91,456	117,922	108,181	112,685	101,127
Motor vehicle, watercraft or aircraft refrigeration	68,219	62,719	105,626	148,672	132,720	99,463
Commercial or domestic use heat pumps	17,124	23,083	25,815	35,125	52,845	61,998

Table 14: Pieces of pre-charged equipment imported from 2013 to 2018.

(Source: DoEE 2019)

While MAC equipment imports are approaching Stationary AC import numbers, the much greater contribution to imported HFCs of pre-charged stationary AC is a result of the larger average charge sizes in stationary AC systems, which range from an average charge of 1.6 kg (*CHF2 1.7 kg*) in residential systems to average charges of greater than 5 kg in small commercial systems. By comparison the average charges in all MAC imported in 2018 was 617 grams (*CHF3 2016, 620 grams*).

The dominance of stationary AC in PCE imports is reflected in the mix of refrigerant contained in those imports in 2018, with the high GWP refrigerant of choice for stationary AC for the last decade, HFC-410A, dominating the mix.

At the same time HFC-32 pre-charged equipment made up 19% of imports by refrigerant mass, the very large majority of which was imported in small split AC systems. HFC-32 was first imported in small stationary AC models in 2012 and has rapidly grown to take market share from HFC-410A charged equipment.

This medium GWP refrigerant has begun to cap the strong growth trend in HFC-410A charged imports that dominated imports from 2006 to 2016 as the preferred replacement to the earlier generation HCFC-22.

HFC-32 charged stationary AC devices in the stock of equipment now number more than 2,086,000 containing more than 2,360 tonnes of HFC-32.<sup>28</sup>

<sup>&</sup>lt;sup>28</sup> Based on pre-charged equipment imported until the end of 2018 calendar year.



(Sources: DoEE 2019)

The growth of the HFC-32 share of PCE imports (from zero in 2011) can be seen in the chart below and is expected to continue to displace HFC-410A charged devices until HFC-32 becomes the dominant refrigerant imported in the small AC split system segment by around 2022.

This trend away from HFC-410A is expected to continue and the use of HFC-32 is also expected to be expanded into medium AC applications over the next five years.

A smaller portion of the 90 tonnes of HFC-410A and HFC-407C imported contained in chillers with a charge greater than 12 kg is expected to migrate to HFC-32 and other HFO blends.

HFC-134a has maintained a steady share of import volumes in PCE for the last ten years as can be seen in the chart below (*Figure 24*), although a rise in HFC-134a pre-charged imports has been discernible in the last two years of the period as vehicle manufacturing in the country declined to zero and an increasing number of pre-charged MAC in vehicles were imported. This increase in PCE MAC does not signal an increasing rate of growth of the bank of refrigerants incorporated in MAC, as the rising PCE imports are only replacing what was previously imported as bulk gas for use by vehicle manufacturers.

PCE imports containing HFC-134a are expected to show steady declines by the mid-2020s due to the following characteristics of the HFC-134a PCE imports:

- At present there is more than 600 tonnes of HFC-134a imported in motor vehicles each year and a significant portion of vehicle imports are predicted to migrate to HFO-1234yf and small volumes of CO<sub>2</sub> refrigerant;
- A portion of the 60 tonnes of HFC-134a currently imported in chillers will migrate to HFO-513A, HFO-1234ze, HFO-1233zd, HFO-514A and other HFO blends; and,
- Small and medium commercial refrigeration will continue the strong trend of migration to hydrocarbon and HFO/HFC blends including HFO-448a, HFO-449a and others.



(Sources: DoEE 2019)

One important trend apparent in the chart above is the decline of HCFC imports to effectively zero by 2014.

A comparison of *Figure 24* above and *Figure 25* below demonstrates the effect of the higher GWP gases in dominating a bank when illustrated by its CO<sub>2</sub>e value. While it can be seen from *Figure 24* that HFC-32 has capped the equipment imports of PCE charged with HFC-410A, the higher GWP value of HFC-410A ensures that the significant portion of the bank now made up of HFC-410A, after some 16 years as the refrigerant of choice in small split AC imports, will dominate the refrigerant bank for many years to come.

<sup>1.</sup> Refer to Appendix B3: Bulk imports and pre-charged equipment imports from 2006 to 2018, for tabulated data.



