# Cold Hard Facts 2021 Appendix A: Methodology – taxonomy, data and assumptions



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# 1 Methodology – taxonomy, data and assumptions

The data presented in this report has been derived from an extensive Excel workbook that has, at its core, a stock model of all RAC equipment employed in Australia (the Expert Group RAC Age-Cohort Mass Balance Stock Model). The central feature of the stock of equipment in this model is that it all employs vapor compression refrigeration systems in the delivery of an energy service, either cooling or heating, or both.

All electro-mechanical RAC equipment employing vapor compression refrigeration systems uses four essential technical elements:

- a compressor
- a refrigerant (the thermal medium which is used to move heat from one place to another)
- an evaporator that uses the adiabatic effect to reduce the temperature of a space by evaporating the previously compressed refrigerant gas
- a condenser or heat exchanger outside the refrigerated space that allows the evaporated then recompressed gas to cool, transferring the excess heat to the atmosphere (air cooled) or into water (water cooled).

These common electro-mechanical elements of RAC technology can be fabricated into equipment in a number of different ways, with the main components incorporated in quite different physical relationships to each other, to deliver heat exchange/cooling services. For instance, all of the four basic elements of vapor compression refrigeration are present in both a domestic refrigerator that is small enough for a single person to pick up, and also in a system that has the capacity to regulate the temperature and humidity of an airport terminal, or the cockpit of a fighter aircraft, but obviously all in very different formats.

Because RAC technology and services, after 150 years of development, have become integrated into every sector of the modern economy, the number and variety of equipment formats that the RAC industry now supplies is highly varied.

To best manage the mass of data that must be captured and analysed in the stock model to understand the scale of the RAC industry and all of the applications and equipment formats that it delivers, the stock of RAC equipment has been divided and categorised into a taxonomy.

# 1.1 Taxonomy of a technology

This taxonomy of a technology is made up of 4 broad classes, 14 segments and 59 product categories as set out in *Appendix: B1: CHF3 Taxonomy*.

The 4 classes of equipment encompass the four main applications for RAC technology, being stationary air conditioning, mobile air conditioning, domestic refrigeration, and the refrigerated cold food chain. These four classes are listed in order of the size of the bank of refrigerant they employ in Australia.

Starting with these four classes the taxonomy is built on a second and a third order classification in the following hierarchy:

- 1. Class
- 2. Segment
- 3. Product category

Each product category has a product code which uses an abbreviation of the name of the class to identify the class to which it belongs followed by a set of numbers identifying the segment number within the class and then the products position or order in the segment. The abbreviations used for each class are listed below:

- Stationary air conditioning (AC)
- Mobile air conditioning (MAC)
- Domestic refrigeration (DR)
- Refrigerated cold food chain (RCFC)

The second order nomenclature of each class or equipment is the segment which describes the general product formats and size of the RAC technology. For instance, the equipment segments in the stationary air conditioning class include:

- AC1: Small AC: Self-contained
- AC2: Small AC: Non-ducted
- AC3: Medium AC: Ducted & light commercial
- AC4: Large AC: Chillers
- AC5: Other.

Finally, the third order nomenclature of the taxonomy is the product category, which are simply numbered for their order in the segment. Product categories may distinguish products on the basis of the size of their refrigerant charge, their refrigerating capacity, or some other distinguishing feature that limits or defines the application of the product, or determines the physical equipment format, the way in which the elements of the core technology of vapor compression refrigeration relate to each other (i.e. self-contained or remote condenser).

For instance, the segment AC1: Small AC: Self-contained includes small equipment up to 10 kWr where all of the elements of the vapor compression refrigeration system are integrated into a single device. The AC1 segment is then broken into two categories to differentiate between units designed to be mounted in a window or wall and those that are portable – AC1-1 Window/wall: Non-ducted unitary <10kWr and AC1-2 Portable AC <10 kWR.

In another example the segment AC3: Medium AC: Ducted & light commercial has two out of nine product categories covering single split systems:

- Single split: ducted 1-phase (AC3-1)
- Single split: ducted 3-phase (AC3-2).

The two product categories AC3-1 and AC3-2 are distinguished by whether the single split system can be connected to single phase or three phase power. In this instance this distinction

provides a direct correlation to the capacity of the compressors used and thus the refrigerating capacity range of the products in each product category.

Not all product category allocations may appear an obvious fit on first inspection. For instance, in the light commercial segment (AC6) of stationary air conditioning there are five product categories including AC6-5 pool heat pump as the last product in the segment. This product has been classified in the selected light commercial segment because in terms of electrical capacity, functional design, refrigerant type, refrigerant charge size and energy service delivered, it is effectively similar to other products in the segment.

Due to the ubiquitous reach of RAC technology there are also some segments and product categories that include some 'miscellaneous' and 'other' descriptions, for instance in the mobile air conditioning class, in the large mobile air conditioning segment, several product categories are listed that include registered shipping and aircraft, locomotives and caravans. Obviously while the physical formats and even the refrigerants used are likely to be very different across these diverse applications, all of these product categories are defined by their end use in mobile systems.

The concept and framework of the taxonomy was developed in the early stages of researching and writing Cold Hard Facts 1 in 2006 and was then formalised and updated in 2013. Since that time additional data has come to light, and indeed some large populations of RAC equipment identified that were essentially not recognised in 2012, that has required some changes to be made to the taxonomy. The taxonomy is the system of organising RAC technology that has been used in research and writing this report, Cold Hard Facts 2021 (CHF 2021) based on the 2020 calendar year.

# 1.2 Data and assumptions

The data presented in this report has been derived from an extensive Excel workbook that has, at its core, a stock model of RAC equipment employed in Australia organised into a comprehensive taxonomy of equipment types, sizes and end-use applications. This model also reports annual usage, consumption and emissions of ODS and SGGs for non-refrigerating applications such as foam blowing, aerosols, and fire protection.

In this report the Expert Group RAC Age-Cohort Mass Balance Stock Model is referred to as the RAC stock model.

# 1.2.1 Data underlying the stock model

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

- Australian Customs import reports for various product categories (primarily air conditioning equipment by capacity, and some categories).
- Department of Environment Water Heritage and the Arts (DEWHA) (now the Department of Agriculture, Water and the Environment) data on pre-charged equipment imports for 2005 and 2006.

- Commercial market research estimating the numbers of residential and small commercial split and packaged air conditioning systems sold in the few years prior to 2006 (by capacity and product type).
- Various sales datasets, some partial, from 2004 and going back as far as 1995 for domestic refrigeration, residential and small commercial air conditioning, collected from a number of importers, manufacturers and from published market research, constructed into the early years of the model and then released for industry comment and review.
- Personal communications and interviews with manufacturers and importers of commercial split systems and chillers.
- Personal communications and interviews with manufacturers of commercial and domestic refrigeration systems.

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

Equipment retirement rates were developed using knowledge of manufacturers' warranty conditions, interviews with suppliers, designers and engineers. These assumptions are reviewed when new information becomes available to support or improve the assumptions, for example field trial of 1,152 split systems at end-of-life by Refrigerant Reclaim Australia (RRA 2021b).

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

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

- The latest issue of the Department of Agriculture, Water and the Environment data including bulk and pre-charged import statistics by quantity, mass, species, licence holder, product category from 2006 to 2020 (DAWE 2021). Not all refrigerants are defined as controlled substances under the Ozone Protection and Synthetic Greenhouse Gas Management Act. All of the major classes of HCFCs and HFCs must be reported.
- Reviews of data included in regulation impact statements and product profiles for air conditioning equipment (i.e., split systems, chillers, close control, portable, etc.) (E3 2016a), refrigerated display and storage cabinets (E3 2016b), domestic refrigerators and freezers (E3 2017b), non-domestic refrigeration (E3 2009), and other products such as high efficiency fans (E3 2017a).
- Reviews of data created for models of domestic energy production.
- Interviews with and surveys of manufacturers, importers and resellers of equipment, and with importers and wholesalers of refrigerant, parts, and tools for the purpose of other RAC industry related studies.
- Interviews with industry associations and professional bodies for the purposes of other industry and government programs.
- In-confidence industry wide surveys of major participants selling commercial refrigeration condensing units and compressors dissected by capacity and refrigerant.

- In-confidence industry wide surveys of suppliers, upstream processors and end-users of natural refrigerants to establish aggregate industry measures.
- Market intelligence reports with monthly sales (\$ and quantity) of HCFCs and HFCs by species including refrigerant re-use.
- Market intelligence reports of refrigeration equipment sales (by type and capacity).
- Surveys of stock on the floor of domestic equipment retailers.

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

The stock model has been further refined following more recent assignments including:

- Cold Hard Facts 2 prepared for the Department of the Environment and Energy, 2013.
- A study into HFC consumption in Australia in 2013, and an assessment of the capacity of Australian industry to transition to nil and lower GWP alternatives away from HFCs, prepared for the Department of the Environment and Energy, April 2014.
- Environmental Impacts of Refrigerant Gas in End-of-Life Vehicles in Australia, prepared for the Department of the Environment and Energy, 2014.
- Assessment of environmental impacts from the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, prepared for the Department of the Environment and Energy, April 2015.
- Cold Hard Facts 3, prepared for the then Department of the Environment and Energy (DoEE 2018) the first annual update in the CHF series, CHF 2019 (DoEE 2019a), CHF 2020 (DAWE 2020a) and this report CHF 2021 prepared for the Department of Agriculture Water and the Environment (DAWE 2021).

# 1.2.2 Product category stock models

Detailed and quite high resolution and high confidence stock models have been developed for some major product categories where sufficient quality historical sales data has been discovered. These models use a cumulative distribution function of the normal distribution function to develop survival curves, stock population and annual equipment retirement estimates by refrigerant species.

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

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

 $\Phi \ (2012\text{-}2000\text{+}0.5;\mu,\sigma) = \Phi \ (12.5;\mu,\sigma)$ 

Where  $\Phi(x;\mu,\sigma)$  is the cumulative distribution function (CDF) of the normal distribution with mean  $\mu$  and standard deviation  $\sigma$  evaluated at x.

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

The historical sales data is dissected by refrigerant species to predict the refrigerant mix of the bank and in retiring equipment. This methodology has been refined further for end-of-life vehicles with a survival curve which is a normal distribution with a mean retirement age of 18.6 years and a standard deviation of 6.2 years up to age 27, then uniform distribution out to age 64 years where it hits 100% of retirements. This curve simulates actual vehicle registrations in the ABS Census of Motor Vehicles.

