Cold Hard Facts 2022









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Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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1 Executive summary

The trend of significant slowdown in the growth of the regulated bank of refrigerants in Australia, as reported in previous issues of Cold Hard Facts for the period from 2016 to 2019, could be reversing.

The Australian bank increased by approximately 700 metric tonnes between 2020 and 2021 to 54,140 tonnes, compared to a decline of around 140 tonnes in the previous year.

The key factors contributing to this unexpected change in trend are:

- Rapid growth in deployment of heat pumps resulting, in part, from government policies aimed at accelerating a migration away from gas appliances and less efficient electric appliances, and towards lower emission appliances.
- Continuing delay in transition to hydrofluoro-olefin (HFO) refrigerants such as HFO-1234yf in mobile air conditioners for motor vehicles.
- Slow transition of commercial refrigeration applications to alternative refrigerants including natural refrigerants (hydrocarbons (HC), carbon dioxide and ammonia) and HFO/HFC blends.

These trends and delayed technology transitions, due in part to COVID-19 and associated supply chain issues, will likely slow the rate of decline of the carbon dioxide equivalent (CO_2e) value of the refrigerant bank.

In Australia some state regulators have legislation and evolving plans to reduce reliance on gas as a critical part of achieving net zero emissions. Heat pumps, which use vapour compression refrigeration cycle technology to heat or both heat and cool (reverse cycle units) water or air, are emerging as the high efficiency technology alternative in a variety of applications including hot water heat pumps replacing gas and electric resistive hot water services; reverse cycle split system air conditioners replacing gas ducted heaters and room space heaters; heat pump clothes dryers replacing older style, inefficient electric resistive clothes dryers; and multi-function larger format chillers that can both heat and cool replacing gas boilers in large commercial buildings.

Domestic hot water heat pumps employing high global warming potential (GWP) HFC-410A have seen a surge of imports. This technology had previously been predominantly using lower GWP refrigerants. Annual sales in 2021 surged by 90% compared to the previous year, adding around 50 tonnes of HFCs to the bank in 2021 with significant growth predicted in the years ahead. Heat pump clothes dryer sales have grown from around 3,300 in 2012 to over 74,000 units in 2021, adding around 36 tonnes to the bank in 2021 with continued strong growth predicted.

The shift from gas ducted heaters to heat pumps is moving rapidly, particularly in new homes. Several national builders have announced future proof all-electric homes and some new estates are choosing not to run gas reticulation throughout the estate.

The rapid transition of small split system reverse cycle units to the lower GWP A2L (low toxicity, mildly flammable) refrigerant, HFC-32, as reported in Cold Hard Facts since 2016, continues.

Whilst the growth of the small split system bank was less than 2% from 2020 to 2021, the growth of the HFC-32 bank in this category was more than 35%. In 2021 the stock of HFC-32 charged, non-ducted single split systems made up more than 38% of the equipment operating in this category, and 34% based on refrigerant mass as HFC-32 models have lower charge sizes.

The use of HFC-32 is continuing to grow in other equipment categories with more adoption in medium and larger air conditioning applications including in ducted split systems, variable refrigerant volume/frequency (VRV/F) systems and in chillers with charges up to 100 kilograms.

Portable air conditioners have rapidly transitioned to the very low GWP HC-290. This transition is noted in several registers including the Greenhouse and Energy Minimum Standards (GEMS) register where, as at 1 July 2021, 84% of portable air conditioner models registered contained hydrocarbon (HC).

Softening of refrigeration and air conditioning (RAC) equipment sales, a trend reported in previous years across many major equipment formats, has also reversed. Equipment sales were up across most commercial refrigeration segments. Food retail and hospitality venue re-fits, driven by the opportunity of COVID-19 shutdowns, instant asset write offs and other forms of government assistance, saw strong sales growth of commercial refrigeration systems in a variety of formats. Another area of commercial refrigeration growth is specialty and gourmet supermarkets with ranges of prepared meals, some of which have on site commercial kitchens.

Increasing numbers of dark kitchens for preparation of home delivered meals also drove growth of commercial refrigeration systems. The increased activity in medium sized commercial refrigeration (remote condensing units and small rack systems) has resulted in the growth in consumption of high GWP refrigerant HFC-404A from an average of 834 tonnes per annum over the previous 5 years to 880 tonnes per annum in 2021.

Medium sized commercial refrigeration is firmly entrenched on HFC-404A for new and replacement applications, with only initial signs of this segment transitioning to HFO/HFC blends or natural refrigerant alternatives, representing less than 10% of installations in 2021. However, the major supermarket chains undertaking re-fits and new builds are more often employing CO_2 trans-critical refrigeration systems.

Trends to smaller charge sizes to deliver equivalent refrigeration services, often employing the more energy efficient hydrocarbon refrigerants in smaller formats, helped to cap HFC bank growth in self-contained commercial refrigeration formats. Trends observed in refrigerated display cabinets in 2019 and 2020 of growth in the adoption of natural refrigerants have been confirmed in 2021 with hydrocarbon charges smaller than 150 grams in this format being a stand-out example of rapid change in the sector. HFO/HFC blends are starting to be employed in larger commercial refrigeration display cases with charge sizes up to 3 kg seen in the market.

Nearly 10 years after its introduction in international markets, HFO-1234yf is starting to contribute to the transition away from HFC-134a in the automotive mobile air conditioning (MAC) bank. We estimate that at least 10% and possibly as much as 13% of all MAC imported in 2021 were charged with HFO-1234yf. Some industry sources think this is too optimistic and suggest the penetration of HFOs in this segment could still be as low as 7% of new vehicle sales in 2021.

Finally, more than a decade after bans on imports into Australia of equipment pre-charged with HCFC-22 were introduced, and 35 years since the Montreal Protocol was created to eliminate ozone depleting substances from the global economy, the end of the ozone depleting HCFC-22 bank in Australia is approaching.

Rapid development and adoption of a wide range of sometimes very specialised new refrigerants continues and is resulting in an increasingly diverse bank. Regulatory arrangements in support of a global HFC phase down, and equipment designers' efforts to improve energy efficiency are broadly driving more of the stock of new equipment and some retrofits to lower GWP natural refrigerants and HFOs. In many instances these alternative refrigerants can deliver the same refrigerating capacity with significantly lower energy consumption, delivering both direct and indirect emissions reductions over the life of the equipment.

Changes in the Australian energy economy are influencing buyer behaviour with homeowners and commercial property owners taking steps to eliminate fossil fuel gas from buildings in favour of electric technology. Significantly higher gas prices are reinforcing the drive to heat pumps for thermal services, while increased electricity prices emphasize the need for new equipment purchases to make electrical efficiency a high priority in the purchasing decision. These fundamental cost drivers are expected to feature in the market for some time with the Australian Energy Regulator warning electricity prices could jump a further 35% next year with additional increases expected in years ahead.

The pressure on equipment owners who have delayed higher efficiency purchases (or recently chosen to buy lower cost but less efficient equipment) or delayed a transition to new refrigerants has, in some cases no immediate solution. The RAC industry is not immune from the negative impacts of global supply line disruptions with higher efficiency electric commutated (EC) fans for instance having lead times for delivery of more than a year. Ammonia charged system components are reported in some cases to have lead times of 2 years.

Despite the obstacles and surge in the HFC-404A bank, the decade long trend towards a falling CO_2e value of the bank is expected to continue as the phase down of HFC imports progresses. However, recent work by the CSIRO estimates that HFC emissions in Australia have been growing at 5% per annum since 2005 (CSIRO 2021). With an existing refrigerant bank in installed equipment that has a total global warming potential of approximately 100 million tonnes (Mt) CO_2e, efforts at improved containment and effective recovery of refrigerants will be important to continue to drive down the direct emissions from RAC services in Australia.

2 Introduction

Cold Hard Facts (CHF) 2022 is the seventh edition of the CHF research series and continues the decade long investigation into the scale and impacts of the cooling economy in Australia. CHF 2022 analyses data from 2021 to identify key developments and emerging trends in the refrigeration and air conditioning industry. CHF 2022 reports on the progress of the HFC phase-down being implemented under the Montreal Protocol, including the transition to lower GWP refrigerants - refrigerants with GWPs lower than those traditionally used for a particular application.

The cooling economy, broadly defined as the total of all goods and services that involve employment of vapour compression refrigeration and heat exchange systems, is a significant fraction of the Australian economy. Direct spending on hardware, consumables and energy, plus employment in the sector, is estimated at around $44 billion, or 2.1% of Australian gross domestic product (GDP) in 2021 (ABS 2022a), which is similar to the spend in 2020.

The cooling economy provides numerous direct and indirect economic, health and social benefits, such as the preservation and transportation of perishable food. For example, in 2018, more than 23 million tonnes of foodstuffs worth $42 billion based on farm gate values passed through the Australian cold food chain. The production and transport of food, and the cold food chain infrastructure required, is projected to grow strongly in Australia over the next 20 years as export capacities expand, driven by ambitious agricultural export targets.

The value of other services delivered by the cooling economy, such as the maintenance of comfortable conditions in commercial buildings, hospitals and universities, cannot easily be quantified. Cooling services are essential in many situations, and optimal management of the technology that underpins the cooling economy has great potential to deliver significant economic and environmental benefits.

This CHF research series is built on a techno-economic model that the Expert Group has been developing since 2006, of all the equipment employed in the cooling economy in Australia. Expert Group's Refrigeration and Air Conditioning (RAC) Stock Model uses a taxonomy of the many different types of refrigerating and air conditioning equipment employed in Australia to manage the mass of data processed through the model. The taxonomy dissects RAC equipment into 4 main classes and more than 50 different product segments. The main classes of equipment are stationary air conditioning (AC), mobile air conditioning (MAC), the refrigerated cold food chain (RCFC) and domestic refrigeration (DR). The scope and structure of the taxonomy of RAC equipment is explained in Appendix A, Section 1.1: Taxonomy of a technology.

Alongside the series of CHF publications, the RAC Stock Model has been continuously improved while being used to underpin analysis of more than forty other research assignments into aspects of the cooling economy in Australia and overseas.

The depth and integrity of the data now employed and the longevity of the CHF series in Australia has resulted in high degrees of confidence in the outputs of the modelling. Significant portions of the data can be verified from external sources such as Australian Bureau of Statistics (ABS), Australian Border Force import statistics, atmospheric monitoring conducted by CSIRO Marine and Atmospheric Research Division, and from RAC industry bodies.

The sum of all refrigerant contained in RAC equipment is referred to as the bank of working refrigerants. Data in this report is largely focused on the regulated bank, the largest part of the overall bank, that is subject to regulation and controls under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*. The regulated bank is comprised of HCFCs and HFCs.

3 The scale of the cooling economy

The RAC Stock Model calculates that RAC services in Australia in 2021 were delivered by more than 60.0 million pieces of equipment (CHF3 2016, 53.6 million) employing a refrigerant bank of regulated gases of more than 54,140 tonnes. Despite the extensive supply line and workforce disruptions of the COVID-19 pandemic, in 2021 Australians spent around $9.3 billion purchasing and installing new devices across all classes of RAC equipment, total spending that was very similar to the first year of the pandemic impacts in 2020.

This stock of equipment is estimated to have consumed more than 67,950 gigawatt hours (GWh) of electricity in 2021, or around 25% of all electricity produced in Australia that year, a small increase on the prior reporting period. National electricity generation was estimated to be 267,452.3 GWh in calendar year 2021, remaining materially unchanged since 2019 at 265,117 GWh and 265,232 GWh in 2020 (DCCEEW 2022b). Electricity related greenhouse gas (GHG) emissions plus direct emissions to air of around 3,114 tonnes of HFC refrigerant from operating equipment, mean that RAC equipment produced around 59.6 Mt CO_2e of GHGs or approximately 12% of Australian national GHG emissions (using the rolling 12 month estimate of emissions to December 2021 of 488.0 Mt CO_2e) (DCCEEW 2022c).

Tables 1 and 2 below list the main metrics produced by the RAC Stock Model for 2021 and for 2016 for comparison.

Table 1: Main refrigeration and air conditioning metrics for 2021

Metric	Units	Air conditioning	Mobile air conditioning	Refrigerated cold food chain	Domestic refrigeration
Share of refrigerant bank	Percent	65	20	13	2
Size of refrigerant bank	Tonnes	35,000	10,900 **a**	7,100	1,100 **b**
Annual usage of HFCs to replace leaks (excl. charging new equipment)	Tonnes	749	751	917	3
Refrigerant in pre-charged equipment imports **c**	Tonnes	2,643	600	58	14 **d**
Estimated stock of equipment	Million units	> 17.2	> 20.1	1.9	20.8 **b**
Annual electricity consumption **e**	GWh	38,400	200 **f**	20,300	9,000
Share of RAC electricity consumption	Percent	57	0.3	30	13
Annual GHG indirect emissions	Million tonnes CO_2e	28.01	2.93 **f**	15.09 **g**	6.61
Share of RAC indirect emissions	Percent	53	6	29	13
Annual GHG direct emissions (ODS) **h**	Million tonnes CO_2e	0.24	0.002	0.06	0.00
Annual GHG direct emissions (SGG)	Million tonnes CO_2e	2.15	1.38	3.12	0.02
Share of RAC direct emissions	Percent	34	20	45	0.3
Share of RAC total emissions (direct and indirect, not including end of life)	Percent	52	8	30	11

GHG greenhouse gas **GWh** gigawatt hours **GWP** global warming potential **HC** hydrocarbon **HFC** hydrofluorocarbon **MAC** mobile air conditioning **ODS** ozone depleting substance **RAC** refrigeration and air conditioning **SGG** synthetic greenhouse gas

Percentages may not total 100 due to rounding.

a An estimated 430 tonnes are refrigerants with a GWP<10. **b** The Cold Hard Facts 2022 model has been updated to include additional sales and incorporate a shorter lifespan of 15.5 years for domestic refrigerators and freezers. Total stock includes small refrigerators, portable and automotive refrigeration. There is an estimated 11.72 million devices containing HC-600a in 2021. **c** There was 2,519 tonnes of HFCs imported in stationary AC and a further 124 tonnes imported in heat pumps. HFC substances in pre-charged equipment imports in non-RAC categories was 318 tonnes. **d** The average volume of HFC-134a imported in domestic refrigerators from 2017 to 2019 was 15.0 tonnes per annum, compared to 21.6 tonnes in 2020 which is considered a COVID-19 related spike rather than a change in trend. **e** The electricity consumption estimate is based on assumptions used in Cold Hard Facts 3 published in 2016 and does not take efficiency improvements into account that *may* have been captured in new equipment additions to the stock from 2016 to 2021. **f** Electricity consumption for MAC is from air conditioners on trains and light rail. Indirect emissions for MAC include indirect emissions from electricity consumption plus emissions from fuel consumption attributed to operating mobile air conditioners in passenger vehicles, trucks, buses and other air-conditioned vehicles. **g** Indirect emissions for the refrigerated cold food chain include indirect emissions from electricity consumption plus emissions from fuel consumption attributed to transport refrigeration. **h** Emissions of ODS have more than halved since 2016 as ODS charged equipment is taken out of service. 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 are managed through the Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol.

Table 2: Main refrigeration and air conditioning metrics for 2016

Metric	Units	Air conditioning	Mobile air conditioning	Refrigerated cold food chain	Domestic refrigeration
Share of refrigerant bank	Percent	61	21	14	4
Size of refrigerant bank	Tonnes	31,200	10,800	6,900	1,900
Annual usage of HFCs to replace leaks (excl. charging new equipment)	Tonnes	520	625	821	20
Refrigerant in pre-charged equipment imports **a**	Tonnes	2,359	626	51	32
Estimated stock of equipment	Million units	> 14.4	> 18.2	1.65	19.2
Annual electricity consumption	GWh	30,400	200	19,000	8,500
Share of RAC electricity consumption	Percent	55	0.3	31	14
Annual GHG indirect emissions	Million tonnes CO_2e	30.44	2.96	17.53	7.77
Share of RAC indirect emissions	Percent	52	5	30	13
Annual GHG direct emissions (ODS) **b**	Million tonnes CO_2e	0.72	0.01	0.13	0.00
Annual GHG direct emissions (SGG)	Million tonnes CO_2e	1.47	1.24	2.91	0.05
Share of RAC direct emissions	Percent	34	19	46	0.8
Share of RAC total emissions (direct and indirect, not including end of life)	Percent	50	6	32	12

GHG greenhouse gas **HFC** hydrofluorocarbon **ODS** ozone depleting substance **RAC** refrigeration and air conditioning **SGG** synthetic greenhouse gas

Percentages may not total 100 due to rounding.

a HFC substances in pre-charged equipment imports in non-RAC categories is 246 tonnes. **b** 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 are managed through the Montreal Protocol.