(Sources: DoEE 2019)

In recent years the Department of Environment and Energy (DoEE) has sought to reduce the regulatory burden on business. In August 2017 as part of the streamlining program DoEE lifted the low volume import licence exemption threshold for PCE imports. The low-level threshold, above which importing equipment pre-charged with synthetic greenhouse gases requires mandatory licensing and reporting has been lifted from 10 kg of SGGs in PCE once every two years to 25 kg annually, thereby reducing the total number of licensed importers by one third.

Analysis of PCE import data from 2017 and 2018, compared to previous years, indicates the measure has had no impact on patterns of pre-charged equipment imports as the total contained gas imported by exempt importers equates to less than 0.2% of total PCE imports.

# 7.2 Bulk refrigerant imports

The second source of growth in the bank is via the import of bulk refrigerant. A controlled substances licence (and quota) 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 iso-tanks containing as much as 18 tonnes each. Bulk imports are brought into the country by 32 licensed importers of HFCs and 4 licensed importers of HCFCs. These importers 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 controlled substances licence holders in total.<sup>29</sup>

The majority of bulk imports do not add to the refrigerant bank, as most of the imported material is used to replace refrigerant lost from installed equipment. Some bulk imports of HFCs are also replacing HCFC refrigerant charges in older equipment. The increasing cost of HCFCs, and the cost to repair and maintain

<sup>&</sup>lt;sup>29</sup> List of licenses and exemptions granted under the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, issued February 2012 and April 2019. There are other entities including the Department of the Environment and Energy that have an essential use licence and four entities that have a used substance licence.

old equipment with HCFC charges, is steadily reducing the remaining stock of HCFC charged equipment as owners either replace with new equipment or retrofit the older equipment with a non-HCFC gas charge.

In 2018 a total of 3,712 tonnes of HFCs and 45 tonnes of HCFCs were imported as bulk gas, of which around 75% was used to maintain the existing stock of RAC equipment. In other words, around 75% of annual bulk imports are being used to replace refrigerant that is lost to air from working equipment every year.

Around 960 tonnes (or 25%) of bulk imports was used to charge new equipment manufactured in Australia, or to charge equipment imported without a charge of refrigerant or used in other applications such as fire protection systems and foam blowing. A small quantity of bulk imports is re-exported as bulk refrigerant, primarily to small markets in the Pacific. Some is used to service refrigeration and AC systems in visiting shipping, or in refrigerated shipping containers serviced on shore.

In 2018 approximately 265 tonnes of HFC-410A and HFC-134a was used in manufacturing domestic and commercial AC systems, and domestic hot water heat pumps.

In 2016 vehicle manufacturing consumed about 100 tonnes of bulk imports 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.

Comparing total bulk imports in 2012 to 2018 is difficult because of the effect of stockpiling. Imports spiked in 2012 before the introduction of the carbon tax, and subsequently reduced for some years afterwards. Imports also spiked in 2017, although to a lesser extent, prior to the introduction of the HFC phase down in Australia.

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



(Source: DoEE 2019)

1. Refer to *Appendix B3: Bulk imports and pre-charged equipment imports from 2006 to 2018*, for tabulated data in tonnes and CO<sub>2</sub>e.

Bulk refrigerant import data up to 2016 shows that the predicted import volume recovery did not occur until the 2015-16 financial year, partly due to lower demand for service gas. This reduced demand for service gas is thought to be a direct result of the price increases experienced in the market following the implementation of the carbon tax. The market saw much higher prices for most major gas species, and many large consumers

took action to improve maintenance on RAC equipment, and to identify and eliminate leaks as far as possible. Since 2012-13 some major consumers have reported dramatic reductions in leak rates in some equipment categories.

Recovery and reclamation of HCFCs has become a fixture in the Australian supply chains as the value of HCFCs has steadily risen. The recovery and recycling of HFCs, which was reported in some instances soon after the introduction of the carbon tax, declined following the repeal of the legislation. The removal of the carbon tax coupled with the multi-year stockpiles of HFCs in the country quickly returned most HFC wholesale prices to similar prices to prior to the carbon tax, making recovery and recycling of HFCs largely uneconomic.