## 1.2.3 Refrigerant charges and species

The size of the refrigerant charges and species used in various equipment classes are known from manufacturers' documentation and checks of equipment and appliances in the market. The size of refrigerant charges can also be correlated (to some extent) with the input power and size of the compressor employed, and the resulting refrigerating capacity of a piece of equipment.

In some product categories the average charge size used in the stock model has been changed over time to reflect changing average refrigerating capacity, and due to the natural rate of improvement of the technology towards smaller charge sizes. For example, air conditioning systems on large buses and coaches greater than 12 tonnes GVM had an average charge of 9.0 kg prior to 2012. Following a detailed review of equipment models from major participants the average charge in 2016 has been revised down to 5.5 kg.

The average charge for the same type of equipment with roughly the same refrigerating capacity can be different by species. For example, the same capacity wall hung split air conditioning system contains an average charge of 1.7 kg of HCFC-22 (as this is older technology), 1.40 kg of HFC-410A or 1.10 kg of HFC-32.

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

From 2006 to July 2012 the Department of the Environment and Energy pre-charged equipment import data was dissected into specific equipment categories including:

- Air conditioning chillers
- Packaged air conditioning equipment
- Window/wall units
- Portable air conditioning
- Splits systems (single and multi-head/variable refrigerant flow);

- Aircraft
- Other heat pumps
- Mobile air conditioning (vehicles less than and greater than 3.5t gross vehicle mass)
- Commercial refrigerated cabinets
- Domestic refrigerators and freezers
- Transport refrigeration (self and vehicle powered truck refrigeration)
- Other commercial refrigeration categories.

This information provided seven years of history that was reviewed in great detail to form or confirm views about average refrigerant charges in various products, and the dissection and transition of refrigerant species in products. The pre-charged equipment date collected by the department since July 2012 has been aggregated into broader equipment categories that require greater interpretation to assess average charges and refrigerant types.

Table 1: Technical characteristics by product category shows the average charges, end-of-life charges, leak rates, service rates and average equipment life span that are applied in the stock model. The average charge shown in Table 1 is the average charge of the most common refrigerant species found in that product category. Charges of other species used in the same product category may differ to some extent.

## 1.2.4 Small MAC refrigerant charges

The CHF2021 RAC Stock model uses both sales data (ABS 2018 and FCAI 2019) and registration data (ABS 2021c) to calculate the current fleet of small MAC comprising passenger and light commercial vehicles, rigid trucks, articulated trucks, non-freight trucks. and small buses with a GVM less than 4.5 tonnes and assumes 100% of vehicles manufactured after 2000 contain air conditioning.

The RAC Stock model uses the polynomial in Figure 1 to calculate average charge by year of manufacture for Small MAC.



RAC refrigeration and air conditioning MAC mobile air conditioning

## **1.2.5** Proportion of hydrocarbon in small MAC

The estimated portion of the fleet containing hydrocarbon refrigerant in 2012 has been revised down to 3.8%. The 2016 estimate was at most 4.2%, which equated to around 743,000 vehicles. The 2018 estimate is 4.1% which equates to around 754,000 vehicles that contain hydrocarbon.

The CHF3 RAC Stock model estimates the number of vehicles charged with hydrocarbon based on the following method and assumptions:

Calculation method:

- The annual supply of hydrocarbon, less service usage, equals volume available for conversions.
- The volume available for conversions, adds vehicles to the hydrocarbon fleet.
- The attrition rate retires vehicles from the hydrocarbon fleet.
- The number of hydrocarbon charged vehicles at the commencement of the following year is the starting fleet, plus conversion, less retirements.

#### Assumptions:

- Number of vehicles charged with hydrocarbon in 2002 is 50,000.
- Average age of vehicle converted is greater than 10 years.
- Attrition rate of vehicles greater than 10 years old is 10%.
- Annual leak rate is 10%.
- Proportion hydrocarbon charge to HFC-134a based on mass is 30%.

• Growth in aggregate supply beyond 2016 is 2% per annum.

The annual aggregate supply of hydrocarbon to the automotive market was provided in confidence by all market participants.

#### **1.2.6** Surveys of mobile air conditioner refrigerants

Refrigerant Reclaim Australia (RRA) conducted more than 2,000 inspections of passenger and light commercial vehicles in annual surveys from 2013 to 2017 to analyse the refrigerants in mobile air conditioners.

The surveys were conducted across all major capital cities as well as regional areas to provide national coverage and dissect the refrigerant types found into the following categories HFC-134a (100% and >95%), HC (100%, >95% and HC mix), CFC-12, and empty. The surveys record the year of vehicle manufacture, which shows a sample that is consistent with the age range of the current fleet with the vehicles most frequently inspected being around 10 years old, and with a long tail of vehicles dating back to the 1970s.

The 2017 survey results found 86.0% of vehicles contained HFC-134a, 6.4% contained some HC, 0.2% contained CFC-12, and 7.5% were empty. The presence of CFC-12 found in the surveys has declined from 2.6% in 2013 to 0.2% in 2017.

The proportion of vehicles that contained some portion of hydrocarbon varied from 3.7% to 6.5% over the five-year survey period, however the number of vehicles that contained >95% HC ranged from 0.6% to 2.5%.

## 1.2.7 Leak rates and direct emissions

At various points in the report the 'leak rate' of refrigerant from a class, segment or product category is discussed.

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

On occasion leak rates are discussed which refer only to the rate of loss of refrigerant from an individual type or even individual piece of working equipment over a period, or as an instantaneous observation. When the term leak is used, it is not intended to capture the entirety of losses of refrigerant over the lifetime of the equipment.

Losses of refrigerant over the total life of a piece of equipment or even a class of equipment are referred to as 'direct emissions' when discussed in the context of greenhouse gas emissions – as compared to the 'indirect emissions' created by the consumption of electricity.

The annual leak rates referred to above are expressed as a percentage of the initial charge per annum, and defined as 'direct emissions' incorporating:

- Refrigerant that leaks from equipment, either from slow leaks in operation, or as a result of 'catastrophic' losses when a piece of equipment suffers some sort of breakdown or failure of containment and the entire charge is lost to air.
- Refrigerant that is lost through handling losses during installation and commissioning of equipment, and during servicing of equipment.
- Refrigerant that is lost along the supply chain while gas is being transported, decanted or handled.

Direct emission rates applied in the model are listed against product categories in *Appendix: B1: CHF3 Taxonomy*.

The understanding of the equipment in the product categories has evolved over several years and partly as a result of having to prepare a series of research papers in this area. In the course of various projects all available data in this area was reviewed and a database of findings and observations of leak rates by other researchers was constructed.

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

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

- Other research used to inform leak rate estimates include the various United Nations Environment Programme (UNEP) Technology and Economic Assessment Panel reports prepared by the Refrigeration, Air Conditioning and Heat Pumps, Technical Options Committee, technical papers by the Institute of Refrigeration in the UK, and a series of papers undertaken by Denis Clodic and his various associates over the last decade for various policy makers in the US and EU.
- A more recent research paper, published by Refrigerant Reclaim Australia in 2021 that gathered field data on charge sizes, leakage rates and refrigerant loss during the recovery process of 1,152 split systems at end-of-life (RRA 2021b).

Direct emissions from product category, in any one year, are always going to be greater than or, at the very best, equal to the service usage for that product category in that year. This is a conclusion from other data and research that shows that in the majority of product categories, particularly those categories that encompass smaller privately owned equipment, service is rarely comprehensive across the stock and at least some part of the stock of equipment in any category at any time is operating on less than the full technical capacity of the refrigerant charge.

This is discussed further in Section 1.2.9.

# 1.2.8 Allocation of bulk gas to manufacturing and servicing of RAC equipment

Bulk gas is primarily imported for servicing and manufacturing RAC equipment. Other uses include, for instance, charging new commercial refrigeration equipment with remote condensers that have been manufactured or imported with a nitrogen charge and then charged on site. Smaller volumes of bulk gas imports are used in non-RAC applications including foam blowing, aerosols, fire protection, as cleaning agents (solvents), and electricity distribution.

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

In CHF2 the annual usage of bulk imports of HFCs, after deducting refrigerant used in installation of new systems and by OEMs in Australia, was used as a proxy for effective leak rates of equipment. It was assumed that the balance of the refrigerant imported every year, and not used in new installations or by OEMs was therefore used maintaining and servicing the stock of equipment. It was further assumed that all product categories in the stock of equipment were maintained at close to an optimal charge, on average, over the effective life of the equipment.

Since CHF2 a number of pieces of research have demonstrated that stocks of operating equipment are not always maintained at optimal charges and that, as evidenced by reports from service technicians, and from surveys of the charge remaining in equipment that has reached the end of its useful life, some segments and product categories will operate for a significant portion of their operating life on sub-optimal charges.

This realisation has been built over a period during which a great deal of work was undertaken by the authors in the course of several projects to reconcile usage of declared bulk refrigerant imports into Australia, for all major refrigerant species, with all the possible end uses of the refrigerant.

Combined with supply chain and service company interviews, the analysis of bulk refrigerant imports, plus the expected losses from the stock of equipment is used to deduce the total volume of refrigerant applied to particular product categories to at least partially replace lost refrigerant across the stock of equipment in the Australian economy.

For example, a mobile air conditioning aftermarket survey was undertaken to assess HFC-134a usage for service, repairs and losses as the result of car crashes. The assessment concluded that the service usage rate for the 2014, 2015 and 2016 was less than 5% per annum of the MAC bank, versus the estimate of 10% leak rate, plus 1.5% applied for car crash losses in 2012. On this basis the service rate is around half of the leak rate, however the usage prior to 2012 was known to be much higher.

Assuming this under-servicing of the stock of equipment is consistently around 25% to 30% of annual losses, then the actual bank of refrigerant in the stock of MAC is about 82% of the capacity of that stock if it was fully charged. The banks in other sectors, with less under-servicing, would be fuller and the total bank is around 92% full.

These insights into the industry and the operation and maintenance of the stock of equipment have led to the development of the concept of a 'service rate' for certain segments and product categories, where a discounted service rate (i.e. a service rate of less than 100%) leads to calculation of a 'partially charged bank', being less than the optimal or full bank.

