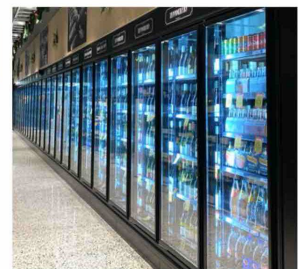
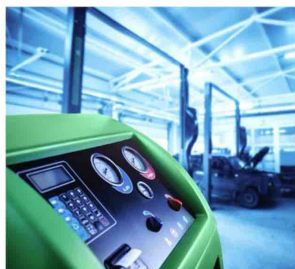


Cold Hard Facts 2021



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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

A significant slowing trend in the rate of growth of the regulated bank of refrigerants in Australia for the period from 2016 to 2019 to just 1.8% compound annual growth in metric tonnes, as reported in Cold Hard Facts 2019, has been confirmed in 2020 with no significant growth in the bank at all in the period, despite surprisingly strong equipment sales.

The confirmation of this trend flattening combined with increasing use of lower global warming potential (GWP) refrigerants, indicates that the GWP value of the Australian bank of refrigerants reached its peak in 2019-20. Current modelling projects a steady decline in the years ahead as the combination of several trends in the refrigeration and air conditioning (RAC) industry accelerates a reduction in the average GWP of the bank.

Zero growth of the refrigerant bank has been driven in part by a softening of RAC equipment sales in 2018 and 2019 across nearly all major equipment segments, in line with softer economic conditions. Growth in the bank of refrigerants has also been curtailed by new equipment designs and new generations of lower GWP refrigerants that require smaller charge sizes to deliver equivalent refrigeration services.

Adoption of natural refrigerants in some segments, particularly in self-contained commercial refrigeration, is displacing traditional hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbon (HFCs) applications - even while the stock of equipment is growing.

A leading example of this trend to reducing the GWP of the refrigerant bank is HFC 32, which has now overtaken HFC-410A in pre-charged equipment imports for the first time and which has grown by 30% in 2020 based on metric tonnes, compared to the previous year.

Adoption of HFC-32 as a more energy efficient, smaller charge and lower GWP alternative to HFC-410A in non-ducted split system stationary air conditioning (AC) segments has now stopped the growth of the HFC-410A share of the bank. HFC-32 is also starting to make an appearance in larger AC applications including split ducted systems and chillers with charges up to 100 kilograms (kg) seen in the market.

Trends observed in 2018 and 2019 of growth in the adoption of natural refrigerants and hydrofluoro olefin (HFO)/HFC blends have been confirmed in 2020 with hydrocarbon (HC) charges smaller than 150 grams in refrigerated display cabinets being a stand-out example of the rapid rate of 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 observed. Portable air conditioners have also rapidly transitioned to HC-290. This transition is noted in several registers including the Greenhouse and Energy Minimum Standards (GEMS) register where, as at 1 July 2021, 83% of portable air conditioners registered contained HC.

Finally, 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. Of the 917,000 new vehicles imported into Australia in 2020 almost 15% were estimated to contain HFOs.

Despite a concerted move by major supermarket chains to deploy trans-critical carbon dioxide (CO₂) charged refrigeration systems, the refrigerated cold food chain maintained refrigerant demand for service and charges for new equipment of more than 850 tonnes of HFC-404A used in 2020. This level of demand has been consistent over the past five years.

Rapid emergence and adoption of a wide range of 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 driving more of the stock of equipment to lower GWP natural refrigerant options and HFOs. In many instances these alternative refrigerants can deliver the same refrigerating capacity with lower energy consumption.

As predicted in earlier editions of Cold Hard Facts the evidence suggests that the peak carbon dioxide equivalent (CO₂e) value of the bank has likely been reached in the past 12 months. Continuing improvements in the energy efficiency of the stock of equipment could also see peak energy related emissions reached in the decade ahead, even though the stock of equipment is expected to grow.

These trends are expected to continue and accelerate in the decade ahead. However, with an existing refrigerant bank in installed equipment that has a total global warming potential of approximately 100 million tonnes (Mt) CO₂e, efforts at improved containment and effective recovery of refrigerants will be important to continue to drive down the total environmental impact of RAC services in Australia. Recent work by the CSIRO estimates that HFC emissions in Australia have been growing at 5% per annum since 2005 (CSIRO 2021).

2 Introduction

Cold Hard Facts (CHF) 2021 is the sixth edition of the CHF research series investigating the scale and impacts of the ‘cooling economy’ in Australia. 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 more than \$44 billion, or around 2.2% of Australian gross domestic product (GDP) in 2019 (ABS 2021a). This is an increase of more than 6% over the previous year, a rate of growth significantly greater than general economic growth.

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 industry export targets.

While the refrigerated cold food chain is only one part of the total cooling economy, and not the largest, recent studies have underlined the potential for improvements in design and operation of the cold food chain to mitigate several related environmental and economic issues. In 2020, a report prepared by the Expert Group produced, for the first time, estimates of food waste attributable to breaks and deficiencies in the cold food chain in Australia. Preliminary 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. The report estimated greenhouse gas emissions from food waste attributable to sub-par practices in the cold food chain at 7.0 million tonnes (Mt) CO₂e in 2018, equivalent to about 1.3% of Australia’s annual greenhouse gas emissions in that year (DAWE 2020b).

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 four 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.

3 The scale of the cooling economy

The RAC Stock Model calculates that RAC services in Australia in 2020 were delivered by more than 58.1 million pieces of equipment (CHF3 2016, 53.6 million) employing a refrigerant bank of high GWP regulated gases of more than 53,400 tonnes. The stock model calculated that in 2020 Australians spent around \$9.3 billion purchasing and installing new devices across all classes of RAC equipment, total spending that was up more than 10% compared to 2019.

This stock of equipment is estimated to have consumed more than 65,750 gigawatt hours (GWh) of electricity in 2020, or around 25% of all electricity produced in Australia that year, a small increase on the prior reporting period. Electricity generation was estimated to be 265,232 GWh in calendar year 2020, remaining materially unchanged since 2019 at 265,117 GWh (DISER 2021a). Electricity related greenhouse gas (GHG) emissions plus direct emissions to air of around 3,300 tonnes of HFC refrigerant from operating equipment, mean that RAC equipment produced around 61.3 Mt CO₂e of GHGs or approximately 12% of Australian national GHG emissions (using the rolling 12 month estimate of emissions to September 2020 of 510.1 Mt CO₂e) (DISER 2021b).

Tables 1 and 2 below list the main metrics produced by the RAC Stock Model for 2020 and in 2016 for comparison.

Table 1: Main refrigeration and air conditioning metrics for 2020

Metric	Units	Air conditioning	Mobile air conditioning	Refrigerated cold food chain	Domestic refrigeration
Share of refrigerant bank	Percent	64.0	20.0	13.0	3.0
Size of refrigerant bank	Tonnes	34,200	10,800 a	7,100	1,300 b
Annual usage of HFCs to replace leaks (excl. charging new equipment)	Tonnes	735	752	911	3.4
Refrigerant in pre-charged equipment imports c	Tonnes	2,272	490	127	22 d
Estimated stock of equipment	Million units	> 16.4	> 19.4	1.8	20.3 b
Annual electricity consumption e	GWh	36,750	200 f	19,900	8,900
Share of RAC electricity consumption	Percent	56.0	0.3	30.0	14.0
Annual GHG indirect emissions	Million tonnes CO ₂ e	28.66	2.93 f	15.77 g	6.94
Share of RAC indirect emissions	Percent	53.0	5.0	29.0	13.0
Annual GHG direct emissions (ODS) h	Million tonnes CO ₂ e	0.31	0.003	0.07	0.00
Annual GHG direct emissions (SGG)	Million tonnes CO ₂ e	2.11	1.42	3.06	0.02
Share of RAC direct emissions	Percent	35.0	20.0	45.0	0.3
Share of RAC total emissions (direct and indirect, not including end of life)	Percent	51.0	7.0	31.0	11.0

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 350 tonnes are refrigerants with a GWP<10. **b** The Cold Hard Facts 2021 model has been updated to include additional sales and incorporate a shorter lifespan for domestic refrigerators and freezers of 15.5 years. Total stock includes small refrigerators including portable and automotive refrigeration. There is an estimated 10.2 million devices containing HC-600a in 2020. **c** HFC substances in pre-charged equipment imports in non-RAC categories was 313 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 event rather than a trend. **e** The electricity consumption estimate does not take efficiency improvements into account that may have been captured by new equipment additions to the stock from 2016 to 2020 and is based on assumptions used in Cold Hard Facts 3 published in 2016. **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	61.0	21.0	14.0	4.0
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	0.3	31.0	14.0
Annual GHG indirect emissions	Million tonnes CO ₂ e	30.44	2.96	17.53	7.77
Share of RAC indirect emissions	Percent	52.0	5.0	30.0	13.0
Annual GHG direct emissions (ODS) b	Million tonnes CO ₂ e	0.72	0.01	0.13	0.00
Annual GHG direct emissions (SGG)	Million tonnes CO ₂ e	1.47	1.24	2.91	0.05
Share of RAC direct emissions	Percent	34.0	19.0	46.0	0.8
Share of RAC total emissions (direct and indirect, not including end of life)	Percent	50.0	6.0	32.0	12.0

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 to be operational 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 recovery and destruction, for many years into the future.

Each of the four 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

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) or cooling only and includes heat pumps for water heating, swimming pools and other applications. Equipment in this class ranges in size from small 2 kW_r (kilowatts of refrigeration capacity) portable air conditioners, with a refrigerant charge of less than 600 grams, to large 4,000 kW_r commercial space chillers containing more than a tonne of refrigerant in a single machine. Evaporative air conditioning, that does not use a vapour compression cycle, is not included.

The four major segments and eighteen product categories that make up this class (see Taxonomy, Appendix A) account for approximately 64% of the bank of refrigerant in Australia (CHF3 2016 61%), or around 34,200 tonnes (CHF3 2016 31,200 tonnes), contained in more than 16.4 million devices.