A better comparison of changes in the trends in bulk imports might be made by comparing average annual imports over a longer timeframe. This normalises the effects of 2012 and 2017 stockpiling.

In the seven years from 2012 to 2018 an average of 3,633 tonnes of HFCs, and 297 tonnes of HCFCs were imported as bulk refrigerant (a total of 3,930 tonnes per annum 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 (a total of 4,500 tonnes per annum on average). Average bulk imports for the past 7 years are well below the average for the period 2006 to 2011 and tend to confirm industry reporting that the overall trend of bulk imports is down.

This decade-long trend in bulk imports of HFCs and HCFCs is illustrated in *Figure 27* below in kilotonnes (kt or 1,000 tonnes) of CO<sub>2</sub>e of the HFC bulk imports over the last 7 years. The average over the period was 8,077 kt CO<sub>2</sub>e of HFCs including the two stock piling events.


(Source: DoEE 2019)

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 declined. Smaller stationary AC moved off shore (i.e. Kelvinator-Electrolux) and manufacturers of ducted systems closed (i.e. Carrier-Apac, Uni-Arie and others).

Following a steady decline in AC manufacturing capacity from the turn of the century, manufacturing of ducted systems and large chillers has remained fairly stable since 2010.

Major manufacturers of refrigeration display cases Frigrite and Orford Refrigeration closed down. 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 with the closure of the Mitsubishi, Holden, Ford and Toyota factories during the period.

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 across categories of large, hardworking commercial equipment.

Better designed and manufactured equipment, in particular in small and medium AC, has contributed to significant drops in direct emissions as well. Small AC split systems now have annual leak rates of around 3.5% and service rate as low as 2.5% in the existing stock of HFC-410A models, and even lower rates on new HFC-32 equipment entering the fleet. This compares to historical leak rates for small and medium split systems of 10% to 15% for most models manufactured between 1990 and 2005.

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

During the period from 2006 to 2012 the use of HFC-134a, by far the most commonly used HFC up to that time, maintained a steady level of around 1,650 tonnes of bulk imports per annum over that period. Following changes in market behaviour arising from the carbon tax, primarily improved containment, as well as the

decline in OEM usage, the five-year average of bulk imports from 2014 to 2018 was 18% lower at approximately 1,352 tonnes per annum.



(Sources: DoEE 2019)

Replacing refrigerant that has been lost through leaks and charging new equipment (mostly in RCFC) is estimated to account for approximately 3,308 tonnes (3,573 tonnes less OEM of 265 tonnes), or 88% of all bulk imports of 3,757 tonnes in 2018.

Servicing MAC, the second largest stock of equipment after stationary AC, is estimated to account for 636 tonnes, or almost 17% of all bulk imports in 2018. Refer to *Table 8: Volumes of HFC-134a sold by calendar year (kgs) based on aftermarket supplier survey*.

### 7.3 Refrigerant usage – HCFCs and HFCs

Insight into refrigerant usage in the Australian economy has been significantly 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, large chillers, hot water heat pumps and refrigerated display cabinets. These are equipment segments 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 precharged volume when installed and commissioned to accommodate applications with longer pipe runs;
- Retrofitting existing equipment with a new refrigerant, for instance in cases where equipment originally designed and installed to operate on HCFC-22 is able to be retrofitted with drop in replacements<sup>30</sup>. Refrigerants such as HFO/HFC blends R448A and R449A are now being considered as retrofit replacements for HFC-404A;
- Servicing the stock of equipment to maintain charge levels as a result of leaks or catastrophic losses of refrigerant; and,
- Handling losses across the supply lines.

Species	2016	2017	2018
HCFC-22 <sup>(1)</sup>	255	224	162
HFC-134a	1,276	1,428	1,344
HFC-404A	800	878	800
HFC-407C	168	173	174
HFC-407A/F	33	31	28
HFC-410A	612	711	733
HCFC/CFC Replacements	99	96	95
HFC-32	16	32	42
HFC-Mix	190 (2)	195	195
Total	3,449	3,768	3,573

Table 15: HCFC and HFC refrigerant usage in tonnes.