The main segments where under-servicing is thought to be significant includes small MAC and whitegoods (i.e. domestic refrigeration, portable AC, window/wall AC and wall hung split systems) particularly where the device is cheaper to replace than service. Notably these two segments are dominated by private ownership.

# 1.2.9 Calculating the full bank and partially charged bank

External references and field experience are used as a starting point for leak rates applied to product categories. Service rates are as set out in the section above. A 'full bank' is the product of a known stock of equipment multiplied by the average original charge rates in the various cohorts of equipment that make up a product category, derived largely from manufacturers' specifications. Residual charges in end-of-life equipment are estimated based on various surveys and published sources.

Using this data, a mass balance equation is used to calculate the actual refrigerant bank, referred to as the 'partial bank', in a product category and thus in the stock of equipment.

Figure 2 illustrates the mass balance concept and relationship between the full bank, service usage and total possible end-of-life residual charges on one side of the equation, and the partial bank, direct emissions and actual end-of-life retirements from the partial bank on the other.

Figure 2: Refrigerant mass flow equation concept diagram						
Service consumption	Leak emissions					
Full bank	Partial bank					
End of Life Retirements (Full charge)	End of Life Retirements (Partial charge)					

The conceptual model of the partial bank can be validated by applying the same data and mass balance equations in a segment or product category for which all data required can be found.

For example, aftermarket surveys covering all major market participants determined that service usage for small MAC was found to be around 5% of the MAC full bank in 2014, 2015 and 2016.

The average end-of-life charge in small MAC is known from surveys of end-of-life vehicles to be 67% of the original charge. A life cycle charge profile for small MAC was developed that assumes vehicles retain 100% of the original charge from years one to five during the typical warranty period, then follows a linear decline from 100% in year five to 67% of original charge at retirement.

Therefore, the annual leaks can be calculated from the mass balance equations in kilograms or tonnes, then converted to a percentage based on the original charge in the full bank. In small MAC this analysis yields an annual average leak rate of the equipment of 6.8% in 2016.

The leak rate in the model depends on the assumptions, for example in 2016 the theoretical leak rate of small AC: Split AC is 3.6% based on a 2% service rate, average lifespan of 12 years and EOL residual of 80%.

In 2021 RRA published the results from a research project to gather field data on charge sizes, leakage rates and refrigerant loss during the recovery process in split systems at EOL (RRA 2021b). These field results found the average loss through operating life was 30% loss over 13.7

years which equates to an average annual leakage rate of 2.2%. These results are very consistent with the 2020 service rate of 2.2%, EOL residual of 80% and theoretical leak rate of 2.7% for single split systems published in Table 1.

Figure 3 provides a graph of the mass balance elements for small MAC from 2016 to 2030. The projected full and partial refrigerant bank axis is on the right in tonnes, and the projected annual flows axis is on the left. This modelling approach provides regulators with reconciled usage projections which can be compared with the annual import quota limit of the HFC phase-down, and annual emissions (leak and end-of-life minus recoveries), essential for domestic emission reduction policy and understanding Kyoto Protocol elements.

Figure 3: Small MAC mass balance elements, annual refrigerant flows and banks from 2016 to 2030 in tonnes



MAC mobile air conditioning

Refer to Table 1: Technical characteristics by product category for equipment service usage rates for each product category in the taxonomy.

# 1.2.10 The bank of refrigerant

In simple terms the bank of refrigerant is calculated by using average charges of refrigerant in each product category to calculate the total 'full bank' of refrigerant by product category and segment, and by species.

Leak rates are used to assess the volume of refrigerant required for servicing equipment segments in any year. This service demand is reconciled against the known volumes imported and sold to deduce a service rate for each product category. The full bank multiplied by the service rate results in a calculation of the 'partially charged bank', generally referred to in this report simply as 'the bank', or the 'refrigerant bank'.

In generating a 'partially charged bank' for any product category, the RAC Stock model also takes account of the changing charge size of the various vintages of equipment in some product categories.

Starting with the bank in 2016, projections of the changing composition of the bank out to 2030 were prepared by combining the outputs from the model that projects the future sales mix of equipment by species employed.

## 1.2.11 Bank by product category

A 'full bank' and 'partially charged bank' of refrigerant can be calculated for each product category with varying degrees of confidence depending on some of the characteristics of the product category, particularly the estimated leak rates and service rates of the different categories.

The 'full bank', or fully charged bank, is calculated based on the number of devices in the product category multiplied by the average original charge of that type of equipment when it is initially installed/purchased.

The 'partially charged bank' will, in practice, be less than the fully charged bank as the charge in individual pieces of equipment in the category declines over time until the equipment retires. How much less the actual bank is than the full bank at any time is determined by both the level of leaks from the equipment in that particular product category, off-set by the normal level of servicing of the stock in that product category. Both leak rates and service rates differ across the entire stock of equipment.

The stock of equipment in each product category is made up of equipment cohorts based on date of manufacture, ranging from new equipment that is fully charged, through to aging equipment eventually reaching end-of-life with only a residual charge of refrigerant remaining. For example, the residual charge of a small mobile air conditioner at end-of-life is estimated to be just two thirds of the original charge, and the average age of vehicles in the fleet is around 10 years (DoEE 2015b).

Table 1 shows the refrigerant charges, end-of-life charges, leak rates, service rates and average equipment life span that are applied in the stock model. These metrics are applied to produce a number of outputs of the RAC Stock model, and ultimately define the bank of refrigerant.

Product segment	Product category	Average charge (kg) a		EOL factors (%)		Rates (% of original charge)		Nominal average
		2012	2020	EOL b	Tech rec c	Service rate (2020)	Theoretical leak rate (2020)	lifespan (years)
Small AC: Sealed	Non-ducted: unitary 0-10 kWr	0.75	0.65	85.0	90.0	2.0	2.5	12.0
	Portable AC: 0-10 kWr	0.6	0.55	85.0	90.0	0.0	2.5	8.0
	HW heat pump: domestic	0.9	0.9	85.0	90.0	2.0	2.5	15.0
	Heat pump clothes dryers	0.46	0.47	85.0	90.0	2.0	2.5	16.5

#### Table 1: Technical characteristics by product category

Product segment	Product category	Average charge (kg) a		EOL factors (%)		Rates (% of original charge)		Nominal average
		2012	2020	EOL b	Tech rec c	Service rate (2020)	Theoretical leak rate (2020)	lifespan (years)
Small AC: Split	Single split: non-ducted <b>d</b>	1.7 (HCFC- 22)	1.10 (HFC- 32)	80.0	90.0	2.2	2.7	12.0
Medium AC	Split system: ducted	4.7	4.7	80.0	90.0	2.2	2.7	16.0
	RT packaged systems	12.2	15.0	80.0	90.0	2.2	2.7	20.0
	Multi split	3.0	3.0	80.0	90.0	2.2	2.7	20.0
	VRV/VRF split systems	11.0	9.0	80.0	90.0	2.2	2.7	20.0
	Close control	30.0	30.0	80.0	90.0	2.2	2.7	12.5
	HW heat pump: commercial	110.0	110.0	80.0	90.0	2.2	2.7	20.0
	Pool heat pump	2.8	2.8	80.0	90.0	2.2	2.7	17.5
Large AC	<350 kWr	40.0	40.0	85.0	95.0	4.0	4.5	20.0
	>350 & <500 kWr	60.0	60.0	85.0	95.0	4.0	4.5	25.0
	>500 & <1,000 kWr	210.0	210.0	85.0	95.0	4.0	4.5	25.0
	>1,000 kWr <b>e</b>	670.0	40.0	85.0	95.0	4.0	4.5	25.0
Small MAC	Passenger and LC Vehicle	0.629	0.622	67.0	90.0	5.7	7.1	18.6
Large MAC	Registered buses (>12 GMT)	9.0	5.5	80.0 <b>f</b>	90.0	8.6	7.3 <b>g</b>	20.0
	Registered buses (>4.5 & <12 GMT)	4.0	3.0	80.0 <b>f</b>	90.0	8.6	7.3 <b>g</b>	20.0
	Un- registered: passenger rail	15.0	15.0	80.0 <b>f</b>	90.0	8.6	7.3 <b>g</b>	30.0
	Un- registered: Locomotive	4.0	4.0	80.0 <b>f</b>	90.0	8.6	7.3 <b>g</b>	30.0
	RV and caravan	0.75	0.75	85.0	90.0	2.0	7.3 <b>g</b>	15.0
	Un- registered: off-road, defence and other (boat, etc.)	2.75	2.75	80.0	90.0	8.6	7.3 g	15.0

Product segment	Product category	Average charge (kg) a		EOL factors (%)		Rates (% of original charge)		Nominal average
		2012	2020	EOL b	Tech rec c	Service rate (2020)	Theoretical leak rate (2020)	lifespan (years)
	Registered marine and pleasure craft	2.25	2.25	80.0	90.0	8.6	7.3 <b>g</b>	15.0
Refrigerated cold food chain	Refrigeration cabinets: self-cont.	0.5	0.5	85.0	90.0	6.0	7.2	11.5
	Refrigeration beverage vending machines	0.25	0.25	85.0	90.0	6.0	7.2	12.0
	Beverage cooling (post mix)	0.7	0.7	85.0	90.0	6.0	7.2	8.0
	Ice makers	1.0	1.0	85.0	90.0	6.0	7.2	11.0
	Water dispensers (incl. bottle)	0.05	0.05	85.0	90.0	6.0	7.2	8.0
	Other self- cont. refrigeration equipment	0.5	0.5	85.0	90.0	6.0	7.2	12.0
	Walk-in cool rooms: mini: Slid- in/Drop-in	0.75	0.75	85.0	90.0	6.0	7.2	12.0
	Walk-in cool rooms: small: Slid- in/Drop-in	1.4	1.4	85.0	90.0	6.0	7.2	12.0
	Walk-in cool rooms: mini: remote	1.0	1.0	80.0	95.0	15.0	15.7	12.0
	Walk-in cool rooms: small: remote	5.0	5.0	80.0	95.0	15.0	15.7	12.0
	Walk-in cool rooms: medium	17.0	17.0	80.0	95.0	15.0	15.7	12.0
	Walk-in cool rooms: large	23.0	23.0	80.0	95.0	15.0	15.7	15.0
	Walk-in cool rooms: warehouse	30.0	30.0	80.0	95.0	15.0	15.7	20.0
	Refrigeration cabinets: remote	10.0	10.0	80.0	95.0	15.0	15.7	15.0