Stationary air conditioning used more than 39% of the 3,231 tonnes of bulk HFC refrigerants imported in 2020. An estimated 1,263 tonnes of HFCs was used for servicing, charging new equipment that was imported without refrigerant or equipment that required additional charge (such as for longer pipe runs at installation), 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.

While sales of single split systems including wall hung, cassette, consoles and ducted systems were up by 5% compared to 2019, sales were still short of the all-time peak hit in 2017 of 1.3 million units per annum.

Single split system sales in 2020 are estimated at 1.22 million, comprising 1.06 million non-ducted split systems and 159,000 split ducted systems. There were a further 35,000 sales of multi split systems, excluding variable refrigerant volume/frequency (VRV/F) systems and more than 250,000 small self-contained AC including window/wall units and portable AC. The very large majority of portable AC sold in 2020 (>80%) were charged with HC-290 refrigerant.

This is the fourth 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 13.5 million small AC and 3.0 million medium AC devices after retirements.

The transition of small split systems to the A2L (low toxicity, slightly flammable) refrigerant HFC-32 is progressing rapidly, with year-on-year growth of more than 31% of the installed HFC-32 bank in small split systems from 2019 to 2020. As a result, the stock of HFC-32 charged non-

ducted single split systems made up more than 30% of the equipment in this category in 2020. HFC-32 is displacing the once nearly universal use of the high GWP HFC-410A in this equipment segment.

As a result, the HFC-410A bank in the small non-ducted split systems bank showed a slight year-on-year decline towards 9,600 tonnes by the end of 2020. This trend is expected to continue in years ahead, with a five year decrease in the HFC-410A bank in small AC split systems segment of some 41% expected by 2025, to just over 5,600 tonnes, as older equipment is taken out of service. The new designs and improved refrigerant containment employed in the HFC-32 charged small AC equipment also means this equipment experiences extremely low leak rates, ensuring more years of operation at close to optimal charge.

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 seen in the market. In 2020 there were more than 1,400 large AC devices imported with a charge greater than 12 kg, of which 35 contained in aggregate 9.0 tonnes of HFC-32 (10% by refrigerant volume). There were more than 68,000 devices imported in the same year containing between 2.6 kg and 6.0 kg of HFC-32. This equates to 25% of all models imported in this size category based on refrigerant weight and 33% based on total units that contained HFC-32. By the end of 2020, there was an estimated bank of more than 4,293 tonnes of HFC-32 in the country across all types of stationary AC, an increase of 30% on 2019.

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. Scroll chillers, that would previously have used HFC-410A, are now being manufactured with HFC-32 for instance.

HFC-32 is being offered in large AC with some manufactures offering chillers from 70 kW up to 700 kW, using HFC-32 charges 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. Daikin now has an extensive range of chillers operating on HFC-32 with nominal capacities ranging from 81 to 701 kW and charge sizes up to 100 kg.

The volumes of HFC-134a refrigerant imported in equipment with charges greater than 20 kgs has declined to 41.3 tonnes in 2020 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 charged on-shore rather than being imported charged.

On the back of the widespread adoption of HFC-32, technology developers are continuing the trend of developing new 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, in 2019 a small numbers of chillers with charge sizes ranging from 273 kg to 2,815 kg were imported pre-charged with HFO/HFC blend R514A, which has a GWP of just 2.

Another relatively new, lower GWP blend being reported in small and medium sized chillers with charge sizes up to 318 kg is R513A, a HFO/HFC blend with a GWP of 629 that is being promoted as a drop-in replacement for HFC-134a, previously the most widely used HFC in chillers.

The emergence of new blends and new refrigerants is expected to be a continuing trend throughout the next two decades, driven by the need for improved energy efficiency and demand for lower GWP refrigerants. At present the proportion of lower GWP refrigerant alternatives 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 five 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 to understand their properties.

Pure HFOs, that mid-last decade had been predicted by industry to grow rapidly in MAC in Australia, 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. Every leading chiller manufacturer is currently offering equipment charged with pure HFOs, with screw chillers available charged with R1234ze and centrifugal chillers using R1233zd. However total sales of pure HFO charged stationary equipment is starting from a very low base and is estimated at no more than 5% of total sales in 2020.

4.2 Mobile air conditioning

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

These two segments and the twelve product categories in this class make up the second largest portion of the total bank of working refrigerants, containing approximately 20% of the bank in Australia, or around 11,200 tonnes in more than 19.4 million vehicles of all sorts (CHF3 2016, 21%, 10,800 tonnes and 18.2 million vehicles).

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 2020. 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 2020 service usage of 681.2 tonnes is a very robust value, based on seven consecutive years of surveying of after market participants. The 2020 service use is up 10% compared to the seven year average of 620.2 tonnes from 2014 to 2020.

HFOs that had been predicted to appear in the Australian market soon after release into international markets from around 2011 have, on the basis of available data, finally began to be employed in a portion of new cars sold in 2020. As HFOs are not regulated and the import of HFOs is not reportable, changes to year-on-year sales and changes to numbers of vehicles imported with HFC charged systems have been used to deduce the likely volume of HFOs imported in MAC.

There were 916,968 new vehicles sold (including passenger vehicles, SUVs and light trucks) in Australia in 2020 dropping by nearly 14% from 2019, making 2020 the lowest year for new vehicle sales since 2003. Based on the reported number of new vehicle imports containing HFCs

we estimate that around 15% of all MAC imported in 2020 were charged with HFO-1234yf. This is a significant increase on 2019 when first HFO imports were apparent and during which period we estimate 5% of all MAC imported were charged with HFOs.

Research conducted in the USA, Europe and Japan in 2020 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 USA and Europe now containing HFO-1234yf, and around 60% in Japan.

The countries of origin of the vehicles sold in Australia in 2020 were Japan 34%, Thailand 23%, South Korea 13%, Germany 6% and USA 4%. Auto-makers in the EU-15, including the UK, and the USA have mostly transitioned to using HFO-1234yf in MAC in their local markets. Japan is transitioning slower than the other two major markets, however, it is a compliant market that will achieve its regulatory requirements that sets a limit of 150 for the GWP of refrigerants in mobile air conditioning systems by the end of 2023. These countries (Japan, USA and EU-15 including UK) supply 49% of imported vehicles sold in Australia in 2020.

Despite this approximately 85% of vehicles imported by the twenty market leading brands sold in Australia are still primarily reporting HFC 134a charges of pre-charged equipment imports.

Combined with interviews with dealers, the evidence indicates that some of the largest selling brands, such as Toyota and Hyundai, had not yet commenced importing systems charged with HFOs into Australia during 2020. However, the data does suggest several brands had commenced imports of some models with HFO, including Japanese auto makers Mazda, Nissan, Honda and Suzuki, and a number of USA and European brands including Ford, Holden, BMW and Renault. In total however, the 2020 total volume of HFO imports in MAC would be less than 15% of all refrigerant imported in MAC that year.

The single biggest supplier to the Australian market, Toyota, has just commenced imports of HFO charged MAC at the time of writing, according to their largest service centre, the Kluger being the first model to feature this very low GWP refrigerant.

All indications are that, despite the very slow start to transitioning the MAC fleet to HFOs, the change will now be quite rapid and Expert Group projects that by 2025 at least 50% of all new passenger and light commercial vehicles imported will contain MAC charged with HFOs.

Whilst CO₂ 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, a range of modular rooftop units for bus air conditioning was showcased at the BusWorld exhibition in Rome in 2019. It employed a flammable refrigerant as the primary refrigerant, isolated from the passenger cabin via a glycol secondary loop to deliver comfort conditions to the occupied space. 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 have been no reported movement away from HFCs in locomotive or passenger rail air conditioning in Australia at the time of writing.

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 cool rooms and milk vats used inside the farm gate and blast freezers on fishing vessels and in abattoirs - systems at the point of production of food - 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 are several notable trends in this class of equipment, including:

The continuing evolution of advanced refrigeration systems seeking higher energy efficiency with lower GWP refrigerants. This trend initially saw the adoption CO₂/HFC two stage cascade systems, although in more recent years there has been accelerated deployment of 'CO₂ only' trans-critical refrigeration systems in new supermarkets in plant rooms.

In the self-contained refrigerated display cases categories 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 50% of all sales in this category in 2020. The charge size limit in Australia means that manufacturers are focussed on delivering HC charged equipment in the common smaller formats for catering equipment, storage cabinets and two/three door display cabinets. Major manufacturers are reporting a concerted move to transition most of their designs to HCs. It is reasonable to assume that most new sales across smaller commercial refrigeration formats will employ HCs within the next three 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 trialled in the market. These blends also 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 and R452A. In recent years these blends were used in possibly only 1 or 2% of total display case sales. In May 2019 the 150 gram HC charge threshold was increased in Europe to around 500 grams in self-contained refrigeration so larger HC charged equipment formats are being developed, tested and deployed in the market and are expected to be ready for deployment into the Australian market within the year. 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 of the standard for R290 charge sizes >150 grams and <494 grams). This development is 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. 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.

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 to operate on a range of HFO/HFC blends, including R454A, R454C and R455A. In Australia the blends offered on remote units were primarily HFC-448A and HFC-449A with an estimated 10 to 20 tonnes sold in 2020 to charge remote units and rack systems with these blends. While refrigeration compressors are now rated for a variety of blends, the main refrigerant of choice in this sector in Australia is still HFC-404A with 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.

4.3.1 Transport refrigeration

Road transport refrigeration technology is made up of:

- the 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; and,
- off-engine vehicle powered refrigeration units used on small trucks and vans.

Trailer/intermodal and diesel drive single temperature units from Europe are imported fully charged, tested and ready to be fitted. These configurations are now rapidly transitioning from HFC-404A to HFO/HFC blend R452A (GWP of 2,139) with improved designs and smaller refrigerant charges by around 25%. As this market is dominated by two main companies, Thermo King and Carrier Transicold, the transition of new sales is expected to be complete within one to two years.