The equipment formats employed across this huge stock of equipment are extremely varied, as is the size of the refrigerant charges in them, from small benchtop drink merchandisers with less than 30 grams of HCs, to large chillers with 1,500 kg of HFCs cooling enormous structures like airport terminals.

Some of the millions of pieces of RAC equipment introduced to the economy every year will continue operating for decades and therefore, even while global agreements are driving the RAC industry towards the use of lower GWP refrigerants, Australia will continue to employ tens of thousands of tonnes of older generation high GWP refrigerants, that will require refrigerant recovery and destruction for many years into the future. In this report, the term lower GWP refrigerant refers to refrigerants with GWPs lower than refrigerants traditionally used for a particular application.

Each of the 4 main classes of RAC equipment, stationary air conditioning (AC), mobile air conditioning (MAC), the refrigerated cold food chain (RCFC) and domestic refrigeration (DR), are discussed in more detail in the sections that follow.

4 Trends and observations by main equipment class

4.1 Stationary air conditioning and heat pumps

Stationary air conditioning and heat pumps are a broad class of equipment. It includes all forms of stationary equipment using the vapour compression cycle to provide human comfort in buildings and to deliver close temperature control in medical and scientific facilities and in data processing centres. This class includes equipment that can operate in reverse-cycle (heating and cooling), sometimes referred to as heat pumps, and equipment designed for cooling only. The rapidly diversifying heat pump segment now includes water heating, including for swimming pools, clothes drying and other applications. Equipment in the broad class of Stationary AC ranges in size from small portable air conditioners delivering 2 kWr (kilowatts of refrigeration capacity), with a refrigerant charge of less than 600 grams, up to large 4,000 kWr commercial space chillers containing more than a tonne of refrigerant in a single machine. Evaporative air conditioning, that does not use a vapour compression cycle, is not included.

The 4 major segments and 18 product categories that make up this class (see Taxonomy, Appendix A) account for approximately 65% of the bank of refrigerant in Australia (CHF3 2016 61%), or around 35,000 tonnes (CHF3 2016 31,200 tonnes), contained in more than 17.2 million devices.

Stationary air conditioning used more than 36% of the 3,518 tonnes of bulk HFC refrigerants imported in 2021. An estimated 1,288 tonnes of HFCs was used for servicing installed equipment, charging new equipment that was imported without refrigerant or equipment that required additional charge at installation (such as for longer pipe runs), retrofitting existing equipment, and use by equipment manufacturers (CHF3 2016 1,055 tonnes).

There are several notable trends in this major class of equipment that will shape the refrigerant bank in the decades ahead.

Sales of single split systems including wall hung, cassette, consoles and ducted systems were at similar levels to the all-time peak in 2017 of 1.3 million units per annum.

Single split system sales in 2021 are estimated at 1.3 million units, comprising 1.09 million non-ducted split systems and 178,000 split ducted systems. Ducted systems were up by at least 10% and strong growth is expected to continue in the years ahead as heat pumps replace gas appliances. There were a further 31,000 sales of multi split systems, excluding variable refrigerant volume/frequency (VRV/F) systems for which detailed information is not available, and around 200,000 small self-contained AC including window/wall units and portable AC. The large majority of portable AC units sold in 2021 (>80%) were charged with HC-290 refrigerant.

This is the fifth year in a row of sales of around 1.2 to 1.3 million small and medium stationary AC units, resulting in an estimated total installed stock in Australia of around 14.0 million small AC and 3.1 million medium AC devices after taking retirements into account.

By the end of 2021, there was an estimated bank of more than 5,706 tonnes of HFC-32 in the country across all types of stationary AC, an increase of 35% on 2020.

The transition of small split systems to the lower GWP A2L classification (low toxicity, slightly flammable) refrigerant HFC-32 is progressing rapidly. HFC-32 is displacing the once nearly universal use of the high GWP HFC-410A in this equipment segment. The installed bank of HFC-32 small split systems was 35% larger in 2021 than 2020.

The bank of HFC-410A in small non-ducted split systems showed a slight year-on-year decline towards 8,900 tonnes by the end of 2021. This trend is expected to continue in years ahead, with a 4 year decrease in the HFC-410A bank in small AC split systems of some 37% expected by 2025, to just over 5,500 tonnes, as older equipment is taken out of service.

The growth in stock of HFC-32 equipment combined with retirement of older HFC-410A equipment has HFC-32 charged systems making up more than 38% of the total stock of installed equipment in the non-ducted single split systems category in 2021, and 34% based on refrigerant mass.

The new designs and improved refrigerant containment employed in the HFC-32 charged equipment deliver extremely low leak rates, ensuring more years of operation at close to optimal charge, slowing the decline in energy efficiency experienced by older, leakier stock, and reducing the overall direct SGG emissions from this stock of equipment.

HFC-32 is also starting to make an appearance in larger AC applications including split ducted systems and chillers with charges up to 100 kg. In 2021 there were more than 1,770 large AC devices imported with a charge greater than 12 kg, of which 463 contained in aggregate 20.7 tonnes of HFC-32 (22% by refrigerant volume in this size range, compared to 10% in 2020). This estimate does not include product manufactured locally or imported and charged locally. There were 116,000 devices imported in the same year containing between 2.6 kg and 6.0 kg of HFC-32. This equates to 51% of all models imported in this size category based on refrigerant weight and 54% based on total units that contained HFC-32.

As HFC-32 is approved for use in more countries, and in larger charge sizes, it is also starting to displace HFC-134a and HFC-410A in some chillers. For instance, scroll chillers, that would previously have used HFC-410A, are now being installed with HFC-32 as engineers and installers are gaining a better understanding of the requirements for applications with A2L refrigerants.

HFC-32 is being offered in large AC with some manufacturers offering chillers from 70 kW up to 700 kW. These size ranges employ HFC-32 charges that are only two thirds of the previous HFC-410A charges required. This trend to HFC-32 in chillers with scroll compressors appears to be firmly entrenched in most Japanese based designs that are also offered in Europe. Suppliers are now offering extensive ranges of chillers operating on HFC-32 with nominal capacities ranging from 80 kW to 700 kW and charge sizes up to 100 kg.

The volumes of HFC-134a refrigerant imported in equipment with charges greater than 20 kgs declined to 41.3 tonnes in 2020 and 40.0 tonnes in 2021, compared to an average of 80.6 tonnes from 2014 to 2018. This approximate 40 tonne difference is most likely the result of new chillers being imported without a refrigerant charge, and then being charged onshore.

Industry participants report that goods imported from China designed for A2L refrigerants are also inclined to be charged in Australia due to restrictions on transporting equipment charged with the mildly flammable refrigerants from that region.

On the back of the widespread adoption of HFC-32, technology developers are continuing the trend of developing new, and often lower GWP refrigerant blends for demanding applications. These often incorporate HFC-32 with other HFCs and a portion of one of the newly developed family of very low GWP refrigerants, HFOs. For instance, HFO/HFC blends R454B (GWP of 465), R513A (GWP of 629) and R515B (GWP of 287) have all been observed in the Australian market.

The emergence of new blends and new refrigerants is expected to be a continuing trend throughout the next 2 decades, driven by the need for improved energy efficiency and demand for lower GWP refrigerants. At present the proportion of lower GWP refrigerants being employed in Australia is relatively small, other than for HFC-32, which is well established and being found in a wider range of equipment formats and sizes. However, the rate of HFC-32 adoption in the past 5 years is likely to be repeated over the coming decade with a wider range of the lower GWP blends being introduced in international markets. The increasing diversity of refrigerants in the market will require the RAC workforce to stay up to date with identification of new refrigerants and knowledge of their properties.

Computer room air conditioners (CRAC) that provide precision temperature and humidity control predominately use HFC-407C, although some HFC-410A is also used. While we expect to see lower GWP refrigerants in this class of equipment in the next couple of years, technical innovation is occurring in other areas. For example, improved energy efficiencies can be achieved with roof-based water chillers using chilled water at around 14˚C to maintain data centre temperatures at optimal conditions instead of employing conventional direct expansion CRAC units. The roof-based chillers typically result in a lower refrigerant charge, and are mostly operating on HFC-410A, however suppliers are exploring lower GWP alternatives such as HFO-1234ze.

Pure HFOs, that mid-last decade had been predicted by industry to grow rapidly in MAC, have only slowly begun to be deployed in Australia. Some suppliers are adopting a two-step approach, moving to a Class A1 HFO/HFC blend with around half the GWP of HFC-134a, such as R513A (GWP of 629), while planning the transition to pure HFOs. While uptake in MAC has disappointed predictions, every leading chiller manufacturer is currently offering equipment charged with pure HFOs. Screw chillers are available charged with R1234ze and centrifugal chillers using R1233zd. Refer Section 7.1 Hydrofluoro-olefin refrigerants (HFOs) for more detail about the transition of chillers.

4.1.1 Emergence of heat pumps

Global initiatives to reduce GHG emissions by replacing gas heating and less efficient electrical technologies with heat pumps will see significant growth in a variety of heat pump technologies. In Australia this is expected to include hot water heat pumps replacing gas and electric resistive hot water services; reverse cycle air conditioners replacing gas ducted heaters and room space heaters; and multi-function larger format chillers that can both heat and cool replacing gas boilers in large commercial buildings.

Many European States are introducing policies to accelerate migration from gas appliances to heat pumps. As a result, global brands including Daikin, Panasonic, Viessmann and Stiebel Eltron have announced significant investments in additional manufacturing capacity in Europe amounting to over 1.2 €billion.

The United States, despite having had very cheap gas in recent years, is also supporting accelerated deployment of heat pumps. President Joe Biden recently declared heat pumps are 'essential to the national defence' and ordered production be ramped up (TWH 2022).

In Australia many state regulators have legislation and evolving plans to reduce reliance on gas as a critical part of achieving net zero emissions. The Victorian Government has released a Gas Substitution Roadmap that examines a range of measures to reduce use of natural gas in support of its net zero emissions by 2050 target (DELWP 2022). The Victoria Energy Upgrades program currently offers incentives for some heat pumps and is expected to offer more financial incentives for installing heat pumps that switch out old gas appliances in the future.

The ACT has introduced legislation to ban new building gas connections by 2023 as part of the commitment to phase out gas and has energy efficiency initiatives including zero interest loans up to $15,000 for eligible homeowners. The ACT uses a reverse auction process to secure long term renewable electricity contracts as part of which electricity retailers contribute funds to ACT Government programs which are used for energy efficiency initiatives including heat pump installations.

In NSW, the Energy Saving Scheme offers incentives for hot water heat pumps for residential and commercial applications as well as incentives for high efficiency reverse cycle air conditioners. At a federal level, the Clean Energy Regulator continues to offer small-scale system renewable energy certificates for hot water heat pumps with capacities no more than 425 litres. These regulations, programs and plans are expected to hasten the transition from gas appliances to heat pumps in water heating and space heating/cooling applications.

Driven by these widespread government policies to move away from natural gas, and in part due to the convenience and relatively high energy efficiency of quality heat pumps, several strong market trends can be discerned:

- Just prior to 2010 domestic hot water heat pump annual sales in Australia peaked at over 72,000 units per annum but then steadily declined to around 20,000 per annum from 2017 to 2019 due to changes to the solar hot water rebate, which had been a significant factor in early sales growth. However, following the recent introductions of new financial incentives to install heat pumps in both Victoria and NSW, installations of hot water heat pumps have increased to 59,203 in 2021, a 90% increase compared to the previous year (CER 2022). This product category is expected to continue to grow strongly over the next 5 years.
- In 2020 this technology class was dominated by models with an average charge of 900 grams of HFC-134a (GWP of 1430 thus 1.28 tonnes CO_2e in each device). HFC-134a charged heat pumps made up nearly 75% of the market, followed by devices with a CO_2 refrigerant charge comprising 20% of the market. At least one brand, Rinnai has been marketing models operating on hydrocarbon refrigerant with a small charge of just 300 grams. The recent surge in sales has had the perverse effect of models being rushed into the market to meet demand operating on around 900 grams of HFC-410A (GWP of 2088 thus 1.87 CO_2e in each device). In 2021 around 50% of models imported contained HFC-410A.

- Heat pump clothes dryer technology sales have grown from around 3,300 in 2012 to over 74,000 units in 2021. This fast-growing technology segment saw sales volumes double in 2021 compared to 2020. The average charge of these products is 480 grams of HFC-134a which equates to over 35 tonnes of HFC-134a being added to the bank in 2021 alone. There is one brand, Beko with models operating on a HFC/HFO blend R450A (with a lower GWP of 601). Miele are now shipping models manufactured in Germany containing HC, with an 8 kg clothes dryer recently observed contained just 138 grams of R290. This technology segment is expected to continue to grow strongly over the next decade. The total annual sales of clothes dryers, including the older style energy inefficient electric resistive type, are over 400,000 per annum in a typical year (E3 2022). Improvements in efficiency and affordability of heat pumps coupled with higher energy costs are likely drive growth of heat pumps in this large market.
- The shift from gas ducted heaters to heat pumps is moving rapidly, particularly in new homes. Several national builders including Henley's have announced future proof all-electric homes and some new estates are choosing not to run gas reticulation throughout the estate.
- An important development in larger building applications has been the emergence of a range of multi-function chillers for commercial buildings being offered by Daikin, Mitsubishi Electric-Climaveneta, Aermec, Blue Box, Carrier and York. These large format systems offer water heating up to around 55°C as well as cooling.
- Commercial building systems exploiting the relative efficiency of heat pump technology have also delivered new dedicated hot water heat pump designs capable of delivering water up to 90°C for commercial applications with 2 circuits employing HFC-134a/HFC-410A and a cascade heat exchanger.
- Commercial scale hot water heat pump sales are increasing in applications replacing gas fired hot water boilers in a variety of applications including models operating on CO_2 refrigerant that are being installed in supermarkets.

The rapid growth of these heat pump formats is expected to add at least many hundreds of additional tonnes of HFCs per annum to the bank over the next 5 to 10 years. These are very electrically efficient technologies, in some cases replacing older generations of inefficient electrical systems, and in others replacing or avoiding the use of natural gas in heating services. However, the use of high GWP HFCs in technology formats that have an intended 15 to 20 year life cycle has the potential to build in significant long term service demand for HFCs and increase end-of-life emissions from residential equipment.

4.2 Mobile air conditioning

Mobile air conditioning (MAC) includes equipment captured in 2 broad segments of the RAC Stock Model, including small MAC and large MAC.

These 2 segments and the 12 product categories in this class make up the second largest portion of the total bank of working refrigerants, containing approximately 20% of the bank in Australia, or around 10,900 tonnes in more than 20.1 million vehicles of all sorts (CHF3 2016, 21%, 10,800 tonnes and 18.2 million vehicles). This portion of the bank in mobile equipment consumed an estimated 751 tonnes of service gas in 2021.

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 2021. 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.

The estimate of the 2021 service usage of 688.8 tonnes is a very robust value, based on 7 consecutive years of surveys of after market participants. The 2021 service use is not greatly different to the 8 year average of 628.7 tonnes consumed for small MAC service gas from 2014 to 2021.

HFOs, that had been predicted to appear in the Australian market soon after release internationally around 2011, appear to have finally begun to be employed in an identifiable portion of new cars sold. As HFOs are not regulated and the import of HFOs is not reportable under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*, changes to year-on-year vehicle sales, and changes to numbers of imported vehicles reported to include HFC charged systems, have been used to deduce the likely volume of HFOs imported in MAC.