Product segment	Product category	Average charge (kg) a		EOL factors (%)		Rates (% of original charge)		Nominal average
		2012	2020	EOL b	Tech rec c	Service rate (2020)	Theoretical leak rate (2020)	lifespan (years)
	Beverage cooling (beer)	40.0	40.0	80.0	95.0	15.0	15.7	15.0
	Milk vat refrigeration	40.0	40.0	80.0	95.0	15.0	15.7	30.0
	Packaged liquid chillers (incl. Milk vat)	40.0	40.0	80.0	95.0	15.0	15.7	20.0
	Process and mfg. (<40 kWr)	40.0	40.0	80.0	95.0	15.0	15.7	20.0
	Supermarket refrig: small	500.0	500.0	100.0 <b>h</b>	95.0	11.8	11.8	15.0 <b>i</b>
	Supermarket refrig: medium	900.0	900.0	100.0 <b>h</b>	95.0	11.8	11.8	15.0 i
	Supermarket refrig: large	1,100.0	1,100.0	100.0 <b>h</b>	95.0	11.8	11.8	15.0 <b>i</b>
	Mobile refrig: road: trailer - inter-modal	10.0	6.5	90.0	95.0	15.0	15.7	12.5
	Mobile refrig: road: diesel drive	7.0	4.0	90.0	95.0	15.0%	15.7	12.5
	Mobile refrig: road: off engine	4.0	2.2	90.0	95.0	15.0	15.7	10.0
	Mobile refrig: marine	130.0	130.0	90.0	95.0	15.0	15.7	25.0
Domestic refrig.	Refrigerators and freezers j	0.140	0.133	90.0	95.0	0.25 <b>k</b>	1.7	
	Portable refrig.	0.055	0.055	95.0	90.0	0.25	1.7	16.5
	Vehicle refrig.	0.035	0.035	95%	0.0	0.25	1.7	12.0

EOL end of life.

**a** Average charge of the most common species found in that product category. Charges of other species used in the same product category may differ. **b** EOL factor used to calculate residual EOL charge at end of life. EOL factors generally consistent with others cited internationally (e.g., ICF 2010) and in IPCC good practice guides. **c** Calculated EOL charge in each segment has maximum technical recovery factor uniformly set at 90% – except for air conditioning chillers, supermarket systems and commercial refrigeration with remote condensing units where technical recovery rates are set to 95%. **d** Charge for HFC-410A, the most common refrigerant in single split systems during the transition from HCFC-22 to HFC-32, is 1.40 kg. **e** HCFC-123 charge is different with capacity range >500 and <1,000 kWr = 180 kg, and >1,000 kWr = 670 kg because they are generally large capacity models. **f** Large MAC EOL % adjusted to be consistent with commercial AC. **g** Theoretical leak rate across large MAC is lower due to low leak rate of RVs and caravans. **h** Supermarket refrigeration

adjusted to 100%, consistent with high service levels, recovery and re-use. i Supermarket lifespan relates to average plantroom refurbishment lifespan. j Refrigerators and freezers average charge for HC is 0.55 g. Portable and vehicle refrigeration rarely use HC. k Service rate in 2018 lowered to 0.25% because service of these appliances rarely involves refrigerant. If refrigerant is required, the unit is typically retired. Higher theoretical leak rate of 1.7% due to higher leak rates of older vintages in the stock model.

## 1.2.12 Hydrocarbons and equivalent refrigerant charge

The equivalent refrigerant charge is a tool used in this report to help visually compare different equipment types on the basis of the work that the refrigerants carry out. This has assisted in illustrating how different sectors are transitioning to new equipment – either at a particular point in time, or the rate of those transitions over time.

The equivalent refrigerant charge shows changing market share. Instead of showing this through the proportion of devices, it shows it through the proportion of refrigerant a particular piece of equipment or device would have used had newer low GWP technology, such as hydrocarbon, not replaced it.

It does not ignore or replace the 'actual' charge; it is an alternative measure used to help represent the rate of transition of the number of devices and the energy services they provide.

The model assesses the charge size and bank based on equivalent refrigerant charge and actual refrigerant charge. The equivalent charge size relates to the amount of high GWP HFC that will be displaced, not the actual charge of the lower GWP refrigerant which can be up to 70% less (e.g. hydrocarbon).

The equivalent charge provides a comparative representation of the rate of transition of the number of devices, and the energy services they provide whereas the actual refrigerant charges in aggregate can provide insights into the scale of the bank and skills required to service different refrigerant classes.

## 1.2.13 Leak rate improvements over time

When considering average economy-wide leak rates it is important to recognise that they generally improve over time. As older equipment retires and is replaced with new designs that employ improved containment, leak rates of new equipment are nearly universally found to be lower, with the effect that the average leak rates across a product category reduces over time.

The evolution of wall-hung and ducted split air conditioning equipment demonstrates this evolution in improved design and manufacturing capability. For instance, the older generation equipment from the 1990s and the 2000s, containing HCFC-22, has leak rates in the order of 8% per annum, versus current generation models with leak rates of around 3% per annum and less.

In addition, as field practices improve, and as the cost of refrigerant increases, leak rates decline and can do so very rapidly. This was amply demonstrated by the market response to the rapid rise in the price of HCFC-22 to wholesale prices of around \$100 per kg that has now stabilised at this level.

The Australian supermarket industry is another good example where leak rates at the beginning of the century were thought to be above 20% per annum, and hence the use of a leak rate of 23% by the *National Greenhouse and Energy Reporting Act 2007*. Current market intelligence and

reconciling usage shows leak rates of HFC-404A less than half this within the main supermarket chains. Supermarkets, and other segments of the industry that employ equipment that is maintained by engineers, have improved leak rates substantially since the introduction of the equivalent carbon tax in 2012. Even though this tax was only in place for two years, it appears to have substantially changed behavior in several sectors of the industry.

# 1.2.14 Losses at end-of-life and recoverable refrigerant

Refrigerant recovery is compulsory under the OPSGGM Act and the associated Regulations. Refrigerant Reclaim Australia (RRA), a not-for-profit organisation, is authorised by the Australian Competition and Consumer Commission (ACCC) to work with industry to recover, reclaim and destroy ozone depleting and synthetic greenhouse gases.

The EOL charge and therefore the potential end-of-life emissions are calculated by multiplying the average refrigerant charge by the EOL factor - the proportion of original charge remaining at end of life for each segment or equipment category, if available at that level. The EOL factors used are generally consistent with those used by the IPCC and ICF International in a variety of technical papers (ICF 2010).

The EOL charge multiplied by the technically recoverable factor (recovery efficiency/recycling factor) equates to the recoverable refrigerant, the amount that is available for either reclamation or destruction. Between 30 June 2007 and 30 June 2012 an average of about 500 tonnes of waste HCFCs and HFCs was collected and destroyed annually in Australia via the RRA scheme. The balance that is not destroyed, re-used nor reclaimed is considered a direct emission.

For some products direct emissions include losses calculated for appliances and equipment reaching the end of the product's useful life. The assumption for some products, such as domestic refrigerators and portable air conditioners, is that all of the remaining charge of refrigerant is lost to air and none is recovered.

# 1.2.15 New sales mix projections

Projections of new sales mix by species are based on linear projections of sales units by species in periods from 2018 to 2020, 2020 to 2025, and 2025 to 2030. The dominant substance is typically used as the residual portion to round off the proportion of sales to 100% and therefore is not linear. For example, with RCFC2: Medium Commercial Refrigeration, HFC-404A is the dominant substance and other substances such as HFC-134a, GWP<2150, GWP<1000 and GWP<10 have linear projections in the model between the nominated periods.

The CHF3 2021 RAC Model has new sales mix inputs for all product categories and aggregated outputs for segments (i.e. AC3: Medium AC: Ducted & light commercial).

New equipment sales mix by equipment type are in units, these sales mixes are multiplied by respective charges sizes by year to provide new sales mix by refrigerant mass. The new sales mix by mass for each equipment types is aggregated into respective product categories to provide an aggregated new sales mix output projection by refrigerant mass. The difference between the two is the input is a 'unit or quantity mix' and the output is an aggregated 'refrigerant mass mix'.

An example of the two sales mix projections is provided in Figures 4 and 5 for small AC: Split.

In this example, the input mix by units in 2018 is HFC-32: 52.9% and HFC-410A: 47.1% and the refrigerant output mix in the same year is HFC-32: 48.5% and HFC-410A: 51.5%. The difference arises due to the different average charge sizes of HFC-32 (1.160 kg) and HFC-410A (1.380 kg). There were more HFC-32 units imported by quantity in 2018, however the refrigerant mass was less due to the lower average charge. These portions are consistent with the pre-charged equipment import data by unit and refrigerant mass in *Appendix: B5: Stationary AC: Pre-charged equipment imports*, charge category  $\geq$  800 grams and < 2.6 kg.





# 1.2.16 GWPs and refrigerant compositions

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

Australia's original legally binding emissions obligations under the Kyoto Protocol (1997 to 2013) were calculated based on the GWP values published in the Second Assessment Report (AR2) of the International Panel on Climate Change (IPCC) released in 1996.

Revised GWP values were reported in the Fourth Assessment Report (AR4) in 2007. The 2nd Kyoto Protocol commitment period is based on AR4 values. The Australian Government adopted AR4 from July 2017. The *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* (the OPSGGM Act) uses AR4 values.

This report uses one hundred year GWP values from the Fourth Assessment Report (AR4 GWP-100). A new class of substances that are mentioned in this report are low GWP unsaturated HFCs known as hydrofluoro-olefins (HFOs) that were not available at the time of publication of AR4. As such the GWPs attributed to HFOs and HFO blends that are discussed herein are based on industry data (HFO-1234yf AR4-100 GWP of 5 and HFO-1234ze AR4-100 GWP of 5). While the Fifth Assessment Report includes HFO-1234yf and HFO-1234ze, the AR5 GWP-100 values have not been used. The AR5-100 GWPs of HFO-1234yf and HFO-1234ze have been revised down to 1.