Diesel powered trailer and truck multi-temperature units are still predominately charged with HFC-404A, with no changes expected to emerge in the Australian market within the next couple of years. Off-engine vehicle powered refrigeration units on small trucks and vans transporting chilled goods are mostly HFC-134a.

The fishing fleet still has limited refrigerant options suitable to the conditions and able to be employed in the existing fleet. In 2012 more than 95% of the 52 long distance vessels that operate in the northern prawn fishery of Australia were using HCFC-22, with just a few employing HFC-404A. These vessels had typical blast freezing capacity of three tonnes of prawns per day. In the intervening eight years the risk of, and the cost of HCFC-22 supply resulted in many of the vessels transitioning to HFC-438A (GWP of 2,264) which is a HCFC-22 drop-in replacement. 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 50% operating on HFC-438A, 42% use HFC-404A/507A and the refrigerant employed in 8% is unknown.

A small mackerel fishing vessel of around 14 meters in length was recently fitted out with equipment containing a charge of around 20 kg of R448A for freezing and chilled brine for a temporary storage tank. This is the first application of a HFO/HFC blend in the sector and according to the specialist contractor the trial is demonstrating promising results.

New designs for larger fishing vessels using ammonia charged refrigeration are starting to enter the market. In 2020 Austral Fisheries took delivery of a new 68 metre vessel, the Cape Arkona out of Norway, primarily to fish for Patagonian Toothfish in the Southern Ocean. This vessel has an on-board fish processing and blast freezing capacity of 50 tonnes per day operating on ammonia contained in a dedicated refrigeration plant room. However, like many other types of commercial and industrial equipment, fishing vessels are designed to have very long operating lives. As such, the turnover of the fishing fleet, and thus opportunities for the introduction of new refrigeration systems, is expected to proceed relatively slowly. While this is one example of a fishing vessel operating on a very low GWP refrigerant, most vessels in the Australian fishing fleet have limited refrigerant options, as smaller vessel size means a dedicated refrigeration plant room is not possible.

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 2020b), produced estimates of food waste attributable to breaks and deficiencies in the cold food chain in Australia for the first time. 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; and
- 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 CO₂e 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 CO₂e). These estimates of emissions resulting from food waste are based on globally accepted estimates of greenhouse gas emissions intensity to produce various food types.

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 2020 containing HC refrigerant. In 2019 just 10.8 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 imported in domestic refrigerators in 2008.

In 2020 there was a spike in HFC-134a imports in domestic refrigerators to 21.6 tonnes possibly a consequence of COVID lock downs as many domestic refrigerators ran out of stock at the beginning of the pandemic lock downs. A large spike in sales of domestic freezers was observed due to COVID lockdowns from 189,000 in 2019 to 318,000 in 2020.

Outdoor camping and caravan refrigerators were also in short supply. 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 HC charges, the proportion of HC charged domestic refrigerators and freezers in the stock of equipment has grown strongly since 2012, with an estimated 50% of the stock (~10.2 million devices) containing HC-600a in 2020. 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 2021 model has been updated to include additional sales (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 later 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 three major equipment classes.

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 Depleting Substances and Synthetic Greenhouse Gas Management Act 1989*. The regulated bank is comprised of HCFCs and HFCs.

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 1, 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 2020. This strong overall growth in the refrigerant bank 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), up to the peak in sales reached in 2017.

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.

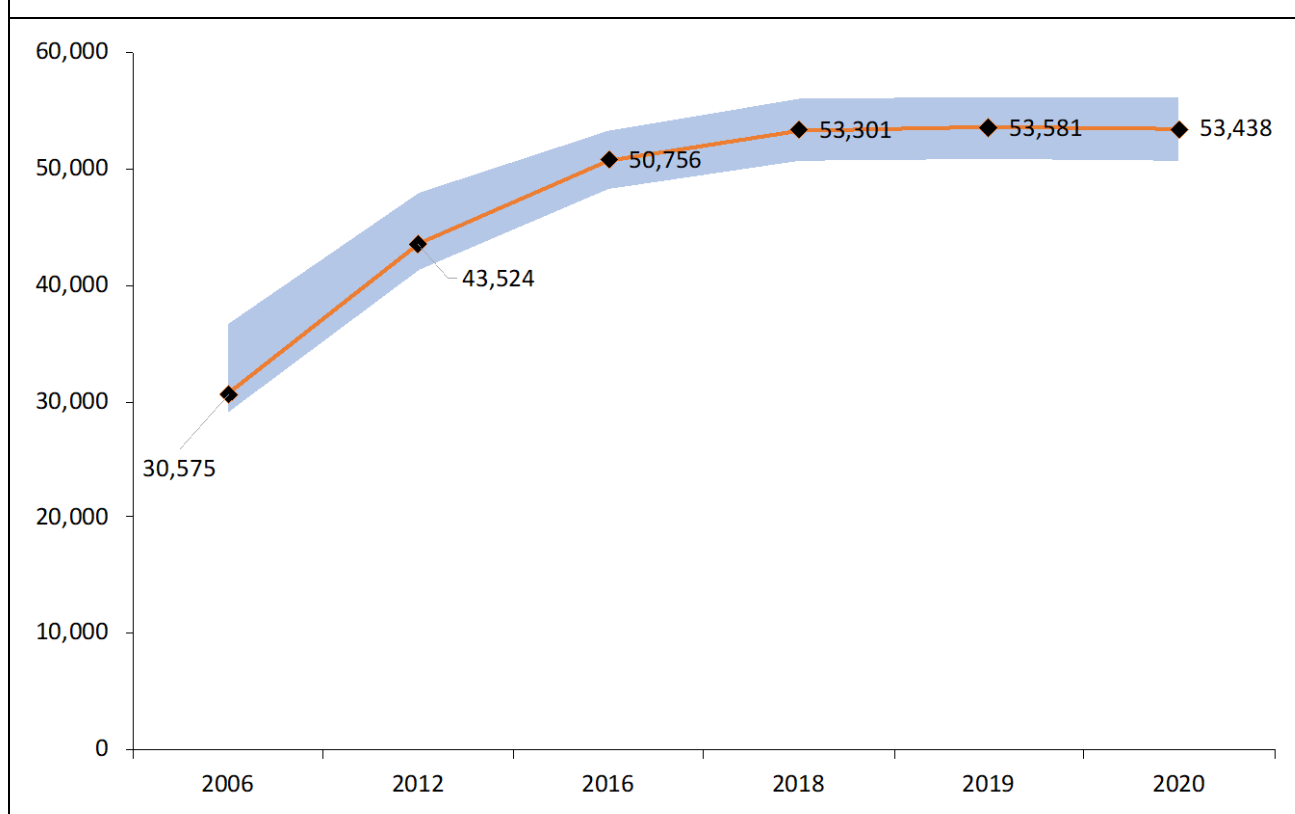
The growing community-wide acceptance of and dependency on AC, and widely held expectation of AC comfort in all forms of buildings, was reinforced by changing climatic conditions that have seen five of the hottest years on the planet ever recorded in the past seven (NASA 2021). This trend that drove growth in the stock of medium and large commercial systems since the late 1990s has resulted in significant commercial and public buildings being nearly universally serviced by air conditioning in Australia by 2020.

The near comprehensive adoption of mobile 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. This sector is also directly affected by hotter temperatures.

The total bank in 2020 is estimated at approximately 53,438 tonnes (CHF3 2016, 50,756 tonnes). This is the slowest rate of growth in the bank since the research series began in 2006.

Despite continuing strong growth in recent years in AC and commercial refrigeration equipment stocks, a trend commencing in 2016 of significantly slowing growth in the total bank of regulated refrigerants has now consolidated, and Expert Group predictions of an approaching ‘peak bank’ appear to be confirmed.

Figure 1: The HCFC and HFC Refrigerant bank from 2006 to 2020 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 point 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. However, from 2016 to 2020 the bank of HFCs and HCFCs has only increased slightly more than 5.5%, achieving a compound annual growth rate of just 1.8%.

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, additional to large ammonia charged systems, there is estimated to be slightly more than 1,500 metric tonnes of non-HFC natural and low GWP refrigerants with a GWP<10 in use in the stock of equipment in 2020, an increase of more than 16% from 2019. While this low GWP refrigerant bank is only equivalent to slightly less than 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

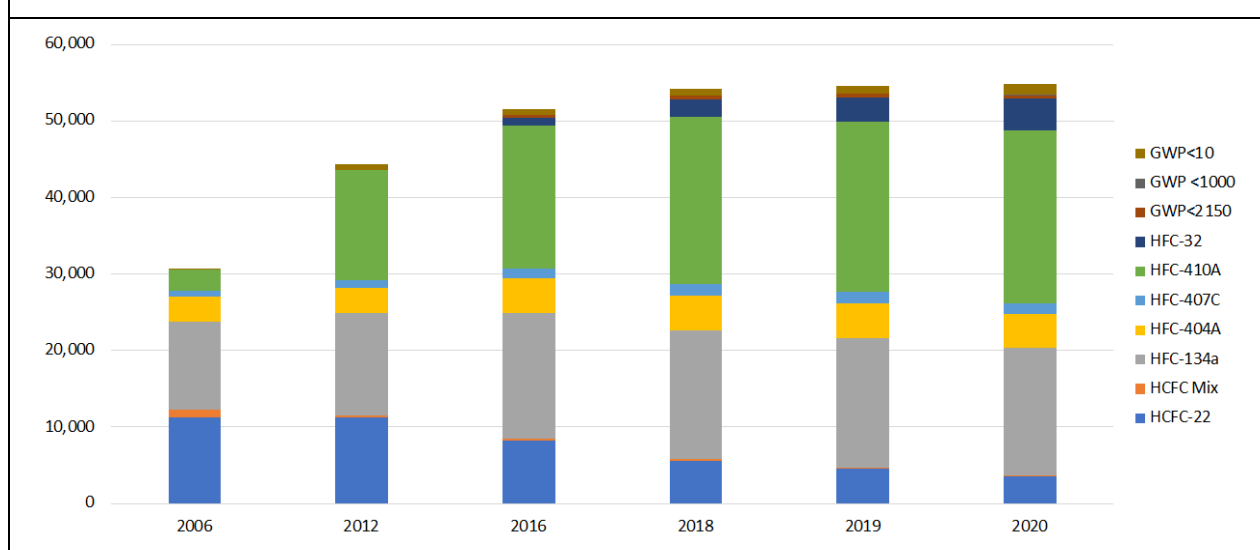
Protocol. This global action is driving increasing diversity in the refrigerants available as a fourth generation of refrigerants is developed and tested, and proven natural refrigerants find wider applications.