1. Maximum imports of HCFCs for 2016, 2017 and 2018 are capped at 2.5 ODP tonnes per annum, which equates to 45.5 metric tonnes of HCFC-22. The additional usage in those years of 210, 179 and 117 tonnes of HCFC refrigerants is possible because the material has been reclaimed and reconditioned to AHRI 700 standard so that it can be resold. There would be additional HCFC-22 recovered by contractors and re-used.

2. Majority used in foam and fire protection applications as well as HFC-125 that could be used in refrigerant blends.

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.

<sup>&</sup>lt;sup>30</sup> HCFC-22/CFC retrofit replacements include HFC-422D, HFC-437A, HFC-417A, HFC-422A, HFC-438A, HFC-426A, HFC-424A, HFC-428A, HCFC-508B, HCFC-508B, HCFC-408A and HCFC-409A.

Additionally, it is estimated that around 50 tonnes of HFCs are re-exported, mostly in shipping vessels and in pre-charged equipment.

## 7.4 Hydrofluoro-olefin refrigerants

The HFO refrigerants with a GWP less than 10 are HFO-1234yf, HFO-1234ze, HFO-1233zd and HFO-514A. The main applications for these refrigerants in Australia in 2018 are supplies to the automotive supply chain and for charging space chillers. Volumes of these refrigerants imported to date is estimated at less than 5 tonnes.

It is expected that trends in global vehicle and equipment manufacturing will see HFO volumes increase markedly, delivering a corresponding decrease in volumes of some of the high GWP HFCs, particularly HFC-134a. As imports of HFO PCE or bulk HFOs are not reportable under current regulatory arrangements, high quality sources of data on import and use of HFOs are still being developed with industry players.

### 7.5 Refrigerant usage projection and the HFC phase down

In 2018 total refrigerant use was approximately 3,630 tonnes of HCFCs and HFCs, plus around 901 tonnes of natural refrigerants (643 tonnes of ammonia, 170 tonnes of CO<sub>2</sub> and 88 tonnes of HC).

This use of HCFCs and HFCs is projected to decline by almost 20% to around 2,930 tonnes of refrigerants in 2030. Overall refrigerant use is projected to remain steady over the projection period with HFOs and natural refrigerants accounting for the growth.



(Source: CHF 2019 RAC Stock model)

Australia commenced a phase-down of HFC imports on January 1, 2018 with a gradual reduction in the maximum amount of bulk HFCs permitted to be imported into Australia in any calendar year, as measured in mega tonnes (Mt) CO<sub>2</sub>-e per year. The process of the HFC phase down is being managed through a quota system on imports of bulk gases by the licensed importers.

The 2018 annual import limit was 8 million or mega tonnes (Mt)  $CO_2$ -e per year. Data reported to DoEE and analysed by the Expert Group indicates that total imports in 2018 were equivalent to around 7.89 Mt  $CO_2$ .

The phase-down introduces new reductions at the start of each two-yearly quota period, aligned with licensing periods under the OPSGGM Act. The phase down has an end point of 1.607 Mt CO<sub>2</sub>e on 31 December 2035 and will remain at 1.607 Mt CO<sub>2</sub>e for each quota period from then on.

*Figure 30* illustrates the HFC phase-down steps to 2030 relative to the projected refrigerant use by species in Mt CO<sub>2</sub>e. In line with the expected decrease of the CO<sub>2</sub>e value of the bank and direct emissions, the CO<sub>2</sub>e value of refrigerants used is expected to drop by more than 40% from around 7.9 million tonnes CO<sub>2</sub>e in 2018 to around 4.6 million tonnes CO<sub>2</sub>e in 2030, five years prior to the final year of the phase down schedule.

The starting point of the Australian phase-down is 25% lower than the starting level adopted in the Montreal Protocol, and stipulates reasonably consistently sized steps down every two years to soften market shocks. The phase down bottoms out in 2036 at the same final point as agreed under the Montreal Protocol.



(Source: CHF 2019 RAC Stock model)

As older equipment tends to leak more than new equipment, to some extent annual use 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 around 2,300 tonnes in just the few years prior to 2018, annual usage of HFC-32 is estimated to have been around 42 tonnes (including filling supply lines) in that year as this refrigerant is employed in an entirely new stock of equipment, with better containment (and less years of operation and wear) than earlier generations of small split systems.