There were 1,049,831 new vehicles sold (including passenger vehicles, SUVs and light commercial vehicles) in Australia in 2021 increasing by 14% from 2020 (FCAI 2022 and FCAI 2021). Based on the reported number of vehicle imports containing HFCs compared to total new vehicle sales, we estimate that at least 10% and possibly as much as 13% of all MAC imported in 2021 were charged with HFO-1234yf. This equates to possibly 136,000 new vehicle imports with HFO charged MAC. This is similar to the estimate in 2020 and is a significant increase on 2019 when HFO imports first became apparent with an estimated 5% of all MAC imported charged with HFOs.

Research conducted in the United States of America (USA), Europe and Japan in 2021 appears to confirm that the transition to HFOs in new vehicles in those markets is well underway with the large majority of vehicles currently manufactured in the USA and Europe now containing HFO-1234yf, and around 70% in Japan.

The countries of origin of the vehicles sold in Australia in 2021 were Japan 33%, Thailand 22%, South Korea 14%, China 7% and Germany 4%. China now ranks fourth for sales by country of origin in Australia due to MG (SAIC Motor Australia), GWM Haval and LDV (Ateco Automotive) with aggregate sales of 76,262, a 148% increase in 2021 compared to the previous year. Whereas vehicles imported from Germany (43,143 in 2021) declined by 26% compared to 2020.

Auto-makers in the European Union (EU), including the United Kingdom (UK), and in the USA have mostly transitioned to using HFO-1234yf in MAC in their local markets. Japan is transitioning slower than the other 2 major markets; however, it is a compliant market that will achieve its regulatory requirements that sets a limit of 150 GWP of refrigerants in all mobile air conditioning systems in new vehicles by the end of 2023.

Despite Japan, the USA, and EU plus UK collectively supplying more than 40% of imported vehicles sold in Australia in 2021, only between 10% and 13% of vehicles contained HFOs. The shift in country of origin towards China is likely to slow the transition to HFO-1234yf further as China does not have an internal regulated target for phase out of HFCs in MAC.

There is some domestic consumption of HFO-1234yf charging locally manufactured trucks and imported American full-size pickup trucks (i.e., large utes) as well as smash repairers equating to less than 3 tonnes in 2021 in total.

All indications are that, despite the very slow start to transitioning the MAC fleet to HFOs, the change is expected to accelerate and Expert Group projects that by 2027 around 50% of all new passenger and light commercial vehicles imported will contain MAC charged with HFOs, and 80% by 2030.

Whilst CO_2 refrigerant was initially considered a viable refrigerant technology alternative for MAC by some automotive manufacturers, recent reports by Mercedes-Benz, subsidiary of Daimler AG, confirm it is unlikely to be considered an option in the future.

There has been no movement with HFOs or HFO/HFC blends in large MAC in the Australian market. However, there have been some sophisticated and expensive concepts emerging in other markets. For example, Thermo King introduced a CO_2 heat pump for electric and hybrid buses at the IAA Transportation show in Hannover in 2022. As well as being optimised to keep the driver and passengers at the right comfort level, it simultaneously protects the bus driveline batteries by providing cooled or warmer water to condition them during charging and discharging. Industry sources confirm there is a lot of interest in charging bus air conditioning with HFO/HFC blend R513A, though none is presently in use in Australia.

There has been no reported movement away from HFCs in locomotive or passenger rail air conditioning in Australia at the time of writing.

The sales growth of recreational vehicles and caravans has continued its strong trend over the past 5 years at 4% to 5% compound annual growth rate with an estimated fleet of over 600,000 ACs on the road in 2021 containing 460 tonnes of HFCs. The large majority operate on HFC-410A and around 20% on HFC-407C. No caravan AC units have been identified operating on HFC-32 or HC.

4.3 Refrigerated cold food chain

The refrigerated cold food chain (RCFC) includes diverse equipment formats employed in processing, storage, transport and display of perishable foods. This includes systems at the point of production of food, for example cool rooms and milk vats inside the farm gate and blast freezers on fishing vessels and in abattoirs, and continues through numerous stationary and mobile refrigerated formats to the point of sale in retail outlets and hospitality venues.

The RCFC is a diverse group of equipment because of the wide range and various scales of applications and situations in which it is employed.

There has been steady growth in food retail in the supermarket and convenience sectors, as well as food services providing pre-prepared meals either home delivered or offered at retail outlets.

The current number of supermarkets with a trading floor greater than 400 m^2 is estimated at 4,240 (WG 2022, CG 2022, MC 2022, AUR 2022). The number of convenience stores reached 7,078 with a 50/50 split between corporate and independent owners (AACS 2022) some of which includes small size metro supermarkets. While the major supermarket chains are steadily reducing their dependency on HFC-404A, it is still the independent supermarket’s refrigerant of choice for new stores and refurbishments. Notably the major supermarket chains no longer have any refrigeration systems operating on HCFC-22.

There are several important trends in this class of equipment.

There is continuing evolution of advanced refrigeration systems seeking higher energy efficiency with lower GWP refrigerants. This trend initially saw the adoption of CO_2/HFC 2 stage cascade systems, and in more recent years there has been accelerated deployment of CO_2 only trans-critical refrigeration systems in supermarket plant rooms.

At the time of writing there were around 220 sites with CO_2 only trans-critical systems with some of the larger sites having 2 systems.

There are 3 independent supermarkets with CO_2 only trans-critical remote condensing units. The smallest trans-critical system installed is in a boutique supermarket, Leaf Armadale, in Victoria with a trading floor of around 450 m^2. Several suppliers recently launched new product ranges of CO_2 condensing units.

The number of CO_2/HFC 2 stage cascade systems is now more than 1,200, however at least a third of these are smaller systems with a charge of less than 25 kg of CO_2. Micro-cascade air cooled condensing units with capacities from 2 kWr and upwards, that sparked some interest around 5 years ago, have not gained market traction.

In the self-contained refrigerated display case category new HC charged system sales continue to take larger market share. While HC refrigerants are not reportable under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*, inspection of offerings at industry exhibitions during 2019, and anecdotal reports from the supply chain suggest that sales of HC charged self-contained refrigeration with charges smaller than 150 grams could have made up as much of 70% of all sales in this category in 2021.

In June 2020, a new edition of *AS/NZS 60335.2.89: 2020, Household and similar electrical appliances - Safety, Part 2.89: Particular requirements for commercial refrigerating appliances and ice-makers with an incorporated or remote refrigerant unit or motor-compressor* was released that allows up to 494 grams of R290 in commercial refrigeration appliances (provided the equipment meets the additional requirements and compliance tests of the standard for R290 charge sizes >150 grams and <494 grams). There is a 3-year transition with new standards and AS/NZS 60335.2.89: 2020 officially replaces the 2010 version in June 2023, however some state authorities already recognise the 2020 version.

These developments are expected to hasten the transition of self-contained commercial refrigeration to HCs with a corresponding dampening effect on HFCs in the bank. An example of movement in this sector by a major food retailer is a significant roll out of around 500 self-contained display cases each containing 180 grams of HC in 2021.

The HC charge size limits in Australia means that manufacturers have focussed on delivering HC charged equipment in the common smaller formats for catering equipment, storage cabinets and 2/3 door display cabinets. Major manufacturers are reporting a concerted move to transition most of their suitable designs to HCs. It is reasonable to assume that most new sales across smaller commercial refrigeration formats will employ HCs within the next 3 years. These smaller self-contained display case formats charged with HCs are delivering significant energy efficiency improvements across this populous and continuously operating stock of equipment.

In some larger formats of self-contained systems, where refrigerant charges larger than 150 grams of HCs would be required, HFO/HFC blends are being observed in the market. These blends deliver improved energy efficiency and have lower overall GWPs due to the <10 GWP HFO constituents. Blends reported in charges up to 1.5 kg include R449A, R448A and R452A. These are mostly refrigerated display cases, and some ice makers operating on R452A. In recent years these blends were used in possibly only 2% of total display case sales. Another HFO/HFC blend on offer in Europe in this segment is R455A (GWP of 145), that has not yet been seen in Australia other than in small quantities of laboratory equipment.

In 2021 and the first half of 2022 there was a significant surge (greater than 80,000 units) of self-contained refrigerated display cases supplied to the market, over and above normal demand, due to financial incentives offered by the Victorian Energy Upgrades Scheme and the NSW Energy Savings Scheme for high efficiency products. Most of these cases were operating on HC, and therefore did not add to the bank of high GWP refrigerants.

Medium sized equipment with remote condensing units, commonly used for walk-in cold rooms (i.e., chillers and freezers) are now offered by European manufacturers operating on a range of HFO/HFC blends, including R454A, R454C and R455A. In Australia the blends offered on remote units were primarily R448A and R449A. Less than 30 tonnes is estimated to have been sold in 2021 to charge remote units and rack systems or undertake retrofits with these blends.

While refrigeration compressors are now rated for a variety of blends, the dominant refrigerant of choice in this sector in Australia is still HFC-404A with some suppliers offering HFC-134a as a lower GWP option for medium temperature applications (i.e., chillers), however this does add cost due to the larger sized components.

While refrigeration contractors are aware of the refrigerant choices, industry sources confirm less than 5% of new equipment applications would choose R448A or R449A. The main obstacles raised by contractors are the refrigerant price difference (approximately $30 to $40 per kg for the end users), and when retrofitting, the uncertainty or the technical risk due to the lack of experience or solutions to deal with the challenges (e.g., glide, discharge temperatures, mass flow). Another risk raised by contractors associated with retrofits is the concern of taking on the responsibility of historical problems that may exist with retrofitting systems, or premature failure of compressors due to higher discharge temperatures. These are all barriers that European contractors have had to overcome due to the bans imposed through F-Gas regulations on HFCs with a GWP above 2,500, including a new equipment ban and a service ban on virgin refrigerant in systems with charges greater than 40 tCO_2e (approximately 10 kg of HFC-404A) effective from 1 January 2020.

One major supermarket chain has a program to retrofit rack systems operating on HFC-404A while undertaking refurbishments and efficiency upgrades. Fifty stores had been completed at the time of writing and a further 30 to 40 are planned to be refurbished per annum.

While the usage of HFO/HFC blends was estimated to be less than 30 tonnes in 2021 compared to 880 tonnes of HFC-404A, it is increasing rapidly and at the time of writing, the rolling twelve months consumption is estimated at 70 tonnes.

4.3.1 Transport refrigeration

Road transport refrigeration technology is made up of:

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

Most trailer/intermodal and diesel drive single temperature units from Europe and the USA are imported fully charged, tested and ready to be fitted, except for multi-temperature units that require extra piping and evaporators. These configurations have rapidly transitioned from HFC-404A (GWP of 3,922) to HFO/HFC blend R452A (GWP of 2,139) with improved designs and refrigerant charges that are around 25% smaller. As this market is dominated by 2 main companies, Thermo King and Carrier Transicold, the transition of most new sales is expected to be complete by the end of 2022, only leaving some models imported from China still operating on HFC-404A. Whilst all the current alternative refrigerant options are Class A1 refrigerants, some models are expected to be released operating on A2L refrigerants soon. There are small quantities of TRUs operating on CO_2 refrigerant in the EU, however these products are considered not commercially available in Australia.

Off-engine powered refrigeration units on small trucks and vans transporting chilled goods are mostly charged with HFC-134a.

Road transport refrigeration is expected to see more innovation in the next couple of years as electrification options evolve and are commercialised for vans, rigid trucks, and intermodal containers.

Marine refrigeration and the fishing industry

The fishing fleet still has limited low GWP refrigerant options suitable to the demanding operating conditions and able to be employed in the existing fishing fleet. As an example, when the 52 long distance vessels that operate in the northern prawn fishery of Australia were upgraded from HCFC-22 during the previous decade, due to the uncertainly and cost of HCFC supply, many of the vessels transitioned to HFC-438A (GWP of 2,264) which is a HCFC-22 retrofit replacement. In 2012 more than 95% of these vessels were using HCFC-22, with just a few employing HFC-404A. These vessels had typical blast freezing capacity of 3 tonnes of prawns per day. Some vessels underwent more expensive equipment upgrades and transitioned from HCFC-22 to HFC-404A with fully welded pipes for improved containment. Of the 52 vessels operating today, none are known to be still operating on HCFC-22 with 68% operating on HFC-438A, and 29% using HFC-404A/507A. The refrigerant employed in the remaining 8% is unknown.

In the first known application of an HFO/HFC blend in the sector in Australia, a small mackerel fishing vessel of around 14 meters in length was fitted out in 2021 with equipment containing a charge of around 20 kg of R448A for freezing, and for chilled brine for a temporary storage tank. According to the specialist contractor it has demonstrated promising results.

4.3.2 Waste in the cold food chain - an opportunity for improvement

A 2020 report prepared by the Expert Group, *A study of waste in the cold food chain and opportunities for improvement* (DAWE 2020), produced estimates of food waste attributable to breaks and deficiencies in the cold food chain in Australia. These preliminary and conservative estimates put the economic cost of food waste within the cold food chain at a minimum of $3.8 billion annually at farm gate values. This figure is made up of:

- 25% of the annual production of fruit and vegetables, or approximately 1,930,000 tonnes worth $3 billion.
- 3.5% of the annual production of meat, or approximately 155,000 tonnes worth $670 million.
- Approximately 8,500 tonnes of seafood worth $90 million.
- 1% of annual dairy production, or approximately 90,000 tonnes valued at $70 million.

The greenhouse gas emissions from food waste attributed to sub-par refrigeration technology and processes in the cold food chain are estimated at 7.0 Mt CO_2e in 2018, equivalent to about 1.3% of Australia's annual greenhouse gas emissions in that year. These emissions were equivalent to more than 35% of the total emissions (direct and indirect) that resulted from operation of the cold food chain in the same year (18.9 Mt CO_2e). These estimates of emissions resulting from food waste are based on globally accepted estimates of greenhouse gas emissions intensity to produce various food types. Much of these losses, costs and emissions are thought to be avoidable and further examination of technological and business system options to reduce these losses should be undertaken.

4.4 Domestic refrigeration

This class of equipment includes both refrigerators and freezers found in every residential 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.

The transition of new domestic refrigerator sales away from high GWP refrigerants is effectively complete with 99% of domestic refrigerators and freezers sold in 2021 containing HC refrigerant. In 2021 just 13.4 tonnes of HFC-134a was imported in domestic refrigeration systems, almost entirely in very small, very low charge portable and vehicle refrigeration systems, compared to a peak of 139 tonnes of HFC-134a imported in domestic refrigerators in 2008.

A large spike in imports of domestic refrigerators and freezers containing HFC-134a was observed due to COVID-19 lockdowns, from 189,000 in 2019 to 318,000 in 2020 (equating to 21.6 tonnes of HFC-134a), which then eased to 243,483 units imported in 2021.

Currently there are no indications that portable and vehicle systems (<65 grams of HFC-134a) are transitioning away from HFC-134a.

As a result of the comprehensive transition of new domestic refrigerators to HC charges, the proportion of HC charged domestic refrigerators and freezers in the stock of equipment has grown strongly since 2012, with an estimated 56% of the stock (~11.7 million devices) containing HC-600a in 2021. As older stock is removed from service and replaced, the proportion of HC charged domestic refrigeration is expected to be greater than 90% of the stock of this equipment segment by 2030.

The CHF 2022 model has been updated to include additional sales numbers (compound annual growth rate of 1.8% from 2012 to 2019) and a shorter lifespan for domestic refrigerators and freezers of 15.5 years, in part due to the cost of replacement compared to the cost of repair, resulting in higher rates of retirements compared to a decade ago.

Service consumption of HFCs has continued to decline in this sector as older equipment charged with HFCs becomes increasingly un-economical to service or repair.

In future editions of the Cold Hard Facts research series, the domestic refrigeration class of equipment will be amalgamated into the refrigerated cold food chain class, simplifying the CHF taxonomy to just 3 major equipment classes.