5.1 Constituents of the bank, GWP and CO₂e

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

- HFCs comprise 49,800 tonnes, or 93% 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 make up 3,700 tonnes or 6.9% 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 economy and the environment well towards the end of the 2020s.
- The bank of natural refrigerants in commercial refrigeration and mobile applications in 2020 is estimated at around 1,500 tonnes (up quite strongly from 700 tonnes in 2016). Natural refrigerants are a group of refrigerants including ammonia, HC and CO₂, 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 5,000 tonnes of ammonia in use in the cold food chain, the vast majority of which is in large chilling, blast freezing and ice making systems in the primary and secondary stages of the cold food chain, and in large cold storage distribution centres. These ammonia refrigerants are not included in the estimate of the bank in 2020 as illustrated in Figure 2.
- 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. In 2020 there was no significant volume 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 2020.

Figure 2: Refrigerant bank by species 2006, 2012, 2016, 2018, 2019, 2020 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 rapid adoption of small and medium AC, coupled with the rapid growth of HFC 410A between 2006 and 2018 and the shift away from HCFCs, can be seen in the slow decline of HCFC-22, which in the early years of the century was the largest single component of the bank.

The move from HCFC-22 to HFC-410A as the predominant refrigerant charge in small and medium stationary AC started around 2005. This occurred around the time small and medium AC sales 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. The decade-long million-plus annual unit sales has built a stock of more than 10.6 million HFC-410A charged pieces of equipment, containing a bank of more than 22,500 tonnes of HFC-410A, representing more than 42% of the entire bank.

This growth in HFC-410A from just 9% of the bank (2,800 tonnes) in 2006 to around 22,500 tonnes in 2020 means that HFC-410A is now the largest single component of the bank, surpassing HFC-134a. The HFC-410A bank is now more than six 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 2020 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 31.2% of the total bank in 2020.

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 declined slightly with now an estimated 4,400 tonnes in 2020 representing just 8.3% 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 4,200 tonnes in 2020. This growth is occurring largely at the expense of the much higher GWP HFC-410A. HFC-32 made up 8% of the bank in 2020, 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 2020 HFC-407C had grown to just under 1,500 tonnes although was still only 2.8% of the overall bank.

HCFC-22 as a proportion of the total bank has declined from 37% in 2006 to 6.6% in 2020.

Previously HCFC-22 was the refrigerant of choice in air conditioning 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 9,000 tonnes from that high point, a drop of more than two thirds, 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.

Despite the ban on import and manufacture of HCFC charged equipment, small quantities of HCFC pre-charged equipment are still able to be imported under special exemptions, mainly as replacement parts for condensing units to match evaporators of air conditioning units already installed.

Expert Group analysis indicates that the tail of greatly reduced HCFC-22 bulk imports until the end of 2029 may not be sufficient to meet demand for service and repair of the remaining HCFC charged equipment. Forecast service demand for HCFC-22 can be met by recovering and recycling much of the remaining bank of HCFC-22 as older equipment is retired or retrofitting a suitable refrigerant. Additional HCFCs, above the import cap, will be required for service and maintenance until at least 2025. In the case of HCFC 123, which is employed in long lasting, large, and expensive chillers, the service requirement is likely to continue for at least another decade.

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.

The first signs of prices of HCFC-22 softening have appeared in the market in 2021, suggesting the volumes of refrigerant recovered plus the import cap is satisfying or slightly exceeding demand.

Given the active market for reconditioned HCFC-22, it would be reasonable to expect the rate of decline in the HCFC-22 bank to slow, with the last generation of HCFC-22 charged equipment, installed as late as 2011 and 2012, potentially being maintained on 100% recycled and reconditioned refrigerants into the early 2030s.

However, predicting the future rate of change in the bank of HCFCs is complicated as market intelligence suggests an increasing amount of unreported HCFC-22 recovery and direct reuse by contractors, the relative cost and benefits of maintaining older equipment, and the changing market prices for recycled HCFC-22.

The table below contains the data from which Figure 2 was produced. The tabulated data of the bank by species notably shows the emergence in 2016 of HFC-32 as a component of the overall bank. HFC-32 with a GWP of 675, as compared to HFC-410A with a GWP of 2088, is expected to cap the overall GWP intensity of the refrigerant bank as it becomes the most common refrigerant employed in the extensive stock of small AC.

Table 3: Refrigerant bank 2006, 2012, 2016, 2018, 2019 and 2020 by mass in tonnes and share in percent

Species	2006 a		2012		2016		2018		2019		2020	
	Tonn es	Shar e %	Tonn es	Shar e %	Tonn es	Shar e %	Tonn es	Shar e %	Tonn es	Shar e %	Tonn es	Shar e %
HCFC-22 b	11,280	37.0	11,227	26.0	8,283	16.0	5,605	10.9	4,475	8.7	3,503	6.9
HCFC Mix	1,000	3.0	201	0.0	217	0.0	199	b	190	b	182	b
HFC-134a	11,389	37.0	13,432	31.0	16,343	32.0	16,803	31.5	16,933	31.6	16,662	31.2
HFC-404A	3,412	11.0	3,306 c	8.0	4,547	9.0	4,560	8.6	4,501	8.4	4,421	8.3
HFC-407C	711	2.0	1,017	2.0	1,336	2.6	1,492	2.8	1,519	2.8	1,475	2.8
HFC-410A	2,783	9.0	14,341	33.0	18,660	37.0	21,893	41.1	22,262	41.5	22,529	42.2
HFC-32	0	0.0	0	0.0	1,035	2.0	2,286	4.3	3,245	6.1	4,217	7.9
GWP<21 50 d	0	0.0	0	0.0	336	0.7	432	0.8	418	0.8	406	0.8
GWP <1000	0	0.0	0	0.0	0	0.0	31	0.1	37	0.1	43	0.1
Total HCFCs and HFCs	30,575	100	43,524	100	50,756	100	53,301	100	53,582	100	53,438	100
GWP<10 e	100	-	799	-	737	-	902	-	1,018	-	1,396	-

(Sources: Expert Group Data and Analysis, CHF1, CHF2 and CHF3 RAC Stock Models)

CHF Cold Hard Facts **GWP** global warming potential **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon

a The 2006 values in the table are estimates from “*ODS and SGGs in Australia: A study of end uses, emissions and opportunities for reclamation*”, prepared by Expert Group in 2008. **b** Some chlorofluorocarbons are still present in the bank, for example in some very old domestic refrigerators, however, are not included in the above table and are included in the estimate of HCFC-22. Some relatively small quantities of HCFC blends used in air conditioning applications are also counted as HCFC-22. **c** This value is the published CHF2 bank of HFC-404A. Based on CHF3 methodology the bank of HFC-404A in

2012 would be higher. Since CHF2 the number of walk-in cold rooms has been revised upward and the stock and bank value has been revised based on improved information. For example, the stock of self-contained refrigeration display cabinets and walk-in cool rooms were revised upward. **d** The category 'GWP<2150' comprises a variety of blends including HFC-407F, HCFC-22 replacement refrigerants, and emerging hydrofluoro-olefins blends such as HFC-448a and HFC-449a which are starting to be used for low temperature commercial refrigeration applications. **e** The GWP<10 substances listed in the above table represents only the bank in those applications that have transitioned from prior generations of equipment employing HCFCs and HFCs and moved to low or zero GWP refrigerants and does not include ammonia systems.

5.2 Retirement and recovery

In 2020 RAC equipment containing an estimated 2,440 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. 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 2020 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 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 due to the high prices being paid for this species.

Approximately 503.8 tonnes of refrigerant was recovered by Refrigerant Reclaim Australia (RRA) in the 2020/21 financial year, comprising 5 tonnes of chlorofluorocarbons (CFCs), 41.1 tonnes of HCFCs, 450.5 tonnes of HFCs and 7.2 tonnes of HC. A further 87.0 tonnes was retained by refrigerant suppliers for reclamation and re-use of which the majority was HCFC-22 (RRA 2021a). Refrigerant recovered by the RRA program is recovered from both EOL equipment and from equipment during service where refrigerant that is not suitable for reuse is removed and replaced with new refrigerant.

Total recoveries by RRA in the 2020-21 financial year increased by 116.8 tonnes on the previous financial year which coincides with an increase in the rebate paid by RRA for recovered refrigerant from \$3 per kg to \$10 per kg effective from 1 January 2021 to 30 June 2021.

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 of HCFC refrigerants is possible because the material employed above the import cap has been 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, however the noticeable decline in total tonnes of HCFC-22 reported as sold 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 kgs
- Average retained charge at EOL: 1.35 kgs
- Average operating life: 13.7 years
- Average loss through operating life: 30% loss over 13.7 years equates 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 two means by which the bank of working gas in Australia grows:

- via imports of equipment pre-charged with a refrigerant gas, referred to as pre-charged equipment (PCE) imports; and,
- 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 applications 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 gas as it is broken down into smaller lots and distributed (sold) into the supply lines for servicing the stock of existing equipment and charging new equipment.