Table 2 lists both AR2 and AR4 GWP values as a reference for readers, and Table 3 provides details of the refrigerant mass composition of common blends used in Australia that are used to calculate the GWPs of the blends from the IPCC reports.

Туре	Substance	AR2 GWP-100 Year	AR4 GWP-100 Year
CFCs, HCFCs and HCFC blends: ozone	CFC-11 <b>a</b>	3800	4750
depleting substances controlled by the Montreal Protocol	CFC-12 a	8100	10900
	HCFC-123	90	77
	HCFC-22	1500	1810
	HCFC-141b	n/a	725
	HCFC-142b	1800	2310
	HCFC-406A	n/a	1943
	HCFC-408A	n/a	3152
	HCFC-409A	n/a	1585
	HCFC-225ca <b>b</b>	n/a	122
	HCFC-225cb <b>b</b>	n/a	595
HFCs and HFC blends: synthetic	HFC-125	2800	3500
greenhouse gases controlled by the Montreal Protocol <b>c</b>	HFC-134a	1300	1430
	HFC-152a	140	124
	HFC-236fa	6300	9810
	HFC-32	650	675
	HFC-404A <b>d</b>	3260	3922
	HFC-407C	1526	1774
	HFC-407F	1824	2107
	HFC-410A	1725	2088
	HFC-417A	1955	2346
	HFC-428A	2930	2999
	HFC-438A	1890	2264
	HFC-507A	3300	3985

Table 2: Global warming potential (GWP) factors of main refrigerant species

Туре	Substance	AR2 GWP-100 Year	AR4 GWP-100 Year
	HFC-227ea <b>b</b>	2900	3220
	HFC-245fa <b>b</b>	n/a	1030
	HFC-365mfc <b>b</b>	n/a	794
HFC/HFO blends: HFC portion subject to HFC phase-down under the Montreal Protocol <b>c</b>	R448A	n/a	1386
	R449A	n/a	1396
	R450A	n/a	601
	R452A	n/a	2139
	R452B	n/a	676
	R454B	n/a	465
	R454C	n/a	148
	R455A	n/a	145
	R466A	n/a	733
	R513A	n/a	629
	R514A	n/a	2
	R515A	n/a	386
Nil or <10 GWP refrigerants			GWP value <b>e</b>
	Ammonia (R717)	n/a	0
	CO <sub>2</sub> (R744)	n/a	1
	HC-290	n/a	3
	HC-600a	n/a	3
	HFO-1233zd <b>f</b>	n/a	5
	HFO-1234yf <b>f</b>	n/a	5
	HFO-1234ze(E) f	n/a	5

**AR2** Second Assessment Report of the International Panel on Climate Change **AR4** Fourth Assessment Report of the International Panel on Climate Change **CFC** chlorofluorocarbon **CO**<sub>2</sub> carbon dioxide **HC** hydrocarbon **HCFC** hydrochlorofluorocarbon **HFC** hydrofluorocarbon **HFO** hydrofluoro-olefin

**a** No longer in common use, banned in 1996. **b** Not used as refrigerant, substances used for foam blowing applications, fire protection and as solvents. **c** GWP values of blends are calculated based on the mass composition of component substances listed in the IPCC assessment reports. **d** All references to HFC-404A throughout the report include both HFC-404A with a chemical composition of HFC-125/143a/134a (44/52/4) and HFC-507A with a chemical composition of HFC-125/143a (50/50) as they are very similar in mass composition and service the same applications. **e** GWP values for substances not listed in AR4 (carbon dioxide, GWP 1, is the reference for GWP values). **f** The GWP values of HFOs are those cited by the manufacturers as based on AR4. The GWPs of HFOs were re-evaluated by the UN since the AR4 report, with HFO-1233zd and HFO-1234ze given a GWP of 1; and HFO-1234yf a GWP of less than 1. This report uses previous cited values to maintain consistency.

ASHRAE refrigerant designation	Composition	Mass %
R404A	R125/R143a/R134a	44.0/52.0/4.0
R406A	R22/R600a/R142b	55.0/4.0/41.0
R407C	R32/R125/R134a	23.0/25.0/52.0
R407F	R32/R125/R134a	30.0/30.0/40.0
R408A	R125/R143a/R22	7.0/46.0/47.0
R409A	R22/R124/R142b	60.0/25.0/15.0
R409B	R22/R124/R142b	65.0/25.0/10.0
R410A	R32/R125	50.0/50.0
R422D	R125/R134A/R600A	65.1/31.5/3.4
R427A	R32/R125/R143a/R134a	15.0/25.0/10.0/50.0
R436A	R290/R600a	56.0/44.0
R438A	R125/R32/R134A/R600/R601a	45.0/5.0/45.0/4.0/1.0
R436B	R290/R600a	52.0/48.0
R448A	R1234yf/R1234ze/R32/R125/R134a	20.0/7.0/26.0/26.0/21.0
R449A	R1234yf/R32/R125/R134a	25.3/24.3/24.7/25.7
R452A	R1234yf/R32/R125	30.0/11.0/59.0
R454B	R32/R1234yf	68.9/31.1
R454C	R32/R1234yf	21.5/78.5
R455A	R32/R1234yf/R744	21.5/75.5/3.0
R507A	R125/R143a	50.0/50.0
R513A	R1234yf/R134a	56.0/44.0
R514A	R1336mzz(Z)/R1130(E)	74.7/25.3
R515A	R1234ze(E)/R227ea	88.0/12.0

# Table 3: ASHRAE refrigerant designation and refrigerant mass composition of common blends used in Australia

Note: Blends in the 400 series are zeotropes. Blends in the 500 series are azeotropes Source: ANSI/ASHRAE 34-2021

## **1.2.17** Energy consumption calculations and comparisons

The electrical consumption of products is estimated to allow a calculation of energy related emissions produced by each product, equipment category and segment.

CHF3 2016 electricity consumption calculations have been compared to the most relevant recent studies commissioned by the Equipment Energy Efficiency (E3) program of the Department of Industry, Science, Energy and Resources.

#### **Domestic refrigeration**

CHF3 2016 RAC Stock model estimates a total stock of greater than 19.2 million domestic refrigeration devices in Australia (including domestic freezers and small portable refrigerators).

The number of these devices that are used in residences is however less than that total stock of equipment. Deducting from this population of 19.2 million devices an estimated 888,000 portable refrigerators, that are run from vehicles, in caravans on and battery power of various sorts, and deducting a further estimated 5% of devices that are assumed to be used in business premises, such as restaurants and takeaway shops, and in office kitchens, and the CHF3 RAC Stock model arrives at an installed base of 17.41 million domestic refrigerators and freezers in residential buildings in Australia in 2016.

This is a value that aligns very well with the results of the Residential Baseline Study 2015 (E3 2015) which estimated an installed base of 17.68 million refrigerators and freezers in Australian homes in 2016.

The CHF3 2016 RAC Stock model calculates the 17.59 million domestic refrigerators and freezers consumed 8,534 GWh in 2016 compared to 29.59 PJ (8,219 GWh) published in the Residential Baseline Study for 2016.

#### Hot water heat pumps

The CHF3 2016 RAC Stock model estimates a stock of greater than 206,000 hot water heat pumps, a value that aligns with those published by the Clean Energy Regulator (CER 2021) of 210,649 devices registered at the end of 2016. The stock model assumes an average lifespan of 15 years, however reduces total stock at a slightly accelerated rate to account for older models that are more likely to have been retired since early 2000s.

As a result the CHF3 2016 RAC Stock model estimates the stock of hot water heat pumps at 206,000 units that consumed 186 GWh in 2016 compared to the Residential Baseline Study that estimated 196,378 devices consuming 0.633 PJ (176 GWh) in 2015.

#### Stationary air conditioning

CHF3 2016 stock numbers and energy use in stationary AC are based on slightly different equipment definitions and a larger number of categories than were used in the Consultation Regulation Impact Statement: Air conditioners and Chillers (E3 2016a). However by combining some of the categories used in CHF3, a comparison of the stocks used in both studies has been made in Table 4.

	CHF2: 2012		RIS: 2016	a	CHF3: 2016	
Equipment type	Stock	Energy use (GWh)	Stock	Energy use (GWh)	Stock	Energy use (GWh)
Non-ducted: unitary <b>b</b>	1,915,000	1,967	1,637,196	764	1,591,808	1,166
Portable AC <b>b</b>	606,000	534	789,897	176	826,561	309
Single split system: non-ducted <b>b</b>	7,145,000	7,542	7,864,553	5,652	9,238,148	7,972
Single split & packaged: ducted <b>b</b>	1,304,000	13,472	1,741,133	6,294	2,025,821	9,254
Multi split <b>b</b>	276,000	2,041	264,496	320	331,165	516
VRV/VRF split system <b>b</b>	276,000	2,041	86,204	626	93,547	617
Heat pump <b>c</b>	269,000	308	n/a	n/a	310,120	507
Close control <b>b</b>	11,500	1,478	20,449	1,553	20,872	1,544
Chiller	28,500	6,335	20,664	6,144	24,914	7,676
Chiller ancillaries <b>d</b>	n/a	3,167	n/a	n/a	n/a	3,838
Total	11,555,000	36,845	n/a	n/a	14,462,956	33,452

Table 4: Comparisons of stock and electricity of	consumption values: CHF2: 2012 vs RIS: 2016
vs CHF3: 2016	

AC air conditioner CHF2 Cold Hard Facts 2 CHF3 Cold Hard Facts 3 GWh gigawatt hours VRV/VRF variable refrigerant volume/variable refrigerant flow

**a** Energy modelling and cost benefit analysis (unpublished), EnergyConsult, prepared for Consultation Regulation Impact Statement: Air conditioners and Chillers, Department of Industry, Innovation and Science on behalf of the Equipment Energy Efficiency (E3) Program, 2016 (E3 2016a). **b** Energy consumption calculations include fan energy where the fan is incorporated into the equipment, which includes all residential and light commercial AC equipment. Fans separate to the equipment such as exhaust and ventilation fans are not included in the energy consumption.

**c** Domestic and commercial hot water heat pumps, swimming pool heat pumps and heat pump clothes dryers. **d** Chillers have separate ventilation systems and ancillaries including pumps and motors. Chiller ancillaries are estimated as 50% of the energy consumption of chillers.