4.5 Quantifying the benefits of maintenance: Penalties and opportunities

Recent Australian research has identified the prevalence and impact on energy efficiency of common faults and maintenance issues for RAC equipment. Regular preventive maintenance and mitigation of these faults has the potential to avoid significant direct and indirect emissions and save equipment owners money over the life of their RAC equipment.

Efforts to improve energy efficiency of and reduce greenhouse gas emissions from RAC equipment have largely focused on increasing the rated energy efficiency of equipment purchased and reducing the global warming potential of refrigerant used. The recent research highlights the emissions abatement opportunity from operating RAC equipment at optimum energy efficiency through appropriate sizing and proper installation, operation and maintenance.

The concept of energy penalty is used to describe the additional energy required to run equipment compared to equipment operating at rated energy efficiency. The size of the energy penalty arising from a fault can be seen as the size of the opportunity to save money, energy usage and to cut emissions by preventing the fault.

Three related studies completed since 2021 are:

- *Leaks, maintenance and emissions: Refrigeration and air conditioning equipment* (DAWE 2021c), a review of more than 300 international papers to identify common issues found with RAC equipment that contribute to refrigerant leaks and excess energy use. Issues arising at installation and those that develop over the life of the equipment were included. This research looked at prevalence and severity of faults to identify the top thirteen common faults.
- *Air conditioning faults – An Australian analysis* (RA 2021) involved analysing an extensive industry database, containing records of millions of assets across tens of thousands of buildings involving in excess of 1.3 million work orders. This invaluable data set was analysed for the prevalence of the most common HVAC faults in Australia.
- The Department of Climate Change, Energy, the Environment and Water commissioned 2 independent testing facilities to bench test 4 pieces of air conditioning and refrigeration

equipment - a refrigerated display cabinet, walk-in cool room, a non-ducted split AC system and a ducted light commercial rooftop packaged unit. The testing was conducted under controlled environmental conditions. The tests captured the excess energy used when common faults were applied to demonstrate the benefits of regular equipment maintenance. The results indicated up to 20% energy losses across most faults tested (DCCEEW 2022d).

The first 2 of the 3 related studies confirmed that a limited number of common faults result in the great majority of refrigerant leaks and energy penalties. These 2 studies identified that the most commonly occurring fault and the most expensive in terms of energy penalty is refrigerant undercharge – generally the result of refrigerant leakage. Leaks often result from a lack of maintenance and go undetected for longer in the absence of leak monitoring. These leaks are a source of direct emissions, often with very high GWP gases. RAC equipment operating with insufficient refrigerant uses more energy to achieve the designed service. This fault causes the highest energy penalty in part due to the robust nature of most RAC equipment that allows it to continue to provide cooling services while operating on very low refrigerant charge.

The majority of the other commonly occurring faults also cause avoidable energy penalties in the operation of RAC equipment. Faults due to a lack of maintenance that cause preventable energy waste include dirty condensers and condenser mechanical issues (fouling, faulty fan) and dirty evaporators and evaporator mechanical issues (fouling, ice-up, obstructions, faulty fan).

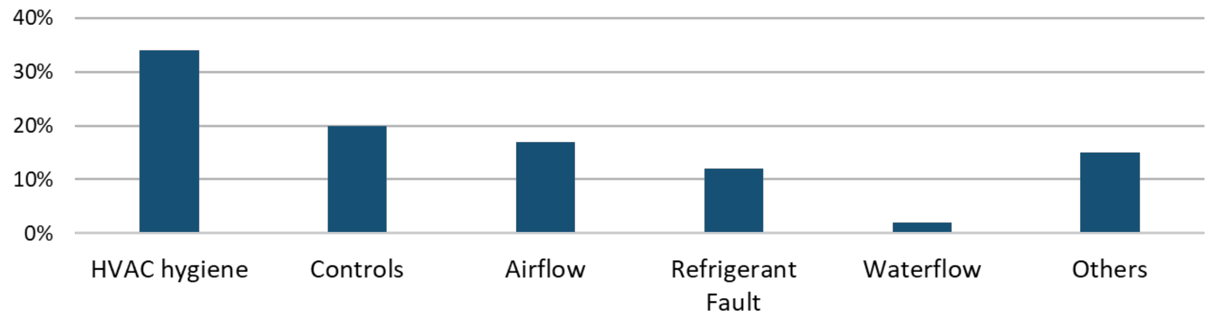
Dirt and grime fouling coils and filters causes reduced heat transfer capacity due to reduced air flow and thermal transfer rates. Equipment working harder to achieve required airflow rates and thermal transfer will run compressors harder for longer, vibrate more and will have higher leak rates and shorter equipment life.

To better understand the scale of the energy penalties and the cost of prevention of the common faults identified in the international literature survey, the Expert Group (supported by Refrigerants Australia) conducted a detailed review of a substantial database of air conditioning system maintenance and repair work orders in Australia. The database owned by Grosvenor Engineering Group (GEG) is a central part of their asset management for clients.

The analysis attempted to quantify the prevalence of common faults, and to understand the severity of the fault in terms of energy penalty, cost and business interruption. The study revealed a short list of the most common faults found across most classes of stationary AC equipment with the potential to cause severe energy penalties for equipment owners.

Of the faults identified in the international literature study, the top four were found in the GEG work order database to result in more than 80% of all work orders issued to equipment owners. Of note, the most common fault, responsible for more than 30% of all work orders, ‘HVAC hygiene’ (e.g., regularly cleaning filters, sweeping away leaves near external unit), can be addressed largely by routine cleaning.

Figure 1: Top 4 faults account for more than 80% of work orders



(Source: RA 2021)

The bench test study (DCCEEW 2022d) looked more closely at the impact on energy use of common faults. The bench testing involved a series of tests on 4 pieces of household and light commercial refrigeration and air conditioning equipment. The faults tested were a blocked condenser, a blocked evaporator, refrigerant undercharge and overcharge, and contaminated refrigerant. These common faults were introduced to each piece of equipment after a baseline record was taken. The findings indicated that on average there were energy penalties between 14 to 20% across most tests. When several faults co-existed, energy consumed increased substantially or the equipment failed.

The combined results of these studies suggest a large emissions abatement opportunity is available to the Australian economy, possibly in the several million tonnes per annum, through routine RAC equipment maintenance. Most of the main faults causing significant energy penalties, and avoidable emissions, can be addressed with routine maintenance and leak monitoring.

Ultimately operational efficiency is in the hands of equipment owners and technicians in the field. Planned and competently delivered routine maintenance, following selection of fit-for-purpose equipment and its proper installation, can dramatically reduce the total cost of ownership over the life of equipment, while avoiding millions of tonnes of direct and indirect greenhouse emissions across the economy.

5 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. Data in this report is often focused on the 'regulated bank', the largest part of the overall bank that is subject to regulation and controls under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*. The regulated bank is comprised of HCFCs, HFCs and a very small quantity of CFCs.

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

As shown in Figure 2, the total refrigerant bank of HCFCs and HFCs in Australia has grown strongly since this research series commenced in 2006, increasing around 75% in the period to 2021. This strong overall growth in the refrigerant bank that Australia has experienced since 2006 has been partly driven by more than 15 years of strong sales growth of small and medium domestic and commercial air conditioning systems (<25 kW). This trend was supported by steady falls in the price of small split AC, combined with increasing marketing budgets invested by the leading manufacturers since the turn of the century.

Sales in the small and medium stationary AC segment appeared to have peaked in 2017 at 1.3 million units, then softened in 2018 for the first time in a decade. Sales in 2021 were similar to those in 2017, and some of this resurgence may be attributed to replacement of gas heaters with reverse cycle AC, or heat pumps as they are also known, as well as the trend of working from home.

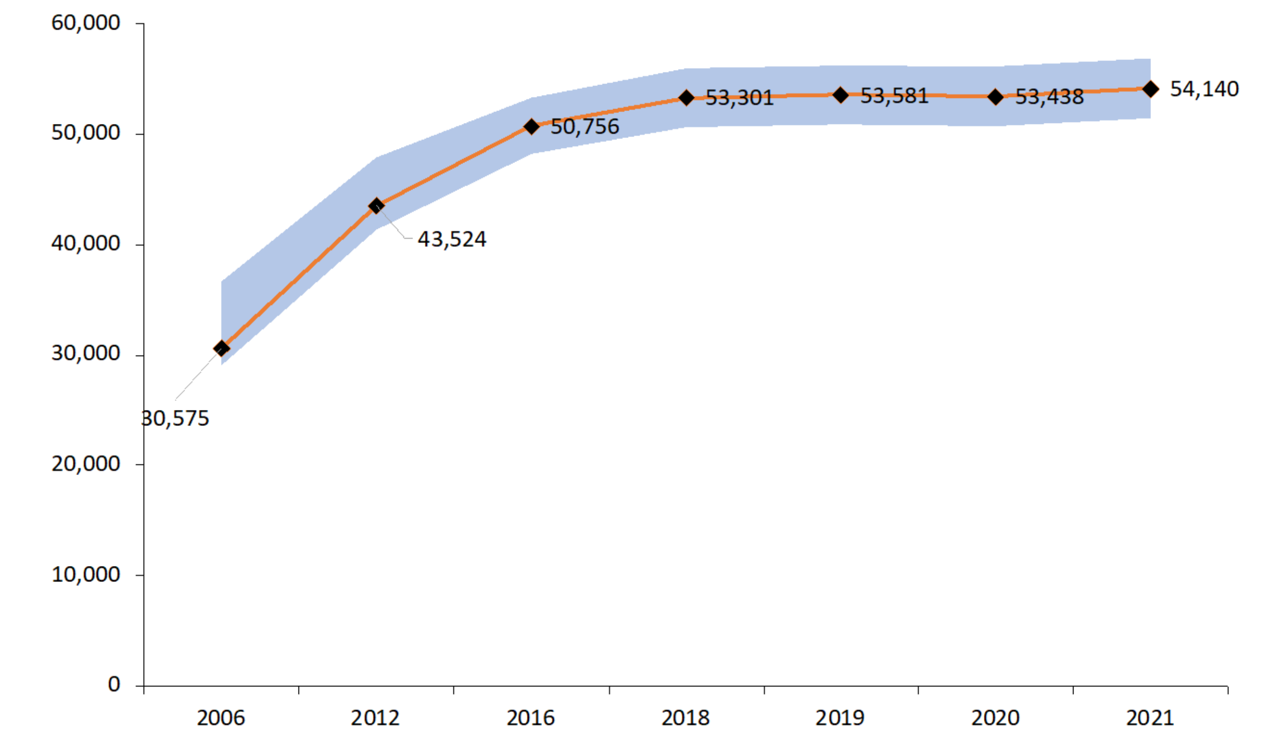
The growing community-wide dependency on AC, and widely held expectation of AC comfort in all forms of buildings, was reinforced by changing climatic conditions where the past 8 years have been the hottest years ever recorded on the planet with 2021 coming in at sixth place (NASA 2022). This trend drove growth in the stock of medium and large commercial systems since the late 1990s and has resulted in significant commercial and public buildings being nearly universally serviced by air conditioning in Australia by 2021.

The near comprehensive adoption of AC in all types of vehicles, and growth in the passenger and light commercial vehicle fleet of more than 50% since the year 2000, has also contributed strongly to growth of the bank.

During the same period, Australia's increasing food exports have driven greater investments in refrigeration systems in agriculture and an expansion of the refrigerated cold food chain in Australia. Demand in this sector is also directly affected by hotter average temperatures.

The total bank of controlled refrigerants in 2021 is estimated at approximately 54,140 tonnes (CHF3 2016, 50,756 tonnes), an increase of around 700 tonnes over 2020. This is the fastest rate of growth in the bank since 2018. The emergence of heat pumps substituting gas appliances will drive more growth of HFCs in the bank over the next decade, potentially putting the observed slowdown in the growth of the bank reported in 2018, 2019 and 2020 at risk.

Figure 2: The HCFC and HFC Refrigerant bank from 2006 to 2021 in tonnes



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

CHF Cold Hard Facts **HCFC** Hydrochlorofluorocarbon **HFC** Hydrofluorocarbon

The band provides sensitivity analysis with the 2006 value (+20%, -5%), 2012 value (+10%, -5%), 2016 to 2020 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.

Using the starting midpoint of 33,185 tonnes in 2006, the regulated bank grew by around 53% between 2006 and 2016, equivalent to a compound annual growth rate of 4.3% over the period. From 2016 to 2021 the bank of HFCs and HCFCs has only increased slightly more than 5.5%, achieving a compound annual growth rate of just 1.6%.

This slowdown in the rate of growth of HFCs in the bank has occurred as sales of small split AC systems have stabilised and then declined slightly, and as non-HFC alternatives have taken more market share in some equipment segments (particularly in domestic refrigerators and self-contained commercial refrigeration).

Notably, there is estimated to be slightly more than 1,700 metric tonnes of non-HFC natural and low GWP refrigerants with a GWP<10 in use in the stock of equipment in 2021, an increase of more than 21% from 2020. In addition, large ammonia charged systems are used in most distribution centres and some industrial settings; these ammonia refrigerants are not included in the estimate of the bank.

While this low GWP refrigerant bank is only equivalent to around 3% of the metric tonnes employed in the bank of regulated refrigerants, it is growing rapidly and is taking market share from HFCs. Efforts to improve the quality of data about the rate of adoption of these unregulated and therefore unreported refrigerants are underway and monitoring will continue.

Having successfully implemented an international phase out of ozone depleting refrigerants, international governments and the refrigerants industry have started an internationally agreed and nationally regulated phase down of HFCs under the Kigali Amendment to the Montreal Protocol. This global action is driving increasing diversity in the refrigerants available as a fourth generation of refrigerants is developed and tested, and proven natural refrigerants find wider applications.

5.1 Constituents of the bank, GWP and CO_2e

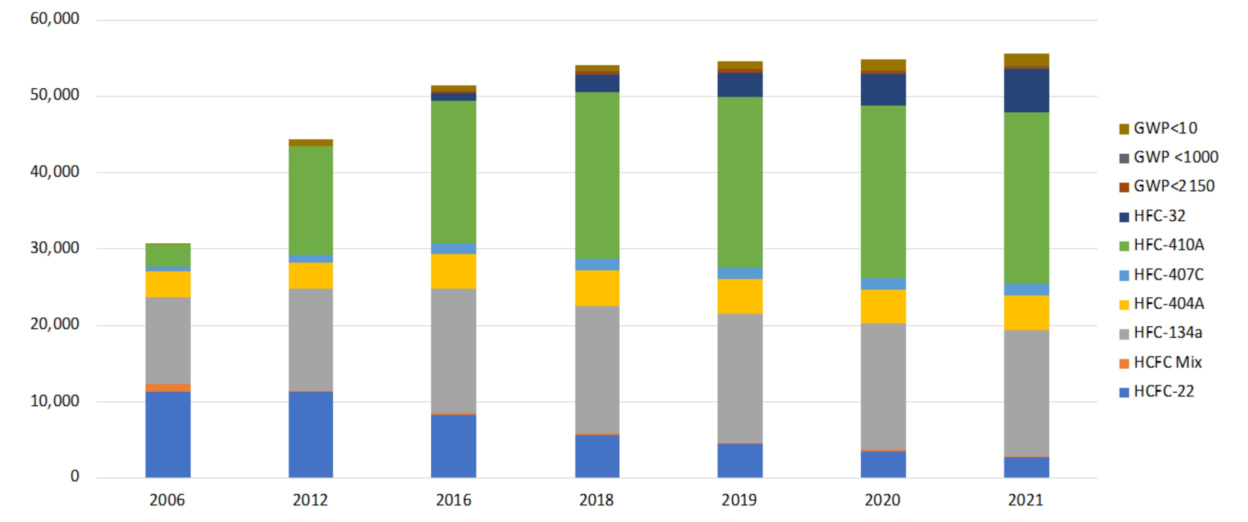
The main species of refrigerants in use today, described below in order of proportion of the bank they comprise, are:

- HFCs comprise 51,200 tonnes, or 94% of the bank, up from 83% in 2016. The half dozen most common HFCs that make up the majority of the bank have high GWP values, ranging from 675 for HFC-32, to 3922 for HFC-404A. HFC consumption is now being phased down from 2018 towards a 2036 target capped at 15% of 2011-2013 levels of annual consumption.
- HCFCs and CFC still make up an estimated 2,900 tonnes or 5.3% of the bank (down from 16% in 2016). These were once the most common species of refrigerant in use. HCFCs are being phased out of production under the Montreal Protocol. Due to the long life of some types of equipment and an active HCFC recovery and recycling economy, HCFCs are expected to persist in the Australian economy mostly in stationary AC well towards the end of the 2020s.
- The bank of natural refrigerants in commercial refrigeration and mobile applications in 2020 is estimated at around 1,400 tonnes (up quite strongly from a total of 700 tonnes in 2016). Natural refrigerants are a group of refrigerants including ammonia, HC and CO_2, that have very low or zero GWP, but that may have other properties, such as flammability, toxicity or requirements for higher operating pressures, that limit their use in some applications (*AS/NZS 60335.2.89: 2020*). There is a further estimated 4,000 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 in large cold storage distribution centres. These ammonia refrigerants are not included in the estimate of the bank in 2021 as illustrated in Figure 3.
- HFOs are the newest generation of synthetic refrigerants that, in most cases, are mildly flammable, but exhibit the properties of thermal stability and non-toxicity that HFCs provide, while also having very low GWPs (the GWPs of HFO-1234yf and HFO-1234ze are 5 and 1, respectively, based on Intergovernmental Panel on Climate Change, Assessment Report 5). HFOs are entering into service internationally, initially in new motor vehicles, and chiller manufacturers are offering models that employ HFOs due in part to the energy efficiency gains they deliver. Adoption of HFOs in Australia has been very slow. In 2021 there was around 530 tonnes of HFOs in use in equipment in Australia. Future data on HFOs in the bank may not be available with the same accuracy that data on imports of HFCs and HCFCs currently allows (i.e. pre-charged equipment data). 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.