Natural refrigerants, ammonia, CO₂ and HC are not scheduled substances under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* and are discussed separately in Section 8. Hydrofluoro-olefin refrigerants are not classified as scheduled substances which are also ingredients used in HFO/HFC blends are briefly discussed at the end of this section (Section 6.4 Hydrofluoro-olefin refrigerants).

6.1 Pre-charged equipment imports

There was approximately 3,108 tonnes of HFCs imported into Australia contained in more than 2.6 million RAC pieces of pre-charged equipment in 2020.

Import volumes of HFCs were similar to volumes in 2019, and down by 17% compared to the all-time high of 3,721 tonnes in 2017. In terms of equipment stocks, 2020 imports at 2,667,219 pieces was similar to 2019 and down more than 16% on 2017 imports.

Volumes of HFCs imported in stationary AC, the most populous equipment segment, were down by nearly 14% in 2020 compared to 2017. This was driven by the decline in the number of sales of small split systems and 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, the volume of HFC-410A declined by more than 33% year-on-year from 2,053 tonnes in 2018 to 1,371 tonnes in 2019 and by a further 20% to 1,088 tonnes in 2020. At the same time volumes of HFC-32 imports increased from 713 tonnes in 2018 to more than 1,157 tonnes in 2020.

Similarly, the volume of HFCs imported in MAC was down by 31% in 2020 as compared to 2017 on the back of lower volumes of vehicle imports. The Federal Chamber of Automotive Industries reported 2019 sales of new vehicles at 1,062,867, a 7.8% decrease on the prior year, and the lowest number of new car sales recorded since 2011 (FCAI 2020). In 2020 new car sales declined further with 916,968 new vehicles sold dropping nearly 14% from 2019, making 2020 the lowest year for new car sales since 2003 (VFACTS2020). While some of the drop in sales in the past two years is clearly COVID related due to forced closures of showrooms, factory shutdown resulting in stock shortages and the pandemic effects on consumer confidence. Early indicators suggest that 2021 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 the first signs of the adoption of HFOs in MAC.

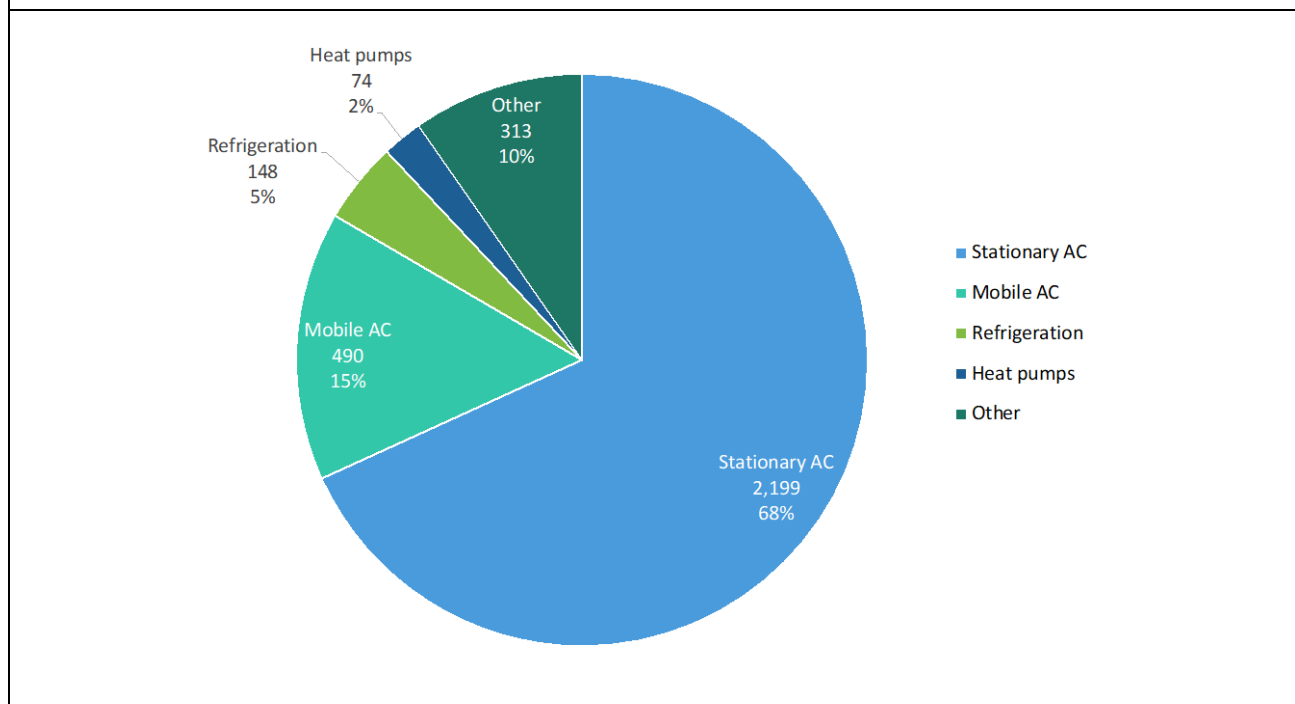
On the other hand, HFC volumes imported in commercial refrigeration equipment were up by almost 150% with the number of pieces of pre-charged commercial refrigeration equipment imported up by more than 27% year-on-year to 90,808 units in 2020. This is despite the continuing trend of self-contained commercial refrigeration to employ natural refrigerants, specifically HC that are not counted in pre-charged equipment.

Combined with the fact that Australia has a commercial refrigeration manufacturing base, and indications from quarterly market intelligence surveys suggest strong 2020 and 2021 sales of Australian made equipment, these commercial refrigeration equipment categories are seeing strong growth. Despite the impact on hospitality during COVID 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 reopens post COVID some of this high demand for commercial refrigeration equipment is expected to soften as the food retail and hospitality return to more business as usual and the once-off drivers of new equipment sales in the past two years fade.

While a relatively small category in terms of equipment numbers at 83,977 pieces imported in 2020, heat pumps across all applications, space and water heating and clothes drying, bucked the trend, growing 24% year-on-year to maintain a long-term trend that have seen annual imports grow by more than 225% since 2015. 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 3: HFC refrigerants in pre-charged equipment imports in 2020 by application, reported in metric tonnes and per cent of annual imports



(Source: DAWE 2021)

AC air conditioning

Stationary AC includes domestic and commercial categories.

Mobile AC includes pre-charged equipment category 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 MAC equipment imports are approaching stationary AC import numbers, the much greater contribution to imported HFCs of pre-charged stationary AC is a result of the larger average charge sizes in stationary AC systems, which range from an average charge of 1.6 kg (down from 1.7 kg in 2016) in residential systems to average charges of greater than 5 kg in small commercial systems.

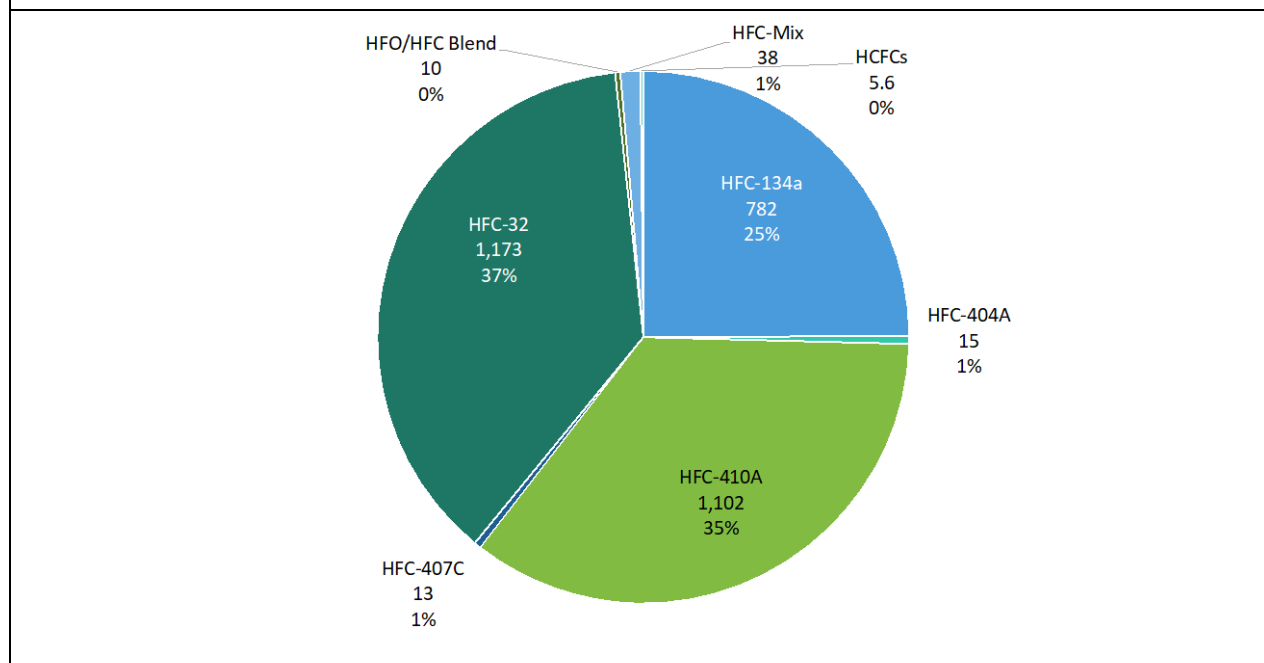
By comparison the average charge in small MAC (i.e. passenger vehicles, light commercial vehicles, trucks and commuter buses) imported in 2020 was 575 grams (down from 620 grams average - CHF3 2016, Stock Model). This is a trend observed in other countries with charge sizes of around 500 grams driven 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 those imports in 2020, with the high GWP refrigerant of choice for stationary AC for the past decade, HFC-410A, still a major part of the mix with 1,088 tonnes in PCE making up 35% of PCE refrigerants in 2020.