#### **Residential AC electricity use calculations**

The CHF2 calculation of residential AC electricity use was based on 500 full load hours of cooling and heating combined and used average COP and EER efficiencies by equipment class without any discounting factors.

The AC RIS 2015 residential calculation was based a 2012 ABS survey of general operating hours of heating and cooling equipment by state, which calculated an average of 979 operating hours for a non-ducted single split system stock mix and 932 operating hours for a ducted equipment stock mix. A product adjustment factor of 0.75 was applied to non-ducted single split systems and heating hours discounted by a factor of 0.56 based on a stock weighted average.

Finally, the AC RIS incorporated part load calculations for a range of part load operating bins and efficiencies, which discounts the equivalent full load hours by varying amounts, depending on the efficiencies and variability of the technology type, before applying an occupancy factor of 0.9 to account for unoccupied dwellings (i.e. holiday homes). The result is that the AC RIS calculated electricity consumption on the basis of equipment being used for 250 full load hours for window wall units, 360 hours for non-ducted single split systems, and 450 hours for ducted single split systems.

The CHF3 residential calculation makes the same assumptions as the AC RIS 2015 except applies a part load to full load factor of 0.75 resulting in 454 full load hours, before applying an occupancy factor of 0.9 and a field efficiency factor of 0.9 for non-ducted single split systems and 0.85 for ducted systems that accounts for sub-optimal performance in the field versus rated efficiencies.

#### **Business electricity use calculations**

The CHF2 calculation of business electricity use was based on 1,255 full load hours (cooling plus heating) based on the assumption there were 251 working days (excluding weekends and statutory holidays), and the system operated 10 hours per day (i.e. 2,510 operating hours per annum) on full load 50% of the time.

The actual operating hours of businesses can vary significantly depending on the type of business. For example, many large supermarkets can be open from 7.00 am to 12.00 pm and only close for Christmas day, equating to more than 6,000 operating hours per annum. Smaller retail stores are often open weekdays plus half a day on the weekend and one night to 9.00 pm weekdays equating to around 2,800 operating hours per annum.

Many businesses have their air conditioning systems pre-programmed to operate around 10 hours per day to take into account occupants arriving early and leaving later. Some medium to large commercial, office and education buildings may have an air conditioning button that occupants can push to provide temporary conditioning outside normal working hours.

The AC RIS 2015 calculation of electricity use in businesses was based on 2,062 operating hours and undertakes part load calculations for a range of part load bins and efficiencies by technology type. When compared to a full load calculation the resulting hours of use in the RIS equates to around 955 full load hours for window wall units, 1,275 full load hours for non-ducted single split system, and, 1,870 full load hours for ducted single split systems.

CHF3 has assumed 251 working days on average (i.e. excludes weekends and statutory holidays), and equipment operating 10 hours per day (i.e. 2,510 operating hours per annum) on full load 40% of the time equating to 1,004 full load hours per annum for all residential style and light commercial equipment types that are installed in business premises.

Both the AC RIS process and CHF stock model would benefit from actual operating data from a variety of types of residences and businesses, which coupled with data on AC equipment efficiency in the field, would enable a much more accurate assessment of the part and full load operating hours of air conditioning equipment in commercial premises.

#### **Close Control AC**

CHF3 assumes that 81% of close control equipment is operating 8,760 hours per year, based on the assumption that 20% of systems have no back up, 40% of systems are 1 operating system to 1 back up, 25% of systems have 5 units operating with one back up, and 15% of large systems with 10 or more units have one back up. A part load to full load factor of 0.75 is then applied equating to 81% of the installed base operating 6,570 full load hours per annum (or 5,322 hours per piece of equipment across the fleet).

#### Proportion of residential and commercial

To allow calculation of indirect emissions as a result of electricity consumption in various product categories, an estimate of annual hours of use of the equipment types is used. Estimates of hours of use vary depending on whether the equipment is employed in a residential or a commercial setting. There are many smaller equipment types that are used in both residential and commercial settings. Table 5 lists the estimated percentage of 'commercial use' of the stock, applied to the product categories where this is the case.

As well as being used in the calculation of indirect emissions these ratios are also used in calculated annual expenditure on electricity as different national average electricity tariffs apply for residential and commercial users.

Product category	Stock used in commercial applications (%)
1Ph non-ducted split: <4kW	5
1Ph non-ducted split: 4-6kW	15
1Ph non-ducted split: 6-10kW	20
1Ph non-ducted split: >10kW	30
3Ph non-ducted split: up to 20kW	95
1Ph ducted	20
3Ph ducted: <20kW	80
3Ph ducted: 20-40kW	95
3Ph ducted: >40kW	100
1Ph non-ducted unitary: up to 10kW	30
1Ph non-ducted unitary: >10kW	100

# Table 5: Estimated proportion of stock used in commercial applications by productcategory

Product category	Stock used in commercial applications (%)
Portable AC: up to 10kW	5
3Ph non-ducted: 20-40kW	100
3Ph non-ducted: >40kW	100
Chillers	100
Multi split system	20
VRV/VRF split systems	75
Close control air conditioning	100
Hot water heat pump: commercial	100

**1Ph** single phase power **3Ph** three phase power **AC** air conditioner **VRV/VRF** variable refrigerant volume/variable refrigerant flow

# 1.2.18 Energy related greenhouse emissions

The total hours each product is operated per annum is multiplied by the electricity demand of each product, and by a national average greenhouse intensity factor for electricity, to arrive at an estimate of indirect, energy related greenhouse gas emissions.

In CHF2 the NGERS state based indirect (scope 2) emission factors from consumption of purchased electricity from a grid for the 2012-13 reporting year was used to calculate a national weighted average based on population using data from the Australian Bureau of Statistics (ABS 2012). The calculated national average for CHF2 in 2012 was 0.914 kg CO<sub>2</sub>e/kWh.

In CHF3 the latest national estimates for scope 2 emission factor for consumption of purchased electricity by end users were used. The scope 2 emission factor used in CHF 2021 was 0.78 kg  $CO_2e/kWh$  (Table 44, NGA Factors DISER 2020a). If scope 2 and 3 were used to account for generation, plus transmission and distribution network losses, the value would be 0.87 kg  $CO_2e/kWh$ .

Fuel combustion emissions for petrol and diesel used by transport refrigeration and mobile air conditioning were calculated using the relevant energy content emission factors for post 2004 vehicles.

Fuel type	Energy content factor (GJ/kL)	Emission factors (kg CO2e/GJ)		
		CO2	CH <sub>4</sub>	N20
Gasoline (petrol)	34.2	67.4	0.02	0.2
Diesel oil	38.6	69.9	0.01	0.5

# Table 6: Fuel combustion emission factors - fuels used for transport energy purposes forpost-2004 vehicles

Source: Table 4: Fuel combustion emissions factors – fuels used for transport energy factors, National Greenhouse Accounts Factors, DISER 2020a

## 1.2.19 Annual expenditure

The number of pieces of any product being imported, manufactured, sold, installed, and commissioned in any year is known from the stock model. The average cost to the end-user of that product is known from surveys of the market and interviews with suppliers. These two factors allow the calculation of total expenditure on RAC equipment in any year.

The quantity of refrigerants that are imported every year is known from the Department of Agriculture, Water and the Environment's bulk import data. The uses to which that refrigerant is put is deduced from the data underlying the calculation of the bank of refrigerants. The cost to the end-users of that refrigerant is known from market surveys and information from wholesalers (i.e. list prices and discounts) and service contractors (i.e. mark-ups to end-users). These factors allow the calculation of total annual expenditure by end-users on refrigerant.

The quantity of electricity consumed in RAC equipment is calculated and an average per kWh price applied to provide an estimate of annual expenditure by equipment and appliance owners on electricity consumed in the equipment. Three national average rates were used in the model, one for commercial end-users, industrial end-users such as cold storage facilities and residential.

Average State based prices up to 2017 were sourced from Australian Energy Market Operator (AEMO) National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, AEMO, published 2017 and national average prices were calculated based on population weightings. Residential, commercial and industrial national average prices have increased from 0.28, 0.16 and 0.13 c/kWh in 2016 to a projected 0.36, 0.24 and 0.21 c/kWh in 2018. Prices for 2018 used AEMO projected prices, as the AEMO 2018 Electricity Statement of Opportunities now only publishes the Price Index, not the actual prices. CHF 2020 uses prices from the Australian Competition & Consumer Commission, Inquiry into the National Electricity Market November 2019. With residential 0.287 c/kWh; SME 0.28 c/kWh; and, commercial and industrial 0.167 c/kWh.

The assumptions made about the proportion of different classes of air conditioning equipment found in commercial applications are tabulated in Table 5: Estimated air conditioning proportion of use in commercial applications. These estimates are based on information provided by major importers and manufacturers, and on first-hand experience of the market for air conditioning equipment in Australia, where some large ducted systems are used in the residential sector, and many small units are found being employed in commercial and retail applications.

The proportion of equipment used in commercial applications influences the result of the calculation of the energy spend because of the different hours of use of commercial equipment versus residential equipment, and because of the different electricity prices applied to commercial equipment.

All domestic refrigeration equipment used the residential tariff. Devices in the refrigerated cold food chain used the commercial rate.

# **1.3** RAC Stock model outputs and projections

The main outputs and projections of the model are:

- Annual refrigerant use of all RAC technology and of classes, segments and some product categories.
- Indirect emissions as a result of energy use by RAC technology owned by commercial enterprises and privately.
- The bank of refrigerant employed in the entire stock of equipment, and in various classes, segments and product categories of the stock.
- Direct emissions by product category in most cases, by segment and class, and as an economy wide average from the entire bank.
- Projections for predicted sales mix of new equipment by the type of refrigerant in that equipment.
- End-of-life emissions from the entire stock of equipment and from some classes and segments of the stock.

The RAC Stock model can also be used to generate projections of the working banks of refrigerant by class, and, in some cases by equipment segment.

The model also produces projections of annual service use by refrigerant type from 2016 to 2030. Projections are calculated in metric tonnes and in millions of tonnes CO<sub>2</sub>e. This enables the model to be used to estimate and analyse the future refrigerant bank in the economy as compared to the bank required under international agreements to phase down HFCs and an overall reduction in greenhouse gas emissions. An example is shown in Figure 6 (tonnes) and Figure 7 (Mt CO<sub>2</sub>e) of the small MAC bank based on the equivalent bank.