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 410 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, falling 19% from its 2018 estimate of 733 tonnes to stay high at more than 545 tonnes in 2030, reflecting the relatively young stock of equipment it is contained in and the lack of alternatives for some HFC-410A applications;

- HFC-134a, presently servicing the second largest portion of the bank by species, falling by 38% from 1,344 tonnes in 2018 (1,428 tonnes in 2017) to a 2030 estimate of 833 tonnes;
- HFC-404A falling by 63% from 800 tonnes in 2018 (878 tonnes in 2017) to around 293 tonnes in 2030;
- HFC-407C falling by more than 61% from 174 tonnes in 2018 to just 60 tonnes in 2030;
- HFC mixes for specialist applications falling more than 58% from 170 tonnes in 2016 to around 70 tonnes in 2030.

These falls are projected to be matched by significant rises in use of non-HFC and GWP<10 refrigerants, following the lead of changes in the composition of the bank.

The model also suggests a 30-fold rise in new refrigerants with GWPs<1000, *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 more of which are being developed and tested. These new generation but still medium GWP blends are expected to allow retrofitting of some older categories of equipment and charging of new equipment with high performance refrigerants containing a small fraction of the HFCs presently employed to do the same task.

HCFC-22 is included in the data and graph for completeness due to its once significant presence in the bank as a refrigerant.

## 8 Natural refrigerants

Natural refrigerants are employed to some extent in most RAC technology segments, with minimal applications in stationary air conditioning. This section examines use of natural refrigerants ammonia,  $CO_2$  and hydrocarbons, the bank and trends.

Commercial and domestic refrigeration has led the way in the adoption of natural refrigerants. The transition of domestic refrigeration equipment to hydrocarbons, a trend that had barely started in 2012, is now effectively complete, with 99% of all domestic refrigeration models examined in a retail survey now found to be charged with hydrocarbons. In more recent years this move to HCs in domestic refrigeration has extended to smaller commercial equipment in Australia with around 4% of the total bank in this segment now being hydrocarbon and expected to grow rapidly.

Natural refrigerants are firmly entrenched in the mainstream supermarket sector with larger commercial refrigeration systems. They are increasingly employed in supermarket rack systems, now boasting a number of highly efficient options including  $CO_2$  cascade systems;  $CO_2$  only trans-critical systems;  $CO_2$ /ammonia chillers;  $CO_2$ /brine; and other variations of two stage cascade refrigeration systems.

This trend is well established and accelerating in larger supermarkets, largely because of the significant associated energy efficiency gains. CO<sub>2</sub> condensing unit combinations up to 15 kW which are suitable for small format supermarkets, convenience stores, liquor outlets and fast food chains are also being developed.

Ammonia is also finding broader applications outside the large cold storage distribution centres and industrial chillers where it has been traditionally used. Other applications include ammonia chillers and low charge ammonia chiller packages.

### 8.1 Ammonia refrigerant

Ammonia, known in the industry as R717, makes up by far the largest portion of the natural refrigerants in the bank.<sup>31</sup> However, because ammonia is manufactured domestically and there is no requirement to report use of ammonia as a refrigerant, estimates of the total ammonia bank have to be derived from a combination of data sources including a 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 m<sup>3</sup>), large chilling systems, 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 15.5 million m<sup>3</sup> of cold storage space operating on ammonia systems. Assuming a benchmark obtained from industry sources of 29 kg per 1,000 m<sup>3</sup> of storage space, this equates to around 440 to 460 tonnes of ammonia in cold stores.<sup>32</sup>

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.<sup>33</sup> In June 2018 there were 96 meat/poultry processing facilities in Australia that employ more than 20 and less than 200 people, and 52 that employ more than 200 people (ABS 8165.0).

<sup>&</sup>lt;sup>31</sup>Ammonia used in refrigeration systems is anhydrous Ammonia meaning it does not contain water, the chemical symbol is NH<sub>3</sub> and the ASHRAE refrigerant number is R717.

<sup>&</sup>lt;sup>32</sup> Industry source: Refrigerated Warehouse and Transport Association.

<sup>&</sup>lt;sup>33</sup> 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.

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 has been repeated annually from 2014 to 2018 and reported an average of 698 tonnes sold during each of those five years.