At the same time HFC-32 pre-charged equipment made up 37% of imports by refrigerant mass (2019, 27%) the very large majority of which was imported in small split AC systems and surpassed total PCE imports of HFC-410A for the first time.

HFC-32 charged stationary AC devices in the stock of equipment now number more than 3.7 million containing more than 4,387 tonnes of HFC-32 (based on pre-charged equipment imported until the end of 2020 calendar year) with more than 1,173 tonnes being added to the HFC-32 bank in 2020.

Figure 4: Pre-charged equipment imports in 2020 by major species in tonnes and as per cent of total imports



(Sources: DAWE 2021)

HFC hydrofluorocarbon

The growth of the HFC-32 share of PCE imports (from nearly zero in 2012) can be seen in Figure 5. 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 two years, is expected to grow strongly over the next five years.

A portion of the 32 tonnes of HFC-410A and HFC-407C imported in 2020 that was contained in chillers with a charge greater than 12 kg is expected to migrate to HFC-32 and to HFO blends in the years ahead.

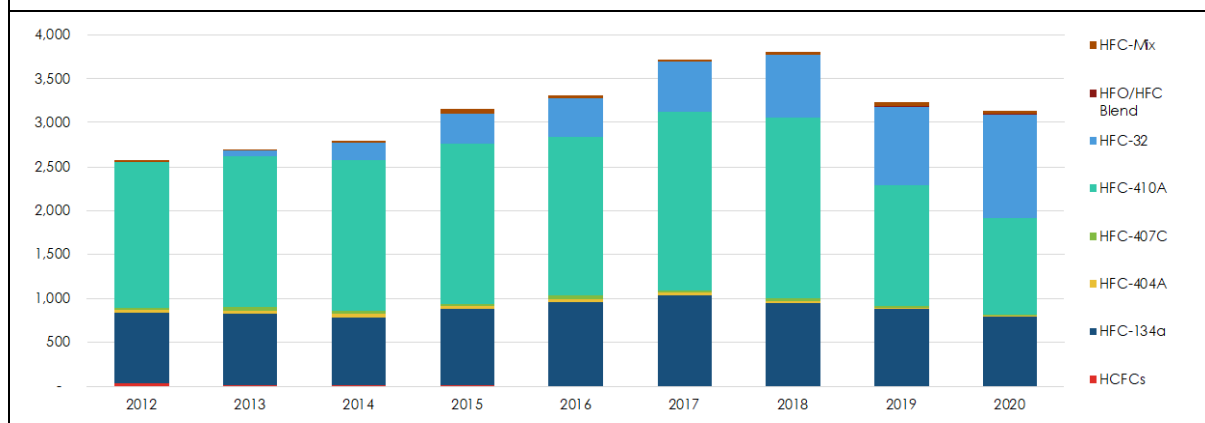
HFC-134a has maintained a relatively steady share of import volumes in PCE during the past decade, as can be seen in Figure 5. A rise in HFC-134a pre-charged imports was discernible in 2017 and 2018 as vehicle manufacturing in Australia declined to zero and all new vehicles sold were imported. However, 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-2020s due to:

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

- A portion of the 60 tonnes of HFC-134a currently imported in chillers 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.

Figure 5: HCFCs and HFCs in pre-charged equipment from 2012 to 2020 by species in tonnes



(Sources: DAWE 2021)

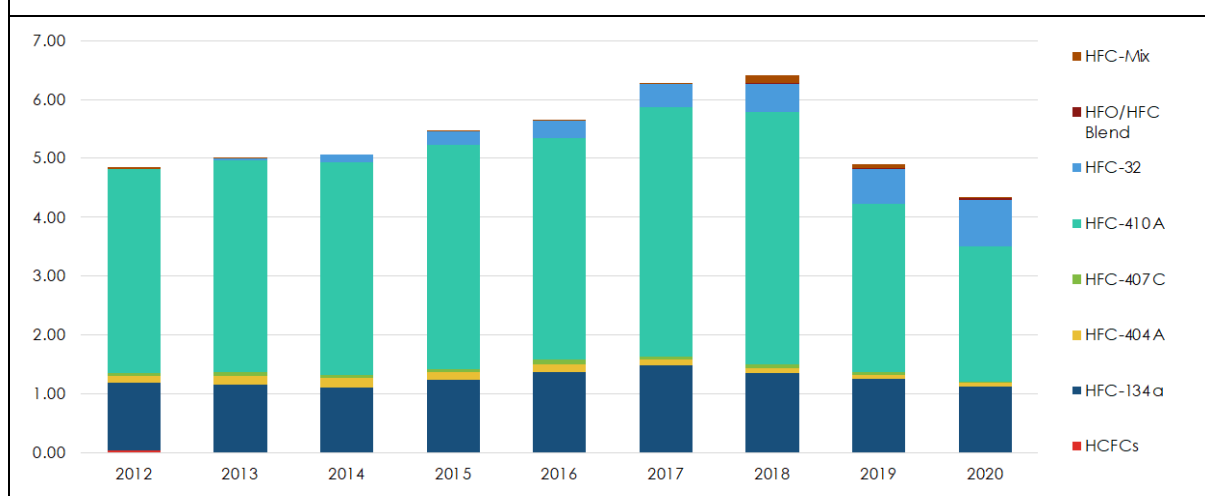
HCFC hydrochlorofluorocarbons HFC hydrofluorocarbon

Refer to *Appendix B Tab 3: Bulk imports and pre-charged equipment imports from 2006 to 2020*, for tabulated data.

A comparison of Figure 5 above and Figure 6 below demonstrates the effect of the higher GWP gases in dominating a bank when illustrated by its CO₂e value. While it can be seen from Figure 5 that HFC-32 has capped the equipment imports of PCE charged with HFC-410A, the higher GWP value of HFC 410A (for some 16 years as the refrigerant of choice in small split AC imports) ensures it will dominate the GWP of the refrigerant bank for many years to come.

Figure 6 shows the 32% decline from a peak of 6.4 Mt CO₂e in 2018 to 4.3 Mt CO₂e in 2020.

Figure 6: HFCs in pre-charged equipment from 2012 to 2020 by species in Mt CO₂e (AR4)



(Source: DAWE 2021)

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

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

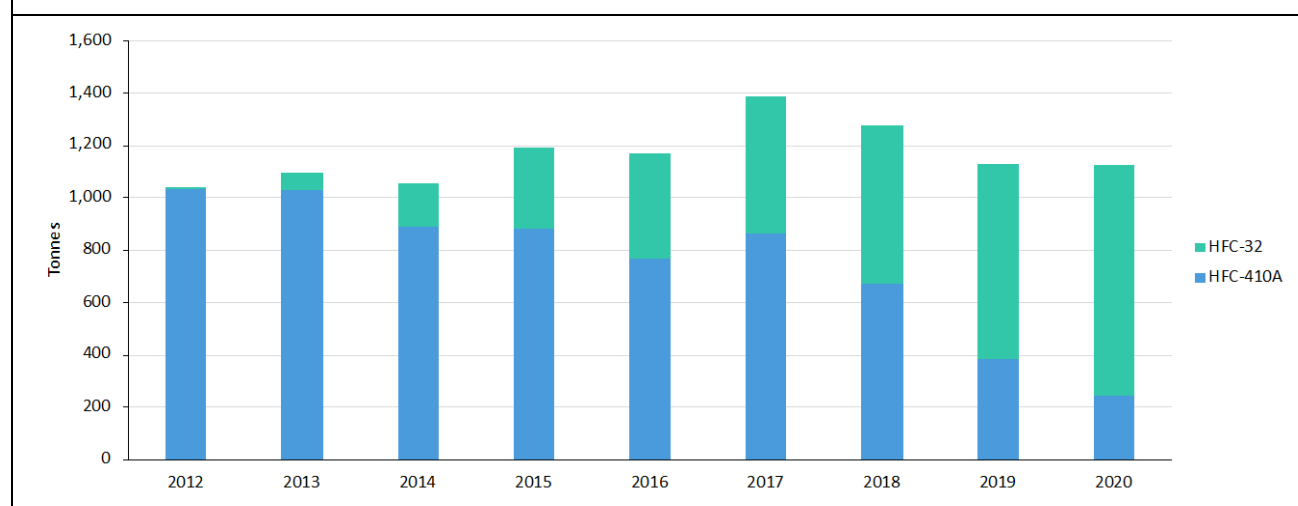
Analysis of PCE imports shows that non-ducted single split systems, designed primarily for residential use, make up most of the equipment. Non-ducted single split systems contain the bulk of the refrigerant mass, based on actual refrigerant charge sizes, of all stationary AC imported into Australia. HFC-32 adoption has continued to grow strongly in non-ducted split systems.

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

Applying these filters highlights the rate of transition away from the much higher GWP HFC-410A, to HFC 32 in this 'residential' size range.

Figures 7 and 8 illustrates this trend, refer to Appendix B Tab 4.2: Stationary AC: Pre-charged equipment for tabulated data.