**MAC** mobile air conditioning



MAC mobile air conditioning Mt million tonnes CO2e carbon dioxide equivalent

Charts and tables illustrating projected changes of the various banks are published in *Appendix B3: Bank projections by class and segment.* 

# 1.4 HVAC & R supply chain business types and end use applications

Understanding the types of businesses in the HVAC&R supply chain and end use applications is important when defining the industry boundaries in terms of business and employment counts. A list of end use applications is provided on the following page. Equipment and services suppliers to these end use applications are generally considered part of the industry sector.

Types of businesses in the HVAC&R industry include:

- Wholesalers (major and independents: full HVAC&R range, air conditioning, auto air, etc.)
- Contractors (installation, service and maintenance)

- Equipment manufacturers
- Equipment suppliers (air conditioning, evaporative coolers, heating, hot water heat pumps, hydronic, commercial refrigeration, domestic refrigeration)
- Component suppliers (compressors, fans, coils, chilled beams, refrigerant, etc.)
- Cool room suppliers (panel and contractors)
- Controls and instrumentation suppliers (IS, software, electronics, data logging, VSDs, sensing/measuring, temp/humidity/air flow/air quality, etc.)
- Filtration and environmental services (supply and cleaning)
- Air movement (ducts, sheet metal, fittings, registers, dampers, diffusers, accessories)
- Fans and ventilation
- Mechanical services engineers
- Consulting and design engineers
- Commissioning engineers
- Energy efficiency and specialist (i.e. natural refrigerants) engineers
- Facilities maintenance
- Accessory suppliers (insulation, pipes, fittings, pumps, valves, lighting, tools, chemicals, oils, corrosion protection, etc.)
- Cooling tower specialist
- Rental companies (air conditioning equipment for events and breakdowns)
- Business services (insurance brokers, etc.)
- Technical services (equipment testing, scientific, calibration, etc.)

#### End use applications

The following is a list of some of the important industrial and commercial applications where RAC systems are found across the Australian economy. This list does not include the common and populous applications of domestic refrigeration and residential air conditioning with which readers would be familiar. This provides an insight into the wide applications of RAC systems that the taxonomy does not reveal, based as that is on the format and capacity of the enabling technology employed in the applications listed below.

If there was any question about the central and essential energy service role that RAC technology plays in the Australian economy, simply read the following list and imagine how the environments and processes listed would be without being serviced by RAC systems.

#### Stationary air conditioning systems

Non-residential buildings ventilation and air conditioning systems:

Commercial and government office accommodation

- Education (all generally also including some larger format refrigeration) such as schools, universities and TAFEs
- Community buildings
- Hospitals and health facilities including mortuaries
- Hotels and accommodation
- Industrial
- Convention centres, retail malls and food courts
- Entertainment, restaurants, swimming pools, gyms
- Transport hubs, underground train stations, airports
- Close Control facilities:
- Computing, server farms and UPS
- Telecommunications switching, PABX and UPS
- Museums, galleries, archives and specialised storage
- Pharmaceutical
- Labs and testing

#### Mobile air conditioning systems

Air conditioned and refrigerated transport:

- Light commercial
- Buses
- Recreational vehicles, mobile homes and caravans
- Mining & construction
- Trains
- Agricultural (including tractors, harvesters)
- Refrigerated trucks & trailers (cold food chain)

#### Aviation:

- Commercial passenger airlines
- Military aviation
- Private and charter aircraft

Maritime systems:

- Fishing fleet
- Specialised sea freight
- Passenger liners
- Luxury boats and private charter

Defence field systems and emergency services

#### Refrigerated cold food chain, industrial and process systems

Commercial refrigeration:

- On farm cool rooms (horticulture, vegetables, wine grapes)
- Aquaculture & wild caught seafood
- Food transport and distribution centres
- Retail display
- Supermarkets
- Pharmaceuticals

Process chillers & industrial refrigeration:

- Brewing and wine making
- Dairy industry
- Milk harvesting and storage
- Milk processing
- Cheese industry
- Food processing (confectionary, frozen foods, drinks, fruit juice, chilled water as additive)
- Ice making

Industrial chiller applications:

- Plastics/die cooling
- Electronic plating
- Printing machines & associated equipment
- Dry cleaning
- Construction
- Laser cutting equipment
- Chilling of water for industrial processes

Other large chiller deep freeze applications:

- Water cooling for medical or chemical equipment such as SEM, MRI and X-Ray units
- Petro-chemical/gas & chemical
- Medical/pharmaceutical/serum/plasma
- Co-generation/tri-generation
- Mining and tunnels
- Liquefaction and cryogenics

Power generation industry:

Mobile plant

Other applications:

- Water coolers
- Heat pump pool heaters

# **2** Glossary

Term	Definition
ABS	Australian Bureau of Statistics
AC	Air conditioning
ammonia refrigerant	Anhydrous ammonia (R717) has excellent thermodynamic properties and a GWP of zero, making it effective as a refrigerant, and is widely used in large cold storage facilities and process refrigeration applications because of its high energy efficiency and relatively low cost. Ammonia is used less frequently in commercial refrigeration applications, such as in supermarket and food retail, freezer cases and refrigerated displays due to its toxicity, and the proximity of the general public.
ANZSCO	Australian and New Zealand Standard Classification of Occupations
AR2	Second Assessment Report of the IPCC
AR4	Fourth Assessment Report of the IPCC
AR5	Fifth Assessment Report of the IPCC
ARC	Australian Refrigeration Council
Article 5 countries	Article 5 of the Montreal Protocol describes the special situation of developing countries. Article 5 countries are developing countries.
BCA	Building Code of Australia
bottom-up model	Method of estimation whereby the average refrigerant charge contained in individual appliances, equipment and product categories that make up the stock of equipment is estimated separately. The individual results are then aggregated to produce an estimate of the refrigerant bank by refrigerant species.
bulk importers	Companies with a licence to import bulk refrigerant.
carbon tax	Synthetic greenhouse gases listed under the Kyoto Protocol had an equivalent carbon tax applied through the <i>Ozone Protection and Synthetic Greenhouse Gas Management Act 1989</i> between July 2012 and June 2014. Gases covered were hydrofluorocarbons, perfluorocarbons (excluding gases produced from aluminium smelting) and sulfur hexafluoride, whether in bulk form or contained in equipment.
cascade refrigeration system	A cascade system is made up of two separate but connected refrigeration systems, each of which has a vapour compression refrigerant circuit including a compressor, evaporator and condenser that are interconnected via a heat exchanger. The separate refrigerant circuits work in concert to reach the desired temperature(s). Cascade refrigeration systems are also sometimes referred to simply as an 'advanced refrigeration system'. The most common configuration in Australia is with HFC-134a as the primary refrigerant and R744 (CO <sub>2</sub> ) as the secondary refrigerant.
CHF1	Cold Hard Facts 1, the original refrigeration and air conditioning (RAC) study undertaken by the authors in 2007 based on 2006 data.
CHF2 and CHF3	Cold Hard Facts 2 and 3, updated studies of the RAC industry in Australia with an expanded brief to encompass new application/equipment classes, new and emerging refrigerants, and report on the refrigerant bank. The second RAC study was undertaken in 2013 based on 2012 data. The CHF3 study was undertaken in 2017 based on 2016 data, and subsequent studies have been undertaken based on 2017, 2018 and 2019 data based on the CHF3 methodology.
chlorofluorocarbons (CFCs)	Molecules containing carbon, fluorine, and chlorine. CFCs are one of the major ozone depleting substances phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer. CFCs are also potent greenhouse gases. CFCs and HCFCs are not counted as part of the GHGs reported under the Kyoto Protocol of the United Nations Framework Convention on Climate Change, as they managed through the Montreal Protocol.
coefficient of performance (COP)	The ratio of the heat extraction rate divided by the power consumed by the refrigeration compressor(s) and necessary ancillaries. The COP is dimensionless and

Term	Definition
	is used to express the system efficiency. COP is also an efficiency measure used for reverse cycle air conditioners when operating in heating mode. Greenhouse and Energy Minimum Standards for split system air conditioning now use an annualised version of these metrics; annual energy efficiency ratio (AEER) and annual coefficient of performance (ACOP).
compressor	A device in the air conditioning or refrigeration circuit which compresses refrigerant vapour and circulates that refrigerant through to its phases of condensation and evaporation, in order to produce the refrigeration effect. The compressor is available in many forms such as piston, scroll, or screw.
compressor rack	The machine assembly or system which accommodates the main high pressure components of a refrigeration circuit in a single structure, allowing off site connection to associated pipe work and vessels.
condensing unit	Condensing units exhibit refrigerating capacities ranging typically from 1 kWr to 65 kWr; they are composed of one (or two) compressor(s), one condenser, and one receiver assembled into a 'condensing unit'.
CO <sub>2</sub> e	Carbon dioxide equivalent is a measure that quantifies different greenhouse gases in terms of the amount of carbon dioxide that would deliver the same global warming.
CO <sub>2</sub> refrigerant	Carbon dioxide is a widely used industrial refrigerant with high thermodynamic properties, and is suitable for process refrigeration applications, and automotive air conditioning use. In the past its high operating pressures have limited its use in small to medium commercial refrigeration applications. Technical innovation such as micro cascade systems and commercial availability of components such as compressors and other in line accessories is assisting its transition into smaller scale applications.
DAWE	The Department of Agriculture, Water and the Environment (DAWE) commenced operation on 1 February 2020, formerly:
	Department of the Environment and Energy (DoEE)
	Department of the Environment (DoE)
	Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC)
	Department of Climate Change and Energy Efficiency (DCCEE)
	Department of Environment, Water, Heritage and the Arts (DEWHA)
direct emissions	Emissions of refrigerant directly from equipment. Measured in CO2e.
drop-in refrigerant	Drop-in (or near drop-in) refrigerant replacements are refrigerants that are intended to replace the original refrigerant with the same refrigerant classification (e.g. A1) and similar technical specification and keep the system running to the same or similar specification. Examples of HCFC-22/CFC replacements include HFC-422D, HFC-437A, HFC-417A, HFC-422A, HFC-438A, HFC-426A, HFC-424A, HFC-428A, HCFC-508B, HCFC-508B, HCFC-408A and HCFC-409A. Refer to refrigerant supplier instructions for further details.
energy efficiency ratio (EER)	The ratio of the cooling output (kWr) divided by the total electric energy input. The EER is dimensionless and is used to express the air conditioning system cooling efficiency. Greenhouse and Energy Minimum Standards (GEMS) for split system air conditioning now use an annualised version of this metric (AEER), refer to COP definition.
energy consumption per year	Energy consumption of the appliance, equipment or system per annum in kWh per year, or GWh per year for an application or equipment sector.
end-of-life (EOL) equipment	Domestic, commercial or industrial device reaching the end of its useful lifespan.
end-of-life (EOL) emissions	End-of-life (EOL) emissions are direct emissions of ozone depleting substance (ODS) and synthetic greenhouse gases (SGG) not recovered for destruction or reclamation.
end-of-life vehicles (ELV)	Passenger and light commercial vehicles with a gross vehicle mass less than 3.5 tonnes that have been de-registered according to the State and Territory motor vehicle registration authorities (i.e. assumes a one month period of grace with renewals).