2014	2015	2016	2017	2018
837.1	712.4	577.2	722	643

Table 16: Volumes of ammonia sold by calendar year (tonnes) based on supplier survey.

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, have very low leak rates, it can be concluded that a significant portion of the ammonia sold every year is being employed in new ammonia refrigeration systems.

However, the bank is estimated to have only grown by around 100 tonnes per annum from a 2012 estimate of 4,400 tonnes to 5,000 tonnes. Although this annual growth 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. New systems have smaller refrigerant charges than the systems being replaced, contributing in part to the relatively slow growth of the bank. Contractors in this segment are reported to be operating at full capacity. The relative shortage of experienced contractors capable of designing and commissioning new ammonia systems is thought to be the main constraint on growth of new ammonia refrigeration.

The capital cost of new packaged ammonia systems is substantially lower than traditional ammonia designs. Smaller ammonia plants are now able to compete head-to-head with the installed cost of 100 kWr HFC-based systems. Small charge packaged ammonia systems are typically more energy efficient than traditional ammonia designs and can be more energy efficient than HFC-based systems.

The relative simplicity and safety of new ammonia designs makes it easier to train technicians. Combined with the trend to more compact, cheaper and safer systems this means the market could experience rising demand in ammonia capacities below 50 kW. A wider range of applications along the cold food chain may develop. 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.

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.).

### 8.2 Carbon dioxide refrigerant

Commercial refrigeration systems employing  $CO_2$  refrigerant have rapidly increased in Australia during the last decade. There are now more than 850 supermarket refrigeration systems containing  $CO_2$ , the majority of

these (>95%) are HFC/CO<sub>2</sub> cascade systems that employ a high GWP HFC in the primary cooling loop, and a charge of CO<sub>2</sub> in a secondary refrigerant circuit. These systems employ as much as 1,000 kg of refrigerants, of which around two-thirds will be HFC-134a and one-third CO<sub>2</sub>.

 $CO_2$  cascade and ' $CO_2$  only' systems are displacing a considerable volume of HFC refrigerant use, particularly in supermarkets and applications where the energy efficiency of these systems makes them increasingly attractive in the majority of applications as electricity prices rise.

The supply chain for  $CO_2$  is very complex with multiple steps, comprising many resellers, and suppliers sometimes going direct to end users, or with end users purchasing  $CO_2$  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 sales volume of  $CO_2$  in 2018 was around 170 tonnes (*CHF3 2016, ~120 tonnes per annum*).

Although aggregate supplies of  $CO_2$  were estimated to be 170 tonnes in 2018, 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  $CO_2$  systems are improving, owners and suppliers of  $CO_2$  refrigerant report the systems occasionally suffer gas line or seal failures and lose their entire charge, as  $CO_2$  systems have very high operating pressures. These factors lead to the current estimate of a relatively small refrigerant bank of  $CO_2$  refrigerant of around 220 tonnes.

It is expected that with the now extensive base of installed  $CO_2$  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.

 $CO_2$  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  $CO_2$  application is the EcoCute technology, widely available in Europe and Japan, that uses  $CO_2$  refrigerant technology on hot water heat pumps to achieve high efficiencies and lower running costs.<sup>34</sup>

In Europe and the US some end users and manufacturers of  $CO_2$  equipment are predicting  $CO_2$  will increasingly enter the industrial arena and are expecting ammonia systems to face increased competition from  $CO_2$  trans-critical systems in the industrial sphere, while foreseeing strong growth in ammonia heat pumps (i.e. low-charge packaged ammonia systems).<sup>35</sup>

Recent innovations developed by equipment suppliers include demonstrations of micro-cascade air-cooled condensing units available in capacities from as small as 2.5 kWr and upwards. These units offer hybrid refrigeration (HFC-134a/CO<sub>2</sub>) systems for use in smaller sites and have potential for application across a broad range of commercial refrigeration applications.

## 8.3 Hydrocarbon refrigerant

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

The growth of hydrocarbon charged domestic refrigerators and freezers in the stock has accelerated dramatically since 2012, with around 6.8 million devices (~35% by units and 22% by mass) containing HC-600a in 2018 (*CHF3 2016, 4.7 million, ~24%*).