The effects of regulation, the introduction of new generations of gases, changing consumer demand and industry trends have all contributed to the current make-up of the refrigerant bank in 2021.

Figure 3: Refrigerant bank by species 2006, 2012, 2016, and 2018 to 2021, in tonnes



(Sources: CHF1, CHF2 and CHF3 RAC Stock Models, excludes ammonia)
CHF Cold Hard Facts **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **GWP** global warming potential

The effect of the move from HCFC-22 to HFC-410A as the predominant refrigerant charge in small and medium stationary AC started around 2005 can be seen in the declining proportion of HCFC-22 in the bank.

HCFC-22 as a proportion of the total bank has declined from 37% in 2006 to 5% in 2021.

Previously HCFC-22 was the refrigerant of choice in air conditioning applications and many commercial refrigeration applications. In absolute metric tonnes it peaked before 2012 when HCFCs made up nearly 30% of the bank. In what is quite a sharp fall, the bank of HCFCs has reduced by more than 9,300 tonnes from that high point, a drop of more than three quarters, in the past 10 years.

This was a predictable outcome due to 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 2016 Australia's HCFC import cap stepped down from 10 ozone depleting potential (ODP) tonnes to just 2.5 ODP tonnes (equivalent to around 45.5 metric tonnes of HCFC-22 per annum), before the final phase out of HCFC imports in 2030.

This phase out of bulk imports was coupled with a ban on imports of most HCFC-22 pre-charged equipment that commenced in July 2010. The import of large chillers charged with HCFC-123 continued until the end of 2015.

The effect of this decreasing supply and price increases for HCFC-22 since 2012 has created an active recycling industry to supply reconditioned HCFC-22. This supply of HCFC-22 as well as the option to retrofit with HFCs provides equipment owners an option to get the longest possible operating life out of their equipment.

Expert Group research and analysis indicates that the tail of HCFC-22 bulk imports until the end of 2029 plus recovering and recycling will be sufficient to meet demand for service and repair of the remaining HCFC charged equipment.

In the case of HCFC-123, which is employed in long lasting, large, and expensive chillers, the service requirement is likely to continue for at least another decade, and possibly past 2036 as the last HCFC-123 chillers were installed in 2016.

A concerted move from HCFC-22 to HFC-410A in small and medium stationary AC occurred around the time that sales in these equipment segments first passed more than one million units a year in Australia; a figure that continued to climb to more than 1.3 million units sold in 2017, with a similar number sold in 2021. The decade-long million-plus annual unit sales has built a stock of more than 10.3 million HFC-410A charged pieces of equipment, containing a bank of more than 22,400 tonnes of HFC-410A, representing more than 41% of the entire regulated bank.

This growth in HFC-410A from just 9% of the bank (2,800 tonnes) in 2006 to around 22,400 tonnes in 2021 means that HFC-410A is now the largest single component of the bank, surpassing HFC-134a. The HFC-410A bank is now more than 8 times larger than the declining bank of HCFC-22 that it was introduced to replace.

After HFC-410A, HFC-134a is the second most abundant refrigerant in the 2021 bank, growing steadily at around 3% per annum up to 2016, at which point it constituted some 32% of the bank. Uptake of new refrigerants has seen HFC-134a decline marginally since 2016 to make up 30.4% of the total bank in 2021.

HFC-404A saw steady growth in overall tonnes between 2012 and 2016, increasing by more than 1,200 tonnes, or more than 30%, to reach 4,550 tonnes, reaching 9% of the total bank in 2016. Since that time, it has increased slightly with now an estimated 4,600 tonnes in 2021 representing 8.5% of the bank.

The rapid adoption of HFC-32, primarily in small and medium sized stationary AC applications, saw total volumes grow strongly from nearly 3,200 tonnes in 2018 to more than 5,700 tonnes in 2021. This growth is occurring largely at the expense of the much higher GWP HFC-410A. HFC-32 made up 10.6% of the bank in 2021, up from just 2% in 2016. Adoption of HFC-32 across a wider range of equipment formats is expected to further accelerate the rapid growth of this HFC in total tonnes, and as a proportion of the bank.

Mostly as a result of having similar refrigeration characteristics as HCFC-22, which it is sometimes used to replace, the bank of HFC-407C reached approximately 1,300 tonnes in 2016, having grown steadily from around 700 tonnes in 2006, increasing its proportion to 2.8% of the bank. By 2021 HFC-407C had grown to just under 1,500 tonnes although was still only 2.8% of the overall bank.

The data from which Figure 3 was produced is available in Appendix B, B3.2 *Refrigerant bank 2006, 2012, 2016, and 2018 to 2021 by mass in tonnes and share in percent*.

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 HFC-32 becomes the most common refrigerant employed in the extensive stock of small AC.

5.2 Retirement and recovery

In 2021 RAC equipment containing an estimated 2,490 tonnes of residual refrigerant reached the end of its useful life. It should be noted that most of the equipment that is retired would not be fully charged, and the Expert Group RAC stock model calculates various rates of remaining partial charge for retiring equipment.

For example, split ducted air conditioners are estimated to retain 80% of their original charge at retirement. Studies of end-of-life (EOL) motor vehicles indicate that average charges of MAC at retirement are around two thirds of the original charge and the RAC Stock Model uses a residual charge of 66% for EOL MAC in vehicles. Refer to Appendix B Table 1: Technical characteristics by product category, for end-of-life factors and assumptions. Further work in this area is required to improve confidence in calculations of refrigerant in EOL equipment.

More than 80% of the refrigerant estimated to have still been in EOL equipment in 2021 would have been in stationary equipment types including domestic refrigerators and freezers, stationary air conditioners and self-contained equipment employed in the refrigerated cold food chain. An unknown but expected to be relatively small portion of this refrigerant is likely to have been recovered by contractors for reuse, particularly if it was HCFC-22 for which an active reclamation market is in place, which until recently reported high prices for this species.

Approximately 637.8 tonnes of refrigerant was recovered by Refrigerant Reclaim Australia (RRA) in the 2021/22 financial year, comprising 3.5 tonnes of chlorofluorocarbons (CFCs), 132.6 tonnes of HCFCs, 433.7 tonnes of HFCs, 0.04 tonnes of HFO and 1.8 tonnes of HC. A further 12.5 tonnes was reported to RRA as retained by refrigerant suppliers for reclamation and re-use of which the majority was HCFC-22. The remaining 53.7 tonnes is awaiting laboratory analysis (RRA 2022). Refrigerant recovered by the RRA program is recovered from both EOL equipment and from equipment during service where refrigerant that is not suitable for continued use is removed and replaced with new refrigerant.

Total recoveries by RRA in the 2021-22 financial year increased by 130.0 tonnes on the previous financial year despite the rebate paid by RRA for recovered refrigerant reverting from the trial amount of $10 per kg to $3 per kg effective from 1 July 2021. There were several other noticeable trends compared to the previous financial year. Firstly, the volumes of refrigerant reported as being retained for recycling by suppliers declined by 74.5 tonnes (-85%). Secondly, the volumes of HCFC returned to RRA increased significantly by 91.5 tonnes (more than 220%). The combination of these trends signals reduced demand for and commercial value of HCFC-22 in the market. Returns from HFCs and other substances remained relatively stable.

Maximum imports of HCFCs between 2016 to 2020 have been capped at 2.5 ODP tonnes per annum, which equates to 45.5 metric tonnes of HCFC-22. The additional use of HCFCs reported for those 5 years of 210, 179, 117, 93 and 56 tonnes respectively was possible because the material employed above the import cap was reclaimed and reconditioned. There is an additional but at present unknown amount of HCFC-22 recovered by contractors and directly re-used in the field.

Overall, the noticeable decline in sales of HCFC-22 between 2016 and 2020 indicates a market in general decline.

In 2021 RRA published the results from a research project to gather field data on residual charge sizes, leak rates and refrigerant loss during the recovery process from split systems at EOL. More than 100 contractors participated in the project, the key data points are:

- sample size: 1,152 systems (52% HCFC-22, 43% HFC-410A and 5% HFC-32)
- average rating plate charge size: 1.93 kg
- average retained charge at EOL: 1.35 kg
- average operating life: 13.7 years
- average loss through operating life, 30% loss over 13.7 years equating to an average annual leakage rate of 2.2%.

These field results are very consistent with the service rate of 2.2% and theoretical leak rate of 2.7% for single split systems published in Table 1 of CHF3, *Appendix A: Methodology – Taxonomy, data and assumptions*. The average lifespan used in the CHF3 model is 12 years for non-ducted split systems and 16 years for ducted split systems (RRA 2021b).

6 Refrigerant imports and usage

There are 2 means by which the bank of working gas in Australia grows:

- Via imports of equipment that are pre-charged with a refrigerant gas, referred to as pre-charged equipment (PCE) imports.
- Via imports of bulk gas, where the bulk gas is used for charging new equipment that has been manufactured in Australia, or it is used for charging equipment that has been imported without a refrigerant charge, or installations with longer than usual pipe runs requiring additional charge.

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

Natural refrigerants, ammonia, CO_2 and hydrocarbon refrigerants are not scheduled substances under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* and are discussed separately in Section 7.3 Natural refrigerants. Hydrofluoro-olefin refrigerants (HFOs) are not classified as scheduled substances although they are also ingredients used in HFO/HFC blends. HFOs are briefly discussed in Section 7.1 Hydrofluoro-olefin refrigerants.

6.1 Pre-charged equipment imports

Approximately 3,620 tonnes of HFCs contained in more than 3.0 million pieces of RAC PCE were imported into Australia in 2021. While import volumes were similar in 2019 and 2020, volumes in 2021 were up by 16% approaching the all-time high of 3,721 tonnes of imports in PCE in 2017.

Volumes of HFCs imported in stationary AC, the most populous equipment segment, were up by nearly 15% in 2021 compared to 2020. There was a similar number of units imported in 2021 when compared to 2017, however the refrigerant volume was smaller compared to 2017 because new HFC-32 charged split systems have a smaller refrigerant charge compared to earlier models employing HFC-410A.

Notably, as part of this overall decline in the total volume of HFCs imported in PCE, the volume of HFC-410A declined by more than 21% year-on-year from 1,954 tonnes in 2018 to 944 tonnes in 2021. At the same time volumes of HFC-32 imports increased from 713 tonnes in 2018 to more than 1,616 tonnes in 2021.

The volume of HFCs imported in MAC was down by 31% in 2020 as compared to 2017 on the back of lower vehicle imports. The Federal Chamber of Automotive Industries reported 2020 sales of new vehicles at 916,968, and the lowest number of new car sales recorded since 2003 (FCAI 2021). In 2021 new car sales increased by 14% to 1,049,831 despite ongoing supply shortages and limited opportunities for discounts (FCAI 2022). At the same time PCE imports of MAC increased from 490 tonnes in 2020 to 600 tonnes in 2021. Some of the drop in sales in the past 2 to 3 years is clearly COVID-19 related due to forced closures of showrooms, factory shutdowns resulting in stock shortages and the pandemic effects on consumer confidence. Early indicators suggest that 2022 sales will also be soft as vehicle manufacturing supply lines continue to face obstacles of both materials and component inputs such as computer chips, and logistical hurdles in distribution. A small part of the decrease in imported gas volumes in MAC is almost certainly the first signs of the adoption of very low GWP HFOs in MAC, although because HFOs are not reportable, the data is not clear and the shift to HFOs in any significant numbers is certainly not confirmed. Of the 1,046,338 new vehicles imported into Australia in 2021 at least 10% and possibly as much as 13% were estimated to contain HFOs.

As an example of the unexpectedly slow migration of MAC to HFOs, far slower than Expert Group had originally predicted, even brands new to the market are still employing HFCs. For instance, electric vehicle sales rose sharply in 2021, with increased model availability, lower prices, and state and territory government incentives stimulating the market. Sales in Australia tripled from the previous year to 20,665 electric vehicles sold, up from 6,900 in 2020. This increase represents 2% market share of all sales, however, is low compared to other industrialised economies, for example the EU average in 2021 was 17% of new vehicles (EVC 2022). Despite the availability of very low GWP HFOs in the countries of manufacture, the large majority of electric vehicles sold in Australia still use HFC-134a for passenger comfort and battery cooling.

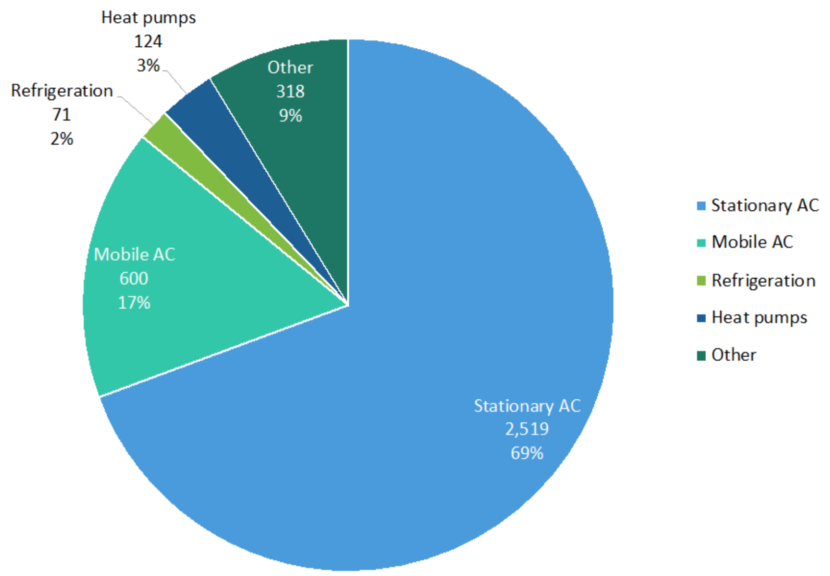
HFC volumes imported in pre-charged commercial refrigeration equipment in 2021 was around 58 tonnes, down more than 50% on the previous year. This resulted from a significant drop in the number of pieces imported in 2021 with 73,396 individual pieces imported, more than 25% lower than the average imports of the previous 5 years. Reduced HFC volumes in these equipment segments are also being driven by more commercial refrigeration being designed for a HC charge that is not a controlled substance.