Figure 7: Mass of refrigerant in pre-charged equipment imports of stationary air conditioning from 2012 to 2020 (with a charge greater than 800 grams and less than or equal to 2.6 kg) by refrigerant type in tonnes



(Source: DAWE 2021)

HCFC hydrochlorofluorocarbon **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 Agriculture, Water and the Environment is considering whether to recommend to government the implementation of an import and manufacturing ban on 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. The registration details include the refrigerant type. As of the 1st of July 2021, the count of GEMS registered models operating on HFC-32 was:

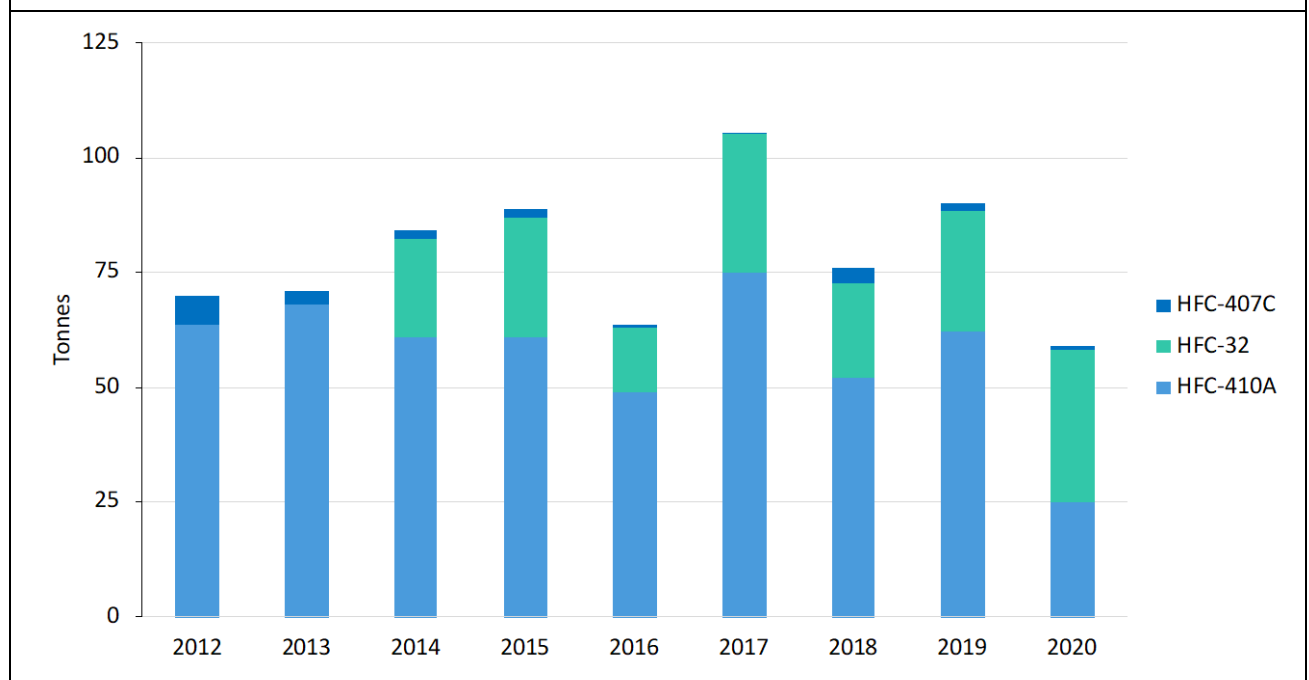
- 1,162 non ducted single split systems registered (62% of all registered non-ducted single split systems);
- 127 window/wall models (57% of all registered window/wall); and,
- 341 single split ducted models (33% of all registered single split ducted).

Analysis of the GEMS database also shows that 83% of portable AC models that have been registered are now utilising HC-290 and 12% HFC-32. This marks a considerable shift to HCs in this low charge application.

Comparison of the number of GEMS registered HFC-32 models from 2020 to 2021 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 before models become inactive, regardless of whether they are still sold over this time period).

Figure 8: Mass of refrigerant in pre-charged equipment imports of stationary air conditioning from 2012 to 2020 (with a charge size less than 800 grams) by refrigerant type in tonnes



(Source: DAWE 2021)

HFC hydrofluorocarbon

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 39 licensed importers of SGGs including HFCs, SF6 and five licensed importers of HCFCs as of December 2020 (DAWE 2020c). In 2012 there were only 17 controlled substances licence holders in total.

In 2020 a total of 3,231 tonnes of HFCs and 43 tonnes of HCFCs were imported as bulk gas. Total HFC imports in 2020 were 337 tonnes (715 kt CO₂e) less than in 2019. Refer to Appendix B Tab 4.1 for tabulated data on HFC and HCFC bulk imports from 2008 to 2020 in tonnes and in kt CO₂e.

Table 4: Bulk imports of HCFCs and HFCs in tonnes

Species	2016	2017	2018	2019	2020
HCFC-22 a	45	45	45	45	43
HFC-134a	1,541	1,837	1,552	1,335	1,363
HFC-404A	384	2,008 b	699	838	822
HFC-407C	190	314	154	179	109
HFC-407A/F	0	0	0	1	10
HFC-410A	602	953	999	889	611
HCFC/CFC Replacements c	118	110	80	111	69
HFC-32	27	31	68	64	95
HFO/HFC Blends d	0.0	15	29	42	48
HFC-Mix e	150	420	130	92	104
Total HCFCs and HFCs f	3,058	5,734	3,757	3,613 g	3,274

HCFC hydrochlorofluorocarbon **HFC** hydrofluorocarbon

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. 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 import values are net values imported that excludes the 5% allowance for the heel and 7.8 tonnes that were exported in 2019 not included in above. There were no exports in 2020.

6.3 Refrigerant usage – HCFCs and HFCs

Insight into refrigerant usage in the Australian economy has significantly improved over the course of 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.

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 2020 was 251 tonnes of HFC-410A, HFC-32 and HFC-134a compared to 305 tonnes in 2019.
- 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.
- Refrigerants such as HFO/HFC blends R448A and R449A will be considered 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.
- 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 5: HCFC and HFC refrigerant usage in tonnes

Species	2016	2017	2018	2019	2020
HCFC-22 a	255	224	168	138	101
HFC-134a	1,276	1,428	1,329	1,462	1,451
HFC-404A	800	878	813	824	856
HFC-407C	168	173	179	185	178
HFC-407A/F	33	31	29	29	25
HFC-410A	612	711	753	800	776
HCFC/CFC Replacements b	99	96	96	94	79
HFC-32	16	32	44	39	50
HFO/HFC Blends c	-	-	13	38	57

Species	2016	2017	2018	2019	2020
HFC-Mix d	190	195	195	201	182
Total HCFCs and HFCs	3,449	3,768	3,619	3,811 e	3,757 e

HCFC hydrochlorofluorocarbon **HFC** hydrofluorocarbon

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 and 2020 include 15 to 20 tonnes per annum consumed in the maritime services industry. Previous years do not include estimates from this sector.

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) CO₂e 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 2020 annual import limit was 8 Mt CO₂e. Data reported to the Department of Agriculture, Water and the Environment and analysed by the Expert Group indicates that total HFC imports in 2020 were equivalent to around 7.15 Mt CO₂e, slightly down from the 2019 figure of 7.44 Mt CO₂e.

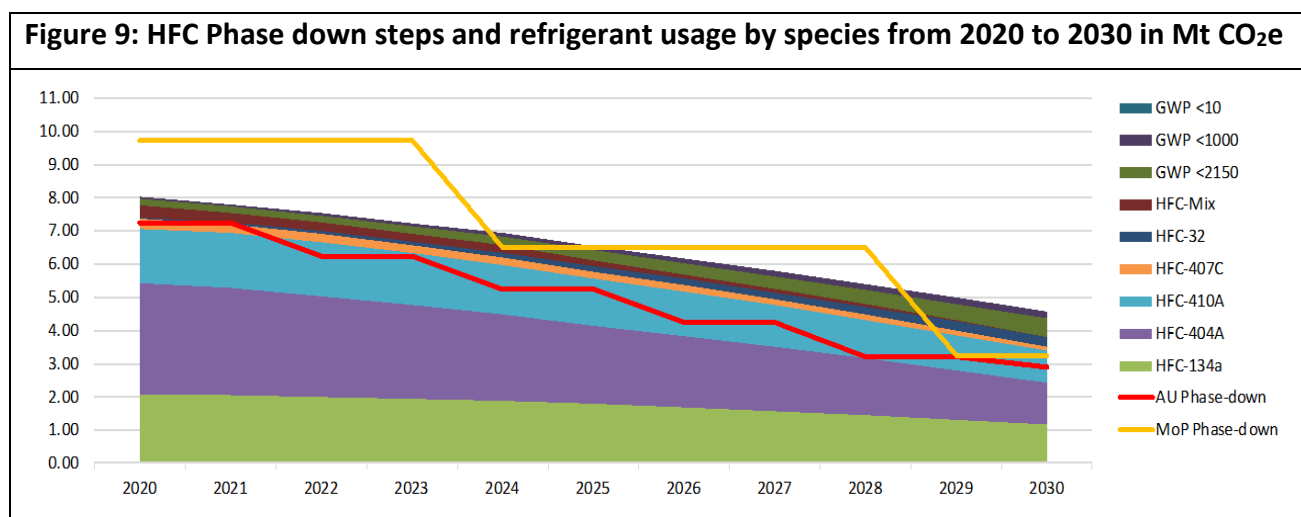
The starting point of the Australian phase-down agreed between the Australian Government and Australian industry participants, is 25% lower than Australia's base level in the Kigali Amendment to the Montreal Protocol. The Australian phase down schedule stipulates reasonably consistent import quota steps down every two 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 phase down introduces reductions at the start of each two-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 CO₂e on 31 December 2035 and will remain at 1.607 Mt CO₂e for each quota period from then on.

Figure 9 illustrates the HFC phase-down steps to 2030 relative to the projected refrigerant use by species in Mt CO₂e. 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 that, at this point, looks to be well above the import cap, 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.

In line with the expected decrease of the CO₂e value of the bank and of direct emissions, the CO₂e value of refrigerants imported is expected to drop by more than 35% from around 7.15 Mt CO₂e in 2020 to around 4.6 Mt CO₂e in 2030, five years prior to the final year of the phase down schedule.