<sup>&</sup>lt;sup>34</sup> Sanden Eco Hot water heat pump system achieves coefficients of performance of around 4.5.

<sup>&</sup>lt;sup>35</sup> Ammonia 21 publication by Shecco, Media, January 2018.

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 and fifteen products (29%) contained HC-600a. Follow up surveys conducted in the same outlet in July 2017 found 117 models out of 123 inspected (>95%) were charged with HC-600a. A recent survey was conducted in February 2019 found 106 models out of 107 inspected (>99%) charged with HC-600a, confirming the transition of domestic refrigerators from HFC-134a to HC-600a is now complete.

The use of hydrocarbons (HC-600a and HC-290) is now also firmly established as an option for buyers of small commercial refrigeration equipment in Australia. Smaller self-contained commercial refrigeration equipment is the leader in this trend with sales of new HC charged equipment in this category reaching nearly 30,000 units in 2018, compared to under 1,000 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.

Self-contained refrigeration display cabinets containing small charges of hydrocarbon refrigerant can now be found in the majority of the 524 Aldi supermarkets<sup>36</sup> (up to 36 individual cases per store with a charge equal to or less than 150 grams in each case) currently operating in Australia. This trend is expected to accelerate rapidly in this product range, including hydrocarbon charged refrigerated display and storage cabinets, and food catering equipment (e.g. Skope Industries). Product development may be driven by the influence of the rapid HFC phase down in the EU, and retailers seeking higher energy efficiencies in these product ranges.

The Queensland Government Department of Mines and Energy register of approved hydrocarbon refrigerant appliances illustrates the rate of increase of HC charged systems. In recent years the number of appliances registered has grown significantly to more than 2,000 models covering domestic refrigerators and freezers, bar refrigerators, laboratory freezers, wine coolers, refrigerated display cases and storage cabinets, hot water heat pumps and portable air conditioners (De Longhi). There are no split system air conditioners registered (QGDME 2019).

Even with this rapid growth in HC charged refrigeration equipment, the high efficiency of the refrigerant and the very small charge sizes required per individual system, the 2018 estimate of the bank of HC employed in commercial refrigeration is just 24 tonnes.

The total actual hydrocarbon refrigerant bank is estimated at 670 tonnes, comprised of 475 tonnes in Domestic Refrigeration, 165 tonnes in Mobile AC, 24 tonnes in commercial refrigeration, and 7 tonnes in Stationary AC, including hot water heat pumps.

A survey of the major suppliers of hydrocarbon refrigerant from 2014 to 2018 shown in *Table 23* reported an average of 79 tonnes sold annually during those three years. Total bulk HC refrigerant sales have been impacted by two main factors, the 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.

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2014	2015	2016	2017	2018
82.0	75.0	72.0	78.0	88.0

Table 17: Hydrocarbon refrigerant sold by calendar year (tonnes) based on supplier survey.

<sup>&</sup>lt;sup>36</sup> Aldi had 524 stores at the end of 2018.

### 8.4 Natural refrigerant bank

The total mass of natural refrigerants employed in the bank for refrigeration and air conditioning would otherwise require approximately 6,000 tonnes of high GWP refrigerants to deliver the same amount of cooling services, equivalent to as much as 8% of the total GWP bank.

Growth has been observed in the use of all natural refrigerants between 2012 and 2018. The growth is particularly notable in the use of  $CO_2$  (up 59%) initially driven by rapid adoption of cascade systems in the supermarket industry, and more recently the growth in use of trans-critical  $CO_2$  only systems. Hydrocarbons also increased strongly (up 77%) including HC-600a, HC-290 and HC-436 due to penetration in domestic refrigeration and self-contained commercial refrigeration equipment. However, these two refrigerants were growing rapidly off a very small base 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 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.

Species	Bank 2018 (Tonnes)
CO <sub>2</sub>	220
Ammonia (R717)	5,000
Hydrocarbons	670
Total <sup>(1)</sup>	5,890

Table 18: Low GWP refrigerant bank in 2018 in tonnes.

1. Sources: In-confidence market survey of all major participants provided actual 2018 market volumes, which was used to derive estimates of the natural refrigerant bank by type.