In addition, Australia has a robust commercial refrigeration manufacturing base, and indications from market intelligence surveys suggest strong 2021 and 2022 sales of Australian made equipment as these commercial refrigeration equipment categories see overall strong continuing growth. Despite the impact on hospitality during COVID-19 lock downs, food processing of home delivered meals in commercial kitchens and take away meal services have, in many settings, been enjoying high demand.

At the same time larger enterprises with strong balance sheets, such as group owned hotels, pubs and clubs, used the periods of prolonged shut down to refurbish and replace equipment. As the economy faces uncertain economic times, some of this high demand for commercial refrigeration equipment is expected to soften as food retail and hospitality return to business as usual and the once-off drivers of new equipment sales in the past 2 years fade.

While non-AC heat pumps is a relatively small category in terms of total equipment numbers installed in the economy, 141,424 pieces were imported in 2021. This covers all applications except stationary AC, including heat pump clothes dryers, hot water heaters and pool heaters, with the continued rapid growth up 32% year-on-year to maintain a long-term trend that has seen annual imports increasing by more than 300% since 2016. This is an equipment category that is eligible for various government incentives at all levels of government in efficiency and renewable energy programs around the country, a trend that is likely to expand and continue as state governments agencies seek to electrify applications traditionally serviced by gas appliances and equipment.

Figure 4: HFC refrigerants in pre-charged equipment imports in 2021 by application, reported in metric tonnes and per cent of annual imports



(Source: DCCEEW 2022)
AC air conditioning **HFC** hydrofluorocarbon
Stationary AC includes domestic and commercial categories.
Mobile AC includes motor vehicle, watercraft or aircraft air conditioning and refrigeration.
Refrigeration includes domestic and commercial refrigeration categories.
Other includes aerosols, components, consumer goods, fire protection and scientific or electrical equipment and switchgear.

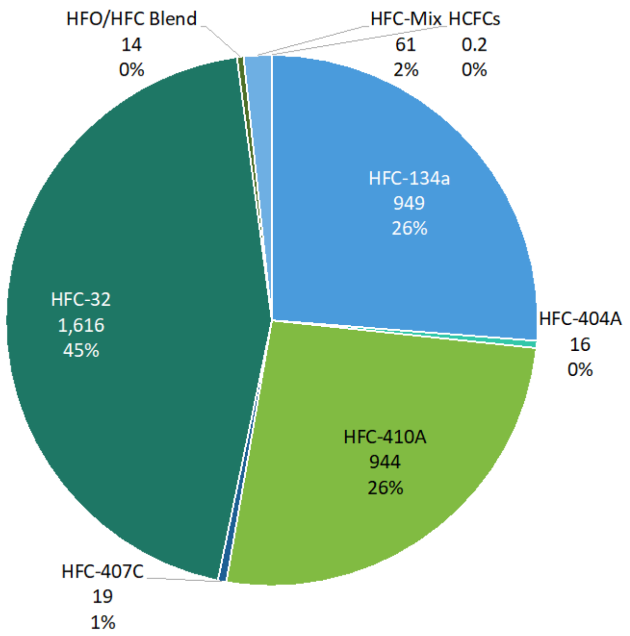
While the annual imports of MAC and stationary AC equipment are both significant (947,000 MAC units and 1,570,000 stationary AC in 2021), stationary AC imports make a much greater contribution to the HFC bank due to larger average charge sizes in stationary AC systems as compared to MAC. Average stationary AC system charges range from 1.1 kg in an average residential non-ducted split system of (down from 1.3 kg in 2016) to average charges of greater than 5 kg in small commercial systems.

By comparison the average charge in small MAC (i.e., passenger vehicles, light commercial vehicles, trucks and commuter buses) imported in 2021 was 570 grams (down from 620 grams average in 2016). This is a trend observed in other countries with charge sizes of around 500 grams driven by both MAC technology and the use of smaller vehicles.

The dominance of stationary AC equipment in PCE imports is reflected in the mix of refrigerant contained in total PCE imports in 2021. The high GWP refrigerant of choice for stationary AC for the past decade, HFC-410A, is still a major part of the mix with 944 tonnes imported in PCE making up 26% of PCE refrigerant volumes in 2021 and comprising 43% in GWP terms of all HFCs imported in PCE. The much lower GWP HFC-32 made up 45% of imports by refrigerant mass (2020, 37%) and 24% in GWP terms, the very large majority of which was imported in small split AC systems.

HFC-32 charged stationary AC devices in the stock of equipment now number more than 5 million, containing more than 5,893 tonnes of HFC-32 (based on pre-charged AC equipment imported until the end of 2021 calendar year, excluding local manufacturing), with more than 1,599 tonnes being added to the HFC-32 bank in 2021.

Figure 5: Pre-charged equipment imports in 2021 by major species in tonnes and as per cent of total imports



(Sources: DCCEEW 2022)
HCFC hydrochlorofluorocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin

The growth of the HFC-32 share of PCE imports (from nearly zero in 2012) can be seen in Figure 6. HFC-32 is expected to continue to aggressively take market share from HFC-410A charged equipment. Uptake of HFC-32 has exceeded predictions with an earlier estimate by Expert Group that HFC-32 would become the dominant refrigerant imported in the stationary AC segment during 2022-23 being beaten by more than 2 years. The use of HFC-32 in medium AC applications, a trend that has just commenced in the past 2 years, is expected to grow strongly over the next 5 years.

While 32 tonnes of HFC-410A and HFC-407C was imported in 2021 contained in chillers with a charge greater than 12 kg, these applications are expected to migrate to HFC-32 and HFO blends in the years ahead.

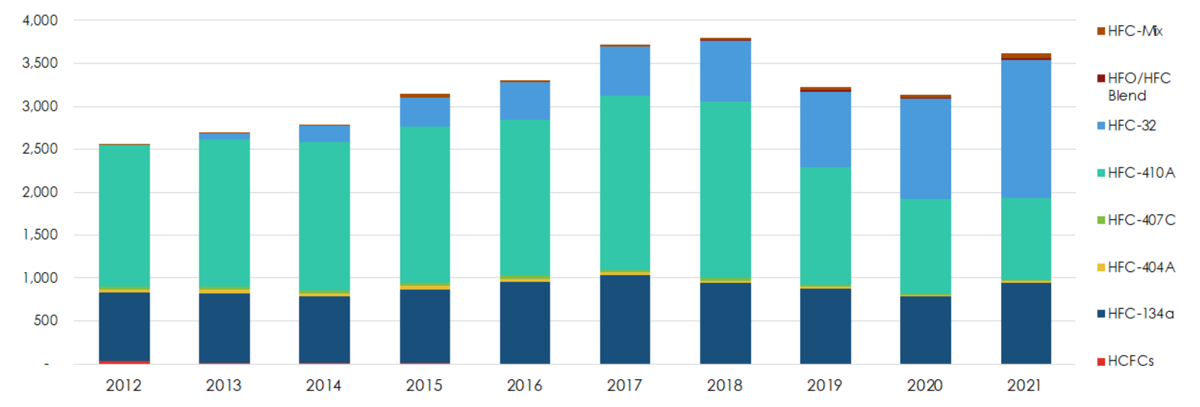
HFC-134a has maintained a relatively steady share of import volumes in PCE during the past decade, as can be seen in Figure 6. A rise in HFC-134a pre-charged imports was discernible in 2017 and 2018 as vehicle manufacturing in Australia stopped and all new vehicles sold were imported. However, the rising PCE imports of HFC-134a were only replacing what was previously imported as bulk gas for use by domestic vehicle manufacturers.

PCE imports containing HFC-134a are expected to show sharp declines leading up to the mid to late 2020s due to:

- A portion of vehicle imports migrating to HFO-1234yf.

- A portion of the 41 tonnes of HFC-134a imported in chillers in 2021 migrating to HFO-1234ze, HFO-1233zd, HFO-1336mzz, HFO/HFC blends such as R513A and R515B, and HFO blend R514A (R514A is a blend of 74.7% HFO-1336mzz and 25.3% trans-dichloroethylene).
- Small and medium commercial refrigeration continuing the strong trend of migration to HC and HFO/HFC blends including R448A, R449A, R450A, R452A, R455A and others. In 2021 5.0 tonnes of R452A was imported in commercial refrigeration equipment, excluding transport refrigeration.
- Small volumes (400 kg) of HFO/HFC blends such as R513A replacing HFC-134a in various industrial equipment including compressed air dryers and specialised chillers.

Figure 6: HCFCs and HFCs in pre-charged equipment from 2012 to 2021 by species in tonnes



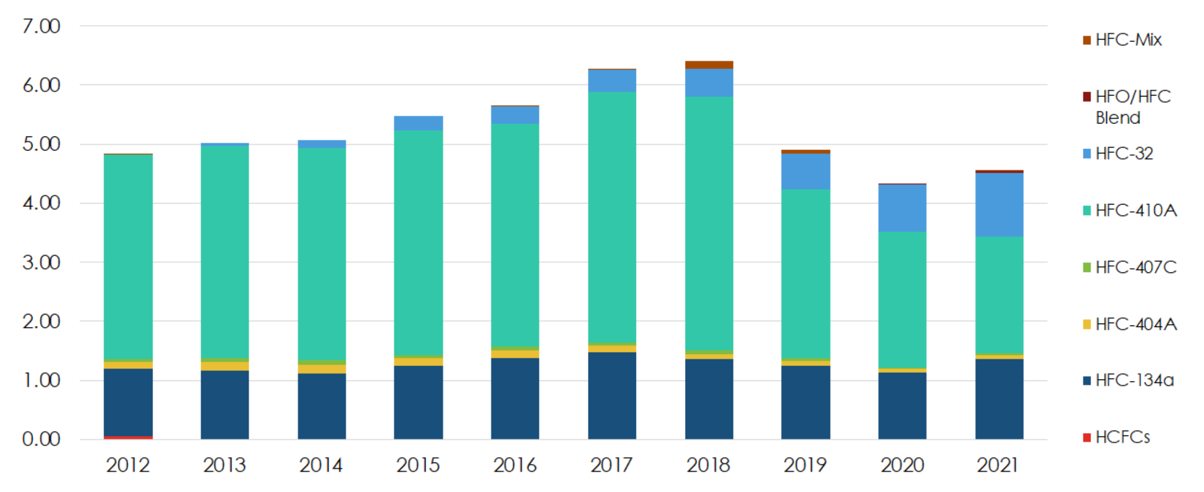
(Sources: DCCEEW 2022)

HCFC hydrochlorofluorocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin

A comparison of Figure 6 and Figure 7 demonstrates the effect of the higher GWP refrigerants entering the bank. While it can be seen from Figure 6 that the transition to HFC-32 in small AC imports has reduced the imports of PCE charged with HFC-410A (the refrigerant of choice in small split AC imports for some 17 years), the higher GWP value of HFC-410A ensures it will dominate the refrigerant bank by CO_2e value for many years to come. Refer to Appendix B 4.1: Net bulk imports and pre-charged equipment imports from 2006 to 2021, for tabulated data used for Figure 6.

Figure 7 shows the 29% decline in the CO_2e value of refrigerant imported in PCE, from a peak of 6.4 Mt CO_2e in 2018 to 4.6 Mt CO_2e in 2021.

Figure 7: HFCs in pre-charged equipment from 2012 to 2021 by species in Mt CO_2e (AR4)



(Source: DCCEEW 2022)

AR4 Global warming potential figures calculated from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change for the United Nations Framework Convention on Climate Change **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin

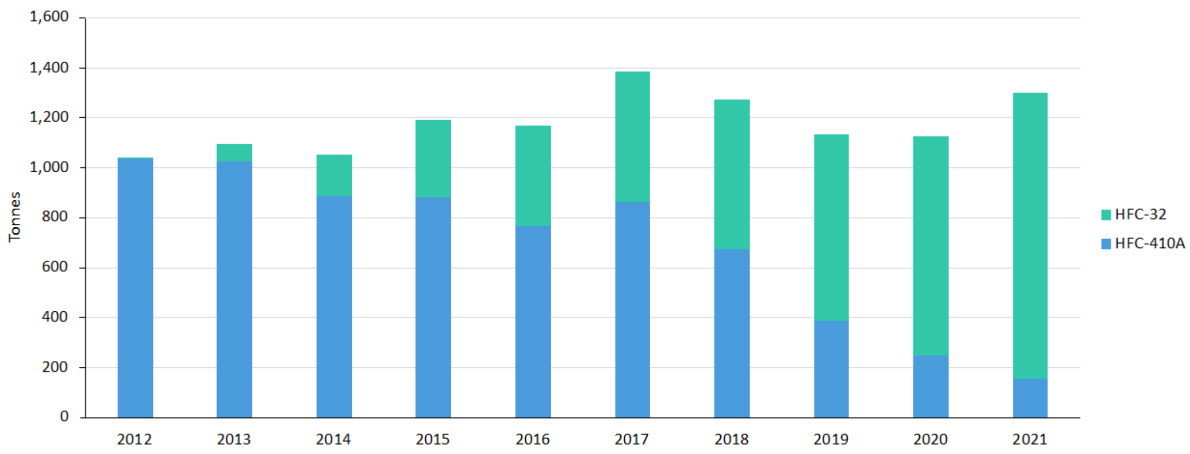
6.1.1 Analysis of pre-charged equipment provides insights into the transitioning bank

Analysis of PCE imports shows that non-ducted single split systems, designed primarily for residential use, make up most of the imported equipment. As a result non-ducted single split systems contain the bulk of the refrigerant mass, calculated on actual refrigerant charge sizes, of all stationary AC imported into Australia.

The adoption of HFC-32 has continued to grow strongly in non-ducted split systems, particularly in units with charge sizes between 800 grams and 2.6 kg, as illustrated in Figure 8, with the penetration reaching 88% based on units in 2021. Refer to Appendix B 4.2: Stationary AC: Pre-charged equipment for tabulated data.

In split system AC (ducted and non-ducted) with charge sizes between 2.6 kg and 4 kg, HFC-32 models make up 60% of imports based on refrigerant charge and 61% based on units. The broader charge category from 4 kg to 12 kg still contains slightly less HFC-32, accounting for 15% based on refrigerant mass and 21% based on quantity of units, as the transition of models with charges above 4 kg is slower.

Figure 8: Mass of refrigerant in pre-charged equipment imports of stationary air conditioning from 2012 to 2021 (with a charge greater than 800 grams and less than or equal to 2.6 kg) by refrigerant type in tonnes



(Source: DCCEEW 2022)
HFC hydrofluorocarbon

This displacement of higher GWP refrigerants in small stationary AC may be accelerated with regulation being considered to drive change in the smaller devices. The Australian Government Department of Climate Change, Energy, the Environment and Water is considering options to ban the import and manufacturing of small AC up to 2.6 kg refrigerant charge using a refrigerant with a GWP over 750. Air conditioners to which this would apply would be non-ducted units for stationary uses, including split systems, window/wall mounted units and portable air conditioners. Any ban would be brought in after a suitable notice period and would not affect equipment already in Australia.