(Source: CHF 2021 RAC Stock Model)

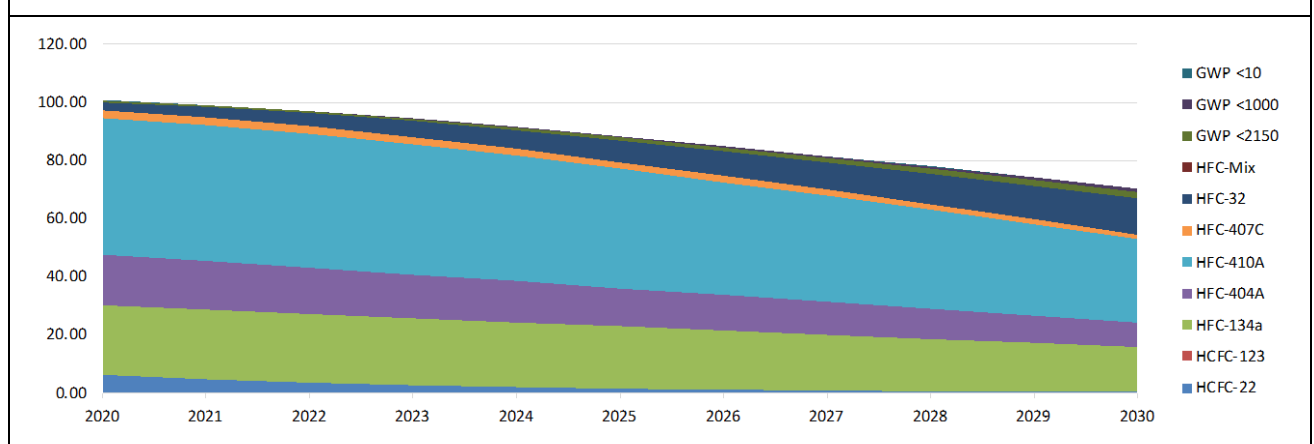
GWP global warming potential **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **Mt CO₂e** metric tonnes carbon dioxide equivalent

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 CO₂e, and the Kigali Amendment control limit for 2020 is 90% of the baseline equating to 9.732 Mt CO₂e. By comparison the Australian voluntarily adopted control limit for 2020 is 7.25 Mt CO₂e. and imports for the year came in at 7.15 Mt CO₂e.

Just as the CO₂e value of refrigerant use, and refrigerant imports, declines over the projection period, so too does the total CO₂e of the refrigerant bank. The refrigerant bank is a lagging indicator of changes to the mix of refrigerant species being introduced to service. The composition of the bank also indicates future demand as the stocks of underlying equipment age and lose some part of their charge to leaks which then creates demand for refrigerant use in service.

Figure 10 illustrates the projection of the bank in Mt CO₂e over the same time frame as the phase down steps illustrated in Figure 9. As stated earlier in the report, after decades of growth in CO₂e terms, all data and projections indicate that the peak CO₂e of the overall refrigerant bank has been reached in 2020.

Figure 10: Refrigerant bank by species from 2020 to 2030 in Mt CO₂e

(Source: CHF 2021 RAC Stock Model)

GWP global warming potential **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **Mt CO₂e** metric tonnes carbon dioxide equivalent

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) however not at a rate or in absolute terms sufficient to change the trend in the overall bank towards a smaller total CO₂e.

7 Trends and observations by refrigerant type

Table 6 shows technology signals (green, amber and red) to indicate the general suitability for transition to lower GWP HFCs, or away from high GWP HFCs to an alternative refrigerant for major equipment classes. This framework, along with interviews of technical experts from global equipment suppliers form the basis for predicting new equipment sales mix projections to 2030, which in turn lead to the projections of the future composition of the bank. The sections that follow provide some examples to support the technology signals and refrigerant selections.

Table 6: 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	HFC-454C b HFC-455A b	HFC-454A b	HFC-449A a HFC-448A a	HFC-452A a
Remote refrigeration	Condensing units for cold rooms and display cases	CO ₂ a	HFC-454A b	HFC-449A a HFC-448A a	N/A
Supermarket refrigeration: Cascade systems	Sub-critical CO ₂	CO ₂ /HFO-1234yf or ze b	CO ₂ /HFC-513A 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	HFC-513A b	HFC-134a a	HFC-452A a
Transport refrigeration	Mobile refrigeration: road: trailer and inter-modal	c	c	c	HFC-452A a
Marine refrigeration	Fishing vessel refrigeration	Ammonia b e	c	HFC-449A a HFC-448A 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	c	HFC-32 a	N/A	N/A
Large AC: Chillers	Chillers with scroll compressors	c	HFC-32 a HFC-454B a	N/A	N/A
Large AC: Chillers	Chillers with screw compressors	HFO-1234ze a	HFC-513A a HFC-515B a	N/A	N/A

New equipment	Equipment Examples	New equipment technical capability (GWP threshold)			
		150	750	1500	2500
Large AC: Chillers	Chillers with centrifugal compressors	HFO-1233zd a HFO-1234ze a HFO-1336mzz a HFO-514A a	HFC-513A a HFC-515B a	N/A	N/A
Small MAC	Passenger and light commercial vehicle, truck, commuter bus AC	HFO1234yf a CO ₂ a	c	HFC-134a a	N/A
Large MAC	Buses and coaches ≥12t Gross Vehicle Mass	c	c	HFC-134a a	HFC-407C a
Large MAC	Locomotive and passenger rail AC	c	c	c	HFC-407C a
Large MAC	Recreational vehicle and caravan AC	c	HFC-32 b	N/A	N/A

Key to technology signals

Mature technology within the Australian market.

Technology available not widely utilised within the Australian market.

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

AC air conditioning **CO₂** carbon dioxide **GWP** global warming potential **HC** hydrocarbon **HFC** hydrofluorocarbon **MAC** mobile air conditioning **N/A** not applicable

a Mature technology within the Australian Market **b** Technology available 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.

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 mean that in some applications the same refrigerating effect can be achieved while reducing electricity consumed. HFOs were released into 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 US and EU from around 2017, in part driven by European F-Gas requirements. Japan has been slower to move and started transitioning about two to three years later and now HFOs is thought to represent around 60% of automotive manufacturing consumption.

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 supplies to the automotive supply chain and for charging space chillers. The penetration of HFOs in automotive is estimated at around 15% of all passenger and light commercial vehicles imported in 2020, whereas the portion of chillers containing HFOs is estimated at around 5% of the market. The uptake of HFO-1234yf into the MAC sector has been very slow in Australia compared to USA and EU, however as manufacturers move more of their production to HFO charged systems the Australian market penetration of HFOs in all new passenger and light commercial vehicles imported by 2025 will transition rapidly.

HFO-1233zd and HFO-1336mzz have exhibited growth in the Australian market in the chiller sector where they are available from major manufacturers and suppliers of centrifugal chiller applications. HFO-1234ze is available as an alternative to HFC-134a in chillers with screw compressors.

As imports of HFO PCE or 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 2020 is estimated at less than 30 tonnes.

7.2 HFO/HFC blend refrigerants

While pure HFOs have not taken as much market share as predicted in the past few years, HFO/HFC blends have begun to be deployed with the volumes of bulk imports of these refrigerant blends imported in 2019 and 2020 being 42 and 48 tonnes respectively. The properties of these blends, their lower GWP, and their ability to deliver higher energy efficiency, and in some instances act as drop-in replacements, gives equipment designers and owners options for extending the life of equipment with a lower GWP refrigerant and improving operational costs.

Non-flammable ASHRAE A1 rated blends such as R448A (GWP of 1386), R449A (GWP of 1396) and R513A (GWP of 629) have made up the majority of imports and are being utilised in both new equipment (PCE) and in retrofit replacements, especially of R404A. Use of R448A and R449A in retrofit application has been slow to be adopted in Australia when compared to New Zealand with an Emission Trading Scheme, and the UK or the EU with a more stringent phase-down. This is thought to be due to HFC-404A still exhibiting strong availability and relatively low market price in comparison to R449A and R448A. The major supermarket chains in Australia have also focused on transitioning to new technology and has preferred to refurbish stores directly to new trans-critical CO₂ racks rather than perform retrofits and prolong the life of existing assets with HFO blends.

R452A (GWP of 2139) is now the refrigerant of choice in transport refrigeration due to its similar characteristics to HFC-404A (GWP of 3922), lower GWP and ability to operate in both medium and low temperature application. 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, R455A and possibly others 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 the consumption of HFC-404A in 2020.

HFO/HFC blends observed in chillers in Australia were R513A and R515B. There was 7.2 tonnes of R513A imported in 2020.

Other HFO/HFC blends emerging globally are the A2L classified R452B, R454A, R454B, R454C and R457A that were recently listed by the Significant New Alternatives Policy (SNAP) Program of the United States Environmental Protection Agency for use in air conditioning and heat pump applications. These refrigerant blends are mostly available in USA designs and are offered by some European manufacturers, but currently not by Japanese manufacturers. Australian trials of

R454B (GWP of 465) chillers are currently underway with a major player in the supermarket sector. It is believed that there are around 30 chillers now operating on R454B in Australia.

7.3 Natural refrigerants

Natural refrigerants are employed to some extent in most RAC technology segments, although with minimal applications in stationary air conditioning.

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 5% of the bank of 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 charges up to 494 grams is permitted by *AS/NZS 60335.2.89: 2020*.

CO₂ 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 cascade systems; CO₂ only trans-critical systems; CO₂/ammonia chillers; CO₂/brine; and, other variations of two 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 fluid being in line with corporate sustainability plans and the journey towards net zero (CSA 2021). Smaller CO₂ condensing unit combinations up to 15 kW which are suitable for small format supermarkets, convenience stores, liquor outlets and fast food chains are also being developed in Australia.

The volumes of CO₂ refrigerant used, primarily in the supermarket sector, are increasing from a low base and are now estimated at around 230 tonnes in 2020.

Ammonia is also finding broader application outside the large cold storage distribution centres and industrial chillers where it has been traditionally used. In recent years applications deployed in Australia include ammonia chillers and low charge ammonia chiller packages.

Ammonia volumes are generally driven by large capital works and ongoing maintenance of existing systems with annual volumes fluctuating accordingly; the seven-year average annual use is estimated at almost 690 tonnes.

Table 7: Volumes of ammonia and hydrocarbon sold by calendar year (tonnes)

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

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.