# 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 is 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.
Carbon Tax	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.
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.
CHF3	Cold Hard Facts 3, 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 third RAC study was undertaken in 2017 and 2018 based on 2016 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 of the 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; annual energy efficiency ratio (AEER) and annual coefficient of performance (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 kWr to 65 kWr; they are composed of one (or two) compressor(s), one condenser, and one receiver assembled into a 'condensing unit'.
CO2 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 <sub>2</sub> 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 (or near 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 (kWr) 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 metric (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 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 <sub>2</sub> ); methane (CH <sub>4</sub> ); nitrous oxide (N <sub>2</sub> O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulfur hexafluoride (SF <sub>6</sub> ) and nitrogen trifluoride (NF <sub>3</sub> ).

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 <sup>3</sup> ).
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 <sub>6</sub> ) 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 kWr).
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 <u>Ozone Protection and Synthetic Greenhouse Gas Management Act 1989</u> controls the manufacture, import and export of ozone depleting substances in Australia.
PJ	Petajoule (1 Joule x 10 <sup>15</sup> ).
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 an 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 <sub>2</sub> 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
	A1 group refrigerants include the A2L group refrigerants include B2L group refrigerants include Refer to AS/NZS ISO 817, Sup Guidelines for further details.	he majority of HFCs and HCFCs. HFO-1234yf and HFC-32. R717 (Ammonia). pplier Material Data Sheets and	equipment supplier Installation
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 sa which all of the refrigerant has (temperature at which a liquid the temperature glide of the re	aturated vapour temperature (o been condensed to liquid) and refrigerant first begins to boil in frigerant.	r dew point, the temperature at the saturated liquid temperature the evaporator) is referred to as
	At a given pressure, single cor therefore azeotropes. Refriger measurable temperature glide HFC-507A is an azeotropic blen	mponent refrigerants such as H rant mixtures (blends) behave when they evaporate (boil) and d whereas HFC-404A is a near az	FC-134a have zero glide and are somewhat differently and have condense at a constant pressure. reotrope.
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 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 t most commonly by a process of and specifies methods of testin source (new, reclaimed and/or by chemical analysis and meet required of virgin refrigerants.	to the reprocessing of used refrig of fractional distillation. AHRI 700 g for fluorocarbon refrigerants to repackaged). The quality of the re or exceed AHRI 700 specificatio	erants to AHRI 700 specifications, D establishes purity specifications o verify composition regardless of eclaimed product must be verified ns which are the same standards
Refrigerant recovery	Recovery refers to the remova recovery container. As defined testing.	al of refrigerants from equipme I by the AHRI, recovery does no	nt and collection in an approved t involve processing or analytical

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 <sup>3</sup> per annum.
Synthetic greenhouse gases (SGGs)	SGGs listed under the Kyoto Protocol and regulated under the <u>Ozone Protection and Synthetic</u> <u>Greenhouse Gas Management Act 1989</u> , hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) sulfur hexafluoride (SF <sub>6</sub> ) and nitrogen trifluoride (NF <sub>3</sub> ).
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
AR5	Fifth 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 <sub>2</sub> 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
ОНЅ	Occupational Health and Safety
OPSGGM Act	Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, including amendments
PCE	Pre-charged equipment
РЈ	Petajoule, or 10 <sup>9</sup> 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

## References

AACS 2018	Australasian Association of Convenience Stores State of the Industry Report, 2017, published April 2018.
AB&C 2019	Australasian Bus & Coach (AB&C) bus and coach deliveries data from 1998 to 2019.
ABARES 2017	Agricultural commodity statistics, 2017, Department of Agriculture and Water Resource Economics and Sciences (ABARES), Published December 2017.
ABS 3101.0 2019	Australian Bureau of Statistics, catalogue 3101.0, Australian Demographic Statistics, population at September 2018, published March 2019.
ABS 8165.0 2019	Australian Bureau of Statistics, catalogue 8165.0, Counts of Australian Businesses as at June 2018, published February 2019.
ABS 9309.0 2019	Australian Bureau of Statistics, catalogue 9309.0, Motor Vehicle Census, July 2019.
ABS 9314.0 2018	Australian Bureau of Statistics, catalogue 9314.0, Sales of New Motor Vehicles, Australia, December 2012 and Jan 2018.
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