Ducted and non-ducted air conditioners up to 65 kW must satisfy Minimum Energy Performance Standards (MEPS) and be registered under the Greenhouse and Energy Minimum Standards (GEMS) Act 2012. There are around 100 stationary AC brands on the register and registration details include the refrigerant type. As of 1 August 2022, the count of GEMS registered models operating on HFC-32 was:

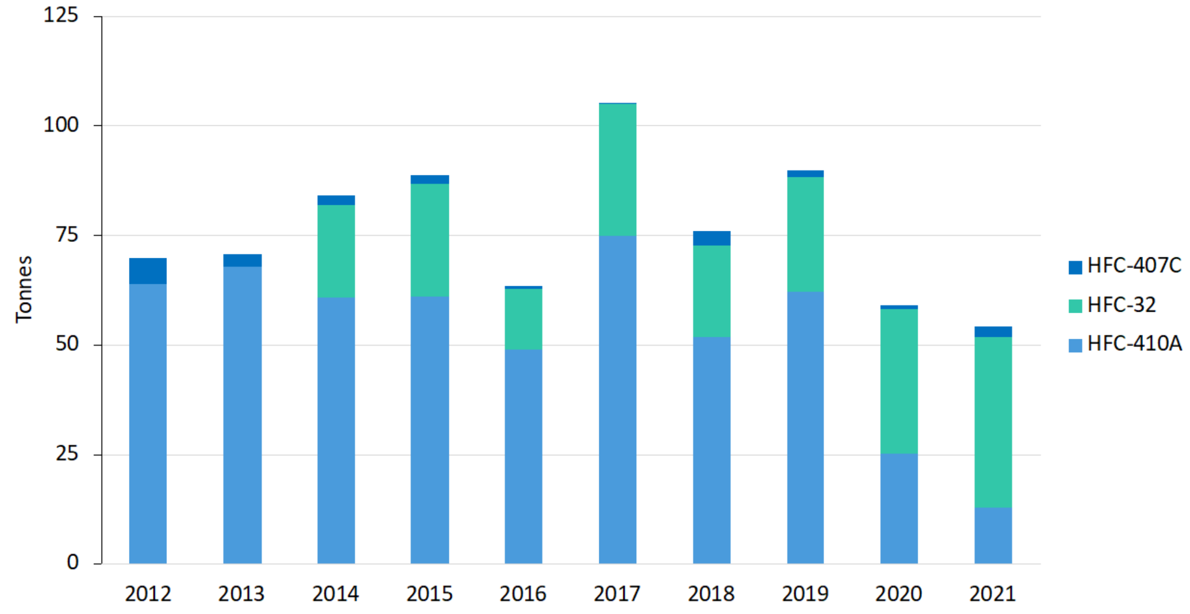
- 916 non ducted single split systems registered (50% of all registered non-ducted single split systems).
- 110 window/wall models (61% of all registered window/wall).
- 182 single split ducted models (21% of all registered single split ducted).

The number of GEMS registered HFC-32 models indicates a steady shift away from HFC-410A in both non-ducted and ducted single split systems as HFC-32 continues to grow. It should be noted however that GEMS data is not sales weighted data and includes all registered models including those that are no longer on the market (GEMS registration lasts for 5 years, regardless of whether they are still sold over this time period). The analysis only includes those registrations that are on the GEMS register as available and excludes those models that are superseded.

Analysis of the GEMS database also shows that 84% of portable AC models that have been registered are now using HC-290 and 6% HFC-32. This marks a considerable shift to HCs in this low charge application.

Figure 9 illustrates the refrigerant trend in very small AC units which are mostly self-contained units (portable and window/wall AC) and some non-ducted split systems below around 3.5 kWr.

Figure 9: Mass of refrigerant in pre-charged equipment imports of stationary air conditioning from 2012 to 2021 (with a charge size less than 800 grams) by refrigerant type in tonnes



(Source: DCCEEW 2022)

HFC hydrofluorocarbon

Data used in Figure 9 includes window/wall AC, portable AC as well as some wall hung split AC for brands that offer multiple non-ducted types such as TECO, TLC, Lennox, Electrolux, Braemar, Gree, Kogan, Dimplex and others.

6.2 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 49 licensed importers of SGGs including HFCs, and sulfur hexafluoride and 5 licensed importers of HCFCs as of October 2021 (DAWE 2021b). These numbers include licences to import very small quantities for laboratory use. In 2012 there were only 17 controlled substances licence holders in total.

In 2021 a total of 3,518 tonnes of HFCs and 43 tonnes of HCFCs were imported as bulk gas. Total HFC imports in 2021 were 287 tonnes more than 2020, however the GWP mix of imports was lower equating to 66 kt CO_2e less than in 2020 (refer to Appendix B 4.1 for tabulated data on HFC and HCFC net bulk imports from 2008 to 2021 in tonnes and in kt CO_2e).

Table 3: Net bulk imports of HCFCs and HFCs in tonnes

Species	2016	2017	2018	2019	2020	2021
HCFC-22 **a**	45	45	45	45	43	43
HFC-134a	1,541	1,837	1,552	1,335	1,363	1,541
HFC-404A	384	2,008 **b**	699	838	822	581
HFC-407C	190	314	154	179	109	137
HFC-407A/F	0	0	0	1	10	10
HFC-410A	602	953	999	889	611	919
HCFC/CFC Replacements **c**	118	110	80	111	69	66
HFC-32	27	31	68	64	95	144
HFO/HFC Blends **d**	0.0	15	29	42	48	39
HFC-Mix **e**	150	420	130	92	104	81
Total HCFCs and HFCs **f**	3,058	5,734	3,757	3,595 **g**	3,274 **g**	3,561 **g**

(Source: DCCEEW 2022)
CFC chlorofluorocarbon **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin
The published import values are net bulk imports which is imports minus exports and excludes the 5% allowance for the heel. The above values do not include smaller amounts of used HFCs and HCFCs imported for destruction.
a Maximum imports of HCFCs for 2016 to 2021 are capped at 2.5 ODP tonnes per annum, which equates to 45.5 metric tonnes of HCFC-22. There was 2.2 tonnes of used HCFC-22 imported for destruction in 2019 not counted in above. **b** The phase down of HFCs through a quota system for imports of HFCs as bulk gas commenced on 1 January 2018. **c** HCFC-22/CFC retrofit 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. **d** HFO/HFC blends includes R448A, R449A, R450A, R452A, R513A, R514A and others imported from 2017. **e** Majority used in foam and fire protection applications as well as HFC-125 that could be used in refrigerant blends. **f** Sum of values in table do not add up to totals due to rounding. **g** The values exported in 2019, 2020 and 2021 were 7.8, 0.0 and 107.7 tonnes respectively.

6.3 Refrigerant usage – HCFCs and HFCs

Insight into refrigerant usage in the Australian economy has significantly improved over the past decade and is now informed by a quarterly survey of refrigerant wholesalers, providing robust data that can be reconciled against annual bulk imports.

Imported 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 successful manufacturers. Refrigerant consumption for local manufacturing of stationary AC in 2021 was 247 tonnes of HFC-410A, HFC-32 and HFC-134a compared to 261 tonnes in 2020. There were small volumes of R290 consumed manufacturing domestic hot water heat pumps with charges of around 300 grams.
- Charging, or adding to a partial charge, for new equipment at point of installation where the device may have been imported without any refrigerant charge (or partial charge) or needs

an addition to its pre-charged volume when installed and commissioned to accommodate installations 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 can be retrofitted with drop-in replacements.
- Servicing the stock of equipment to maintain charge levels as a result of leaks or catastrophic losses of refrigerant.
- A small fraction of imports is lost during decanting into small cylinders that are distributed into wholesale supply lines.

Table 4 provides estimates of the HCFC and HFC refrigerant usages over the last 6 years. Observations of trends are as follows:

- HCFC-22 usage has more than halved from 255 tonnes in 2016 to 91 tonnes in 2021. The equipment ban imposed over 12 years ago is working as intended.
- HCFC/CFC replacements are declining as anticipated from 99 tonnes in 2016 to 72 tonnes in 2021 (-27%) as the demand for retrofitting old equipment diminishes.
- Usage of HFC-134a has remained steady at around 1,459 tonnes per annum over the past 3 years.
- HFC-404A usage remains stubbornly high and is up 5% compared to the average over the previous 5 years. Despite being the highest GWP commonly used refrigerant, HFC-404A is being routinely deployed in new installations.
- While the volumes of HFO/HFC blends R448A and R449A are increasing, it is not transitioning as anticipated with volumes equating to less than 5% of HFC-404A usage. A key barrier to greater uptake is the refrigerant price differential and the additional cost to retrofit. R448A and R449A will be more likely to be used as retrofit replacements for HFC-404A when the price of HFC-404A increases in time due to its high GWP and the HFC phase down.
- Usage of HFC-410A has remained steady at around 790 tonnes per annum over the past 3 years. At least two-thirds of this consumption is to service the large stock of AC equipment.
- Usage of HFC-32 has grown as anticipated from 16 tonnes in 2016 to 75 tonnes in 2021 and will continue to grow as the AC bank of equipment transitions from HFC-410A to HFC-32.

Table 4: HCFC and HFC refrigerant usage in tonnes

Species	2016	2017	2018	2019 f	2020 f	2021
HCFC-22 **a**	255	224	168	138	101	91
HFC-134a	1,276	1,428	1,329	1,462	1,451	1,433
HFC-404A	800	878	813	824	856	880
HFC-407C	168	173	179	185	178	169
HFC-407A/F	33	31	29	29	25	20

Species	2016	2017	2018	2019 f	2020 f	2021
HFC-410A	612	711	753	800	776	793
HCFC/CFC Replacements **b**	99	96	96	94	79	72
HFC-32	16	32	44	39	50	75
HFO/HFC Blends **c**	-	-	13	38	57	42
HFC-Mix **d**	190	195	195	201	182	168
Total HCFCs and HFCs	3,449	3,768	3,619	3,811 **e**	3,757 **e**	3,738 **e**

CFC chlorofluorocarbon **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin
The total sum of values may not add up due to rounding.
a Maximum imports of HCFCs for 2016 to 2020 are capped at 2.5 ODP tonnes per annum, which equates to 45.5 metric tonnes of HCFC-22. The additional, declining usage in those years of 210, 179, 117, 93 and 56 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. **b** HCFC-22/CFC retrofit 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. **c** HFO/HFC Blends includes R448A, R449A, R450A, R452A, R455A, R513A, R514A and others imported from 2017. The value includes the HFO and HFC component. **d** Majority used in foam and fire protection applications as well as HFC-125 that could be used in refrigerant blends. **e** The HFC usages in 2019, 2020 and 2021 include 15 to 24 tonnes per annum consumed in the maritime services industry. Previous years do not include estimates from this sector. **f** The 2019 and 2020 usage data has been updated from CHF2021 and now include an additional 30 and 38 tonnes respectively from new data sources.

6.4 Refrigerant usage projection and the HFC phase down

Australia commenced a phase-down of HFC imports on 1 January 2018 implemented as a gradual reduction in the maximum amount of bulk HFCs permitted to be imported into Australia in any calendar year, measured in million tonnes (Mt) CO_2e per year. The HFC import cap is managed through a quota system on imports of bulk gases by the licensed importers. This is a tried and tested system for management and reporting of substances controlled by the Montreal Protocol, established for the management of CFCs and HCFCs during the 1990s.

The 2021 annual import limit was 7.25 Mt CO_2e. Data reported to the Department of Climate Change, Energy, the Environment and Water and analysed by the Expert Group indicates that total HFC imports in 2021 were equivalent to around 7.082 Mt CO_2e, slightly down from the 2019 figure of 7.146 Mt CO_2e.

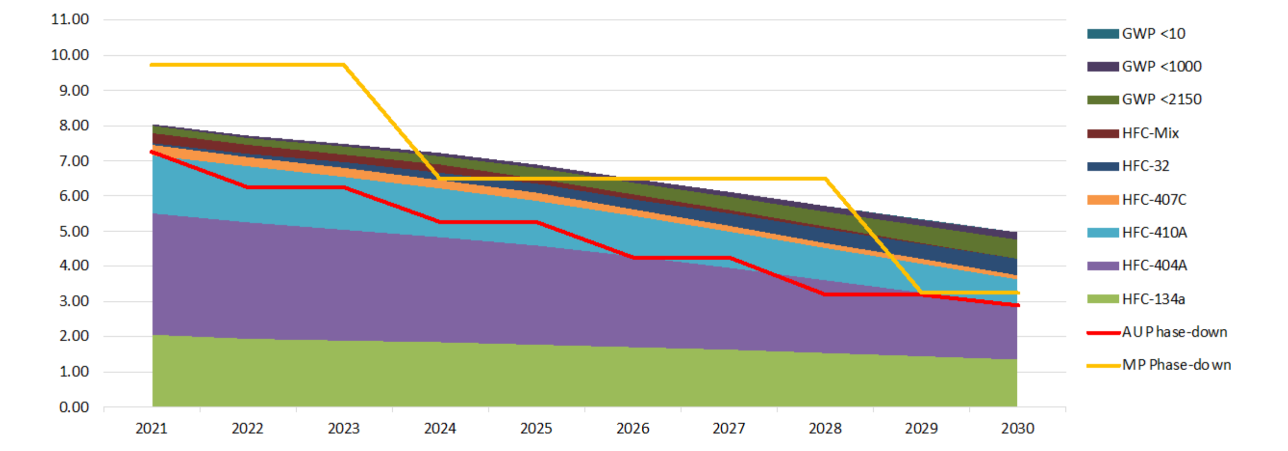
The starting point of the Australian phase-down agreed between the Australian Government and Australian industry participants, is 25% lower than Australia's base level in the Kigali Amendment to the Montreal Protocol. The Australian phase-down schedule stipulates reasonably consistent import quota steps down every 2 years to soften market shocks. The phase-down bottoms out in 2036 at the same final point as agreed under the Kigali Amendment to the Montreal Protocol.

The quota limit reduces at the start of each 2-yearly quota period, aligned with licensing periods under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989*. The phase-down has an end point of 1.607 Mt CO_2e on 31 December 2035 and will remain at 1.607 Mt CO_2e for each quota period from then on.

Figure 10 illustrates the HFC phase-down steps to 2030 relative to the projected refrigerant use by species in Mt CO_2e. The CO_2e value of refrigerants imported will drop by more than 37% from around 7.85 Mt CO_2e in 2021 to around 4.9 Mt CO_2e in 2030, 5 years prior to the final year of the phase down schedule. While there is inherent uncertainty in aspects of the modelling and subsequent projections of demand and use, the Expert Group projections of refrigerant use show demand will at times be higher than imports permitted under the phase down particularly towards the end of this decade, and at the end of the projection period.

Some of this demand for refrigerant will likely be met by recovery and reuse of refrigerants, as is currently the case with HCFC-22. The balance of this demand is likely to be displaced by lower GWP, HFO/HFC drop-in replacements that are expected to be introduced to market in the period of the projection.

Figure 10: HFC Phase down steps and refrigerant usage by species from 2021 to 2030 in Mt CO_2e



(Source: CHF 2021 RAC Stock Model)

AU Australia **GWP** global warming potential **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **Mt CO_2e** metric tonnes carbon dioxide equivalent **MP** Montreal Protocol on Substances that Deplete the Ozone Layer

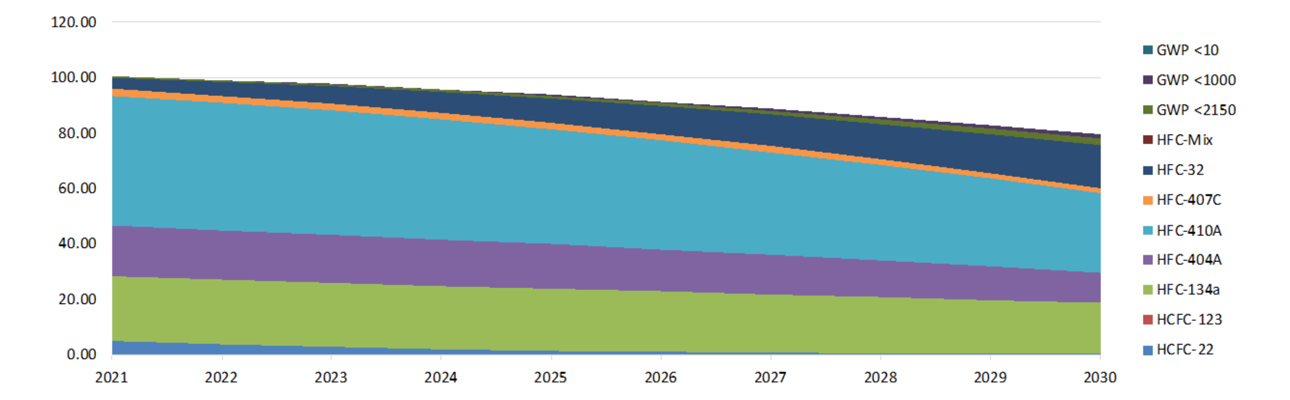
HCFCs are not included in the above chart as emissions of ozone depleting substances are not counted as part of the greenhouse gases reported under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, as they are managed through the Montreal Protocol.

Montreal Protocol HFC baseline for Australia is 10.814 Mt CO_2e, and the Kigali Amendment control limit for 2020 is 90% of the baseline equating to 9.732 Mt CO_2e. By comparison the Australian voluntarily adopted control limit for 2020 is 7.25 Mt CO_2e. and imports for the year came in at 7.15 Mt CO_2e.

The CO_2e value of the refrigerant bank, a lagging indicator of changes to the mix of refrigerant species being introduced to service, declines over the projection period more slowly than the CO_2e value of refrigerant imports. The composition of the bank also indicates future demand as the stocks of equipment using the refrigerant ages and requires replacement refrigerant.

Figure 11 illustrates the projection of the bank in Mt CO_2e to 2030. As stated earlier in the report, after decades of growth in CO_2e terms, trend data and projections indicate that the peak CO_2e of the overall refrigerant bank has been reached in 2021 and that wider adoption of natural and lower GWP refrigerants will continue to drive total CO_2e value of the bank lower.

Figure 11: Refrigerant bank by species from 2021 to 2030 in Mt CO_2e



(Source: CHF 2021 RAC Stock Model)

GWP global warming potential **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **Mt CO_2e** metric tonnes carbon dioxide equivalent

Because the overall bank comprises various equipment classes and segments, some of which are expected to continue to grow for some time (e.g., refrigerated cold food chain and heat pumps) the total metric tonnage of refrigerant in the bank is likely to stay above 50,000 tonnes for some time. However, growth in metric tonnes of high GWP HFCs should decline as natural refrigerants and HFOs displace HFCs entirely in some applications, and lower GWP refrigerants, particularly HFC-32 and HFC-HFO blends continue to be deployed. On balance it is expected that the long-term trend in the overall bank towards a lower total CO_2e value should be maintained.

It must be noted that, in the short term, the continuation of this trend to a lower CO_2e bank would benefit from a more rapid uptake of HFOs, particularly in MAC, than has been seen to date. The market may be relatively easily driven to more HFOs with corporate and government purchasing policy. Similarly, the very recent surge in HFC-410A charged heat pumps presents a risk to the declining CO_2e value of the bank and options to avoid the growth of this long life high GWP refrigerant in the economy could be as simple as minor amendments to the fuel shifting programs that have created increased demand for heat pumps.

7 Trends and observations by refrigerant type

Table 5 illustrates the state of technology readiness (green, amber and red) for the main RAC equipment classes to transition to lower GWP HFCs or alternative refrigerants. This framework, combined with interviews with technical experts from global equipment suppliers, forms the basis for predicting new equipment sales mix projections to 2030, which in turn inform the projections of the future composition of the bank. The sections that follow provide some examples to support the technology readiness assessment and alternative refrigerant selections.

Table 5: Summary of technology opportunities for new equipment by GWP threshold in 2021

New equipment	Equipment Examples	New equipment technical capability (GWP threshold)			
		150	750	1500	2500
Domestic refrigeration	Domestic refrigerators and freezers, and portable	HC-600a **a**	N/A	N/A	N/A
Small self-contained refrigeration	Integral display and storage cabinets, water dispensers, vending machines	HC-290 **a d**	N/A	N/A	N/A
Larger self-contained refrigeration	Integral cases, ice makers	R454C **b** R455A **b**	R454A **b**	R449A **a** R448A **a**	R452A **a**
Remote refrigeration	Condensing units for cold rooms and display cases	CO_2 **a** R290 **f**	R454A **b**	R449A **a** R448A **a**	N/A
Supermarket refrigeration: Cascade systems	Sub-critical CO_2	CO_2/HFO-1234yf or ze **b**	CO_2/R513A **b**	CO_2/HFC-134a **a**	N/A
Supermarket refrigeration: CO_2 only systems	Trans-critical CO_2	CO_2 **a**	N/A	N/A	N/A
Transport refrigeration	Refrigerated shipping containers	CO_2 **b** HFO-1234yf **c**	R513A **b**	HFC-134a **a**	R452A **a**
Transport refrigeration	Mobile refrigeration: road: trailer and inter-modal	CO_2 **c**	N/A	N/A	R452A **a**
Marine refrigeration	Fishing vessel refrigeration	Ammonia **b e**	N/A	R449A **a** R448A **a**	N/A
Small AC: Sealed	Wall units, portables	HC-290 **a**	HFC-32 **a**	N/A	N/A
Small AC: Split	Non ducted split systems	HC-290 **b**	HFC-32 **a**	N/A	N/A
Medium AC	Ducted split, VRV and packaged systems	N/A	HFC-32 **a** R454B **b** R468A **b**	N/A	N/A
Large AC: Chillers	Chillers with scroll compressors	N/A	HFC-32 **a** R454B **a**	N/A	N/A

New equipment	Equipment Examples	New equipment technical capability (GWP threshold)			
		150	750	1500	2500
Large AC: Chillers	Chillers with screw compressors	HFO-1234ze **a**	R513A **a** R515B **a**	N/A	N/A
Large AC: Chillers	Chillers with centrifugal compressors	HFO-1233zd **a** HFO-1234ze **a** HFO-1336mzz **a** HFO-514A **a**	R513A **a** R515B **a**	N/A	N/A
Small MAC	Passenger and light commercial vehicle, truck, commuter bus AC	HFO-1234yf **a** CO_2 **a** R474A c	N/A	HFC-134a **a**	N/A
Large MAC	Buses and coaches ≥12t Gross Vehicle Mass	N/A	N/A	HFC-134a **a**	HFC-407C **a**
Large MAC	Locomotive and passenger rail AC	N/A	N/A	N/A	HFC-407C **a**
Large MAC	Recreational vehicle and caravan AC	N/A	HFC-32 **b**	N/A	N/A

Key to technology signals

Mature technology within the Australian market.

Technology available but not widely utilised within the Australian market.

Technology not available at this time, there may be pilot trials underway.

AC air conditioning **CO_2** carbon dioxide **GWP** global warming potential **HC** hydrocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin **MAC** mobile air conditioning **N/A** not applicable

a Mature technology within the Australian Market **b** Technology available but not widely used within the Australian market. **c** Technology not available at this time, there may be pilot trials underway. **d** R290 is in widely used in self-contained commercial refrigeration appliances with a refrigerant charge <150 grams. In June 2020, a new edition of *AS/NZS 60335.2.89:2020* was released that allows up to 494 grams of R290 in commercial refrigeration appliances (provided the equipment meets the additional requirements of the standard for R290 charge sizes >150 grams and <494 grams). **e** Larger fishing vessels with separate refrigeration plant rooms from the main engine room are known to use ammonia refrigeration systems, and therefore would be considered technology that is robust and available, however are not widely utilised within the Australian market as the very large majority of the fleet do not have separate plant rooms. F Small capacity remote condensing units (<1 kWr) operating on R290 is not commercially available in Australia at this time, however, have been showcased at various international exhibitions (EM 2022).

7.1 Hydrofluoro-olefin refrigerants (HFOs)

HFOs have very low GWPs (<10), and in many applications require a smaller refrigerant charge to deliver the same refrigerating effect. Like HCs, the effectiveness of HFOs as a refrigerant means that in many applications the same refrigerating effect can be achieved while also reducing electricity consumed, delivering a double greenhouse gas abatement benefit of reduced GWP of refrigerant lost to air and reduced indirect emissions from electricity used.

The HFO refrigerants with a GWP less than 10 are HFO-1234yf, HFO-1234ze, HFO-1233zd and HFO-1336mzz. The main applications for these refrigerants in Australia are automotive and space chillers.

HFOs were introduced to international markets from around 2011 and were expected to make relatively rapid in-roads into the bank of refrigerants imported in MAC in new passenger vehicles. International auto makers adopted HFOs for most major markets including the USA and EU from around 2017, driven by European F-Gas regulatory requirements. Japan started transitioning about 2 to 3 years later and now HFOs are thought to represent around 70% of automotive manufacturing consumption in Japan.

Even though Australia imports more than 40% of its new vehicle sales from Japanese, European and USA car manufacturers, the penetration of HFOs in vehicles in Australia is estimated at around 10% to 13% of all passenger and light commercial vehicles imported in 2021, continuing the trend of very slow transition in this sector in comparison to uptake in the USA and EU. It is expected that the speed of transition to HFOs of MAC in Australia will increase with the introduction of new vehicle platforms designed with AC operating on HFO-1234yf only. For some leading brands this transition is expected to occur from 2025, however countries that continue to permit importation of vehicles operating systems charged with HFCs can expect vehicle manufacturers to continue to offer those models for sale as long as the older production lines are in operation.

HFO use in the chiller market is starting to gain momentum with many new screw and centrifugal compressor models shifting from HFC-134a to HFO-1234ze. The key drivers for change include recognition under both Greenstar and National Australian Built Environment Rating System (NABERS) building rating schemes, and consulting engineers more routinely specifying HFOs. This is particularly the case with larger water-cooled units which have a longer life span where the market penetration is now estimated to be above 30% of new units sold. Smaller air-cooled units are more likely to use HFC-134a due to price pressures, especially in ‘Design and Construct’ projects.

HFO-1233zd and HFO-1336mzz have also exhibited growth in the Australian market in the chiller sector, mostly within new-build applications. Low pressure HFO chillers are less commonly used in retrofit projects due to plant room size constraints.

As imports of HFO PCE and bulk HFOs are not reportable under current regulatory arrangements, reliable sources of data on import and use of HFOs are still being developed with industry. Volumes of these refrigerants consumed as bulk refrigerants in 2021 is estimated at around 33 tonnes at the time of writing.

7.2 HFO/HFC blend refrigerants

HFO/HFC blends have also been slow to penetrate the Australian market - bulk imports have been 42, 48 and 39 tonnes respectively in 2019, 2020 and 2021. Imports have been dominated by ASHRAE A1 rated blends R448A (GWP of 1386), R449A (GWP of 1396), R452A and some R513A (GWP of 629) which have the flexibility to be used in either retrofit applications to extend the life of existing equipment, or in new installations. R448A and R449A have seen increased volumes in PCE entering Australia, especially from Europe where HFC-404A has been banned in new equipment. R448A and R449A offer lower GWP and higher energy efficiency than existing HFC solutions, especially in high ambient temperature conditions.

Use of R448A and R449A in retrofit applications has been slow to be adopted in Australia when compared to New Zealand, where its adoption has in part been driven by an emission trading scheme that applies a CO_2e value to refrigerants, and the UK and the EU that both employ a more stringently regulated HFC phase-down than required to meet their obligations under the Montreal Protocol. The slow pace of change to these higher efficiency lower GWP refrigerants is thought to be due to HFC-404A still enjoying ready availability in the Australian market and relatively low price in comparison to R449A and R448A.

The major supermarket chains in Australia have generally chosen to transition to new trans-critical CO_2 racks when refurbishing existing stores rather than perform retrofits and prolong the life of existing assets with HFO blends. However, one major supermarket chain has an active program to retrofit stores operating on HFC-404A when undertaking refurbishments and efficiency upgrades. Fifty stores had been completed at the time of writing and a further 30 to 40 are planned to be refurbished per annum.

R452A (GWP of 2139) is now the refrigerant of choice in transport refrigeration due to its similar characteristics to HFC-404A (GWP of 3,922), its lower GWP and ability to operate in both medium and low temperature applications. R452A usage is expected to continue to grow in this sector in the short term before a lower GWP option emerges to replace it.

While it is early days in the acceptance of HFO/HFC blends in the market, their adoption in some populous classes of equipment, such as the use of R448A, R449A, R450A, R452A, and R455A in commercial refrigeration applications, is a trend that will be watched closely in subsequent editions of Cold Hard Facts. The volumes of R448A and R449A imported as bulk refrigerant equate to just over 4% of usage of HFC-404A in 2021. A modest start as compared to the scale of the bank and annual consumption of HFC-404A, but sufficient to demonstrate that the market adoption of this refrigerant has commenced.

HFO/HFC blends observed in chillers in Australia were R513A and R514A. There were 7.2 tonnes of R513A imported in 2020 and only 1.3 tonnes in 2021. A non-HFC blend, R515B (containing R1336mzz(Z) and R1130(E) with a GWP of 2) is expected to grow over the next couple of years as an alternative to HFO-1234ze in enclosed plant rooms, due to flammability concerns about the latter.

Other HFO/HFC blends emerging globally are the A2L classified R452B, R454A, R454B, R454C and R457A that are exhibiting some growth in the European market. The A2L blends are reaching the Australian market predominantly through PCE imports from European, USA and some Japanese manufacturers. The largest uptake has been of R454B (GWP of 465) in scroll chillers. In 2021 bulk imports of R454B was 0.8 tonnes and demand is expected to grow in the years ahead.

7.3 Natural refrigerants

Natural refrigerants are employed to some extent in most RAC technology segments, although with minimal use in stationary air conditioning, other than small portable units.

Commercial and domestic refrigeration has led the way in the adoption of natural refrigerants. The transition of domestic refrigeration equipment to hydrocarbons (HC), 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 HCs. In more recent years this move to HCs in domestic refrigeration has extended to smaller commercial equipment in Australia with around 10% of the refrigerant bank in self-contained commercial refrigeration equipment now being HC and expected to grow rapidly. HC use in small commercial refrigeration equipment is now the norm in Europe - equipment trials in the sector signal that this is a trend that is likely to be followed in Australia in applications where a charge up to 494 grams is permitted by *AS/NZS 60335.2.89: 2020*.

HC is starting to be used in new applications overseas, for example in self-contained monoblock units for small walk-in cold rooms. These are referred to in Australia as 'drop-in' or 'slide in' units and are now available in the EU and USA operating on R290 with charges less than 150 grams per circuit (ZA 2022, HM 2022).

While no Australian suppliers are currently offering remote condensing units on HC, smaller capacity models less than 1 kWr are expected in the years ahead. Embraco showcased its range of R290 condensing units at Chillventa 2022 in Nuremberg, Germany, October 2022 (EM 2022).

CO_2 refrigerant is firmly entrenched in the mainstream supermarket sector with larger commercial refrigeration systems. It is increasingly employed in supermarket rack systems and food processing applications, in a number of highly efficient options including CO_2 only trans-critical systems, CO_2/ammonia chillers, and CO_2/brine 2 stage cascade refrigeration systems.

This trend is accelerating in larger supermarkets with the focus primarily on trans-critical systems, largely because of the low GWP of the refrigerant being in line with corporate sustainability programs and the journey towards net zero (CG 2021). Smaller trans-critical CO_2 condensing units with capacities up to 15 kW, which are suitable for small format supermarkets, convenience stores, liquor outlets and fast-food chains, have recently become available in the Australian market.

The volumes of CO_2 refrigerant used, primarily in the supermarket sector is estimated at around 230 tonnes in 2021.

Ammonia continues to dominate the industrial refrigeration market including large cold storage distribution centers, abattoirs and industrial chillers used in process cooling.

Ammonia volumes used are generally driven by large capital works and ongoing maintenance of existing systems with annual volumes fluctuating accordingly. The 7-year average annual usage from 2014 to 2020 estimated at almost 690 tonnes is thought to contain around 20% non-RAC applications. The 2021 estimate of 538 tonnes mostly includes RAC applications.

Improvements in data collection to track ammonia in RAC applications will be required in future years as more hydrogen energy system applications that use ammonia as the storage medium begin to develop.

Table 6: Volumes of ammonia and hydrocarbon sold by calendar year (tonnes)

Species	2014	2015	2016	2017	2018	2019	2020	2021
Ammonia	837	712	577	722	643	684	634	538
Hydrocarbon	82	75.0	72	78	88	101	106	110

Volumes exclude non-HVAC&R (heating, ventilation, air conditioning and refrigeration) applications. 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. Includes estimates of some participants and volumes include export.