Term	Definition
equivalent and actual refrigerant charge	Some modern, lower GWP refrigerants, such as hydrocarbons, require much smaller refrigerant charge sizes to do the same work as some older generation higher GWP refrigerants.
	The 'equivalent charge' is a measure of the amount of high GWP HFC that would have been used in a particular piece or class of equipment had low GWP refrigerants not replaced it. For some charting and visualisation purposes the 'equivalent charge' is then attributed to the lower GWP refrigerant that displaces it. For other measuring and comparison purposes the 'actual' charge of low GWP refrigerants are used. Refer refrigerant charge in glossary.
E3	Equipment Energy Efficiency Committee of the Council of Australian Governments (COAG) which operated under the Ministerial Committee on Energy and was administered by the Department of the Environment and Energy (Now the Department of Industry, Science, Energy and Resources).
gas	A general term used in reports where applications extend beyond refrigeration and air conditioning equipment as a working fluid and include fire protection, aerosols and foam blowing. The term refers to ozone depleting substances, synthetic greenhouse gases and natural refrigerants.
GEMS	Greenhouse and Energy Minimum Standards administered by the Department of Industry, Science, Energy and Resources, see www.energyrating.gov.au
global warming potential (GWP)	Global warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. A GWP is calculated over a specific time interval, commonly 20, 100, or 500 years and is expressed as a factor of carbon dioxide (whose GWP is standardised to 1). The Kyoto Protocol and Montreal Protocol are based on GWPs from pulse emissions over a 100-year time frame abbreviated as GWP-100.
greenhouse gas/es (GHG)	The Kyoto Protocol $2^{nd}$ commitment period covers emissions of seven main greenhouse gases, namely carbon dioxide (CO <sub>2</sub> ); methane (CH <sub>4</sub> ); nitrous oxide (N <sub>2</sub> O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulfur hexafluoride (SF <sub>6</sub> ) and nitrogen trifluoride (NF <sub>3</sub> ).
GVM	Gross vehicle mass
GWh	Gigawatt hours is a unit of measurement for electricity use (1 watt hour x $10^9$ ).
high GWP substances or refrigerants	For the purposes of this report this term is used to refer to refrigerants commonly used today with GWPs greater than 1400. This includes the widely employed HFC- 404A (GWP of 3922), HFC-410A (GWP of 2088) and HFC-134a (GWP of 1430). Refer to definition of reduced GWP refrigerants and low GWP refrigerants.
hydrocarbons (HCs)	Hydrocarbon is a chemical that contains only carbon and hydrogen. The term hydrocarbon used in this report refers to the main types and blends of hydrocarbon refrigerant in use in Australia including HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290). Users should refer to equipment manufacturer installation guidelines for further details.
hydrochlorofluorocarbons (HCFCs)	Chemicals that contains hydrogen, fluorine, chlorine, and carbon. They deplete the ozone layer, but have less potency compared to CFCs. Many HCFCs are potent greenhouse gases. HCFC-22 is the most common refrigerant in the Australian refrigerant bank. CFCs and HCFCs are not included in the GHGs reported under the Kyoto Protocol or United Nations Convention on Climate Change, as they are managed through the Montreal Protocol.
hydrofluorocarbons (HFCs)	Chemicals that contain hydrogen, fluorine, and carbon. They do not deplete the ozone layer and have been used as substitutes for CFCs and HCFCs. Many HFCs are potent greenhouse gases.
hydrofluoro-olefins (HFOs), and HFO blends	Chemicals known as hydrofluoro-olefins that contain hydrogen, fluorine, and carbon, and are described as unsaturated HFCs. They do not deplete the ozone layer and have very low GWP values. For example HFO-1234yf and HFO-1234ze were originally cited by industry to have a GWP of 5, and a GWP-100 of 1 based on AR5. Refer <i>Section 3.4</i> for further details.
HVAC&R	Heating, ventilation, air conditioning and refrigeration

Term	Definition
IEA	International Energy Agency
indirect emissions	Emissions from the generation of the electrical energy required to operate electrical equipment, sometimes also referred to as 'energy related emissions.' Measured in $CO_2e$ .
indirect emission factor	The indirect or $CO_2$ emission factor is the mass of $CO_2$ emitted by the power generator per kWh of electrical power supplied to the refrigeration installation taking into account efficiency losses in generation and distribution.
IPCC	Intergovernmental Panel on Climate Change
Kigali Amendment	The Kigali Amendment to the Montreal Protocol agrees a phase-down of HFC production and imports starting from 1 January 2019. It sets out a timetable for a phase-down of HFC production and imports that results in total HFC production and imports falling to 15% of the baseline levels from 2036 onwards. Australia started its phase down of HFCs one year earlier on 1 January 2018.
kt	Kilotonnes, or thousand tonnes
kWh	Kilowatt hour (1 watt hour x 10 <sup>3</sup> ).
kWr	Kilowatt refrigeration, refers to kilowatts of refrigeration capacity whereas kW relates to kilowatts of electrical power.
Kyoto Protocol	The Kyoto Protocol to the United Nations Framework Convention on Climate Change sets binding emissions limits for the seven greenhouse gases listed in the protocol. The Australian Government committed to reducing emissions of the seven main greenhouse gases, which includes the synthetic greenhouse gases (SGGs) listed under the Kyoto Protocol, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF <sub>6</sub> ) and nitrogen trifluoride. The Paris Agreement follows the Kyoto Protocol.
lifespan	Lifespan is the expected useful life of the equipment in years.
LPG	Liquefied petroleum gas
L	Litre
low GWP substances or refrigerants	For the purposes of this report this term is used to refer to refrigerants with a GWP of less than or equal to 10, including the 'natural' refrigerants (CO <sub>2</sub> , ammonia, hydrocarbons), and the newly commercial HFOs sometimes referred to as low GWP HFCs. Refer to the definitions for High GWP Refrigerants and Reduced GWP Refrigerants.
low temperature refrigeration	Te0mperatures below 0°C.
MAC	Mobile air conditioning
minimum energy performance standards (MEPS)	The Minimum Energy Performance Standard is a specification, containing a number of performance requirements for energy-using devices that effectively limits the maximum amount of energy that may be consumed by a product in performing a specified task. MEPS is regulated under the Greenhouse and Energy Minimum Standards Act 2012 and in the RAC sector covers domestic refrigerators, refrigerated display cases, and most air conditioners (excluding single duct portable, spot coolers, and chillers below 350 kWr).
MJ	Megajoule, or million joules
Montreal Protocol	The Montreal Protocol on Substances that Deplete the Ozone Layer sets binding obligations for all countries to phase out import and production of ozone depleting substances and phase-down obligations for HFCs.
Mt	Megatonne, or million tonnes
natural refrigerants	Hydrocarbons (R600a, R290 and R436), ammonia (R717) and carbon dioxide (R744) are commonly referred to as natural refrigerants. The term 'natural' implies the origin of the fluids as they occur in nature as a result of geological and/or biological processes, unlike fluorinated substances that are synthesised chemicals. However it has to be noted that all 'natural' refrigerants are refined and compressed by bulk gas

Term	Definition
	manufacturers via some process and transported like other commercial gases so also have an 'energy investment' in their creation, storage and transport.
OEM	Original equipment manufacturer
OHS	Occupational Health and Safety
operating hours per year	The number of hours the appliance, equipment or system operates at full input load or maximum capacity.
OPSGGM Act	Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, including amendments
ozone depleting substances (ODS)	Chemicals that deplete the ozone layer (e.g. HCFCs) and are controlled under the Montreal Protocol. The <u>Ozone Protection and Synthetic Greenhouse Gas Management</u> <u>Act 1989</u> controls the manufacture, import and export of ozone depleting substances in Australia.
РЈ	Petajoule (10 <sup>15</sup> joules).
pre-charged equipment (PCE)	Pre-charged equipment is defined as any equipment, primarily air conditioning equipment or refrigeration equipment, (including equipment fitted to a motor vehicle) that is imported containing an SGG and any air conditioning or refrigeration equipment that is imported containing a HCFC.
RAC	Refrigeration and air conditioning.
RAC stock model	The Expert Group RAC Stock Model is an age-cohort mass balance stock model. Inputs include bulk imports by HFC and HCFC species since 2005; pre-charged equipment (PCE) imports by HFC species by equipment class since 2005; PCE containing HCFCs (largely banned in 2010); motor vehicle registrations; monthly sales (\$ and quantity) of HCFCs and HFCs by species including refrigerant re-use; equipment sales data (air conditioning and refrigeration equipment by type); data from targeted surveys including usage of HFC-134a in mobile AC aftermarket; annual sales of natural refrigerants (HC, CO <sub>2</sub> and ammonia) last 7 years; retail market survey of HC in domestic refrigerators on showroom floors; penetration of CO <sub>2</sub> in various equipment categories and applications; and, in-confidence interviews.
recovery efficiency	Proportion of refrigerant charge that is recovered from a system when it is decommissioned at the end of its useful working life. The recovery/recycling factor has a value from 0 to 1 with a value of 1 indicating that the entire charge is recovered.
reduced GWP substances or refrigerants	This term has been used for the purpose of this report. A number of recently developed or used HFC substances or refrigerants that have significantly reduced GWP relative to those commonly used high GWP refrigerants they are designed to replace. HFC-32 (GWP 675) and blends with GWPs less than 1400 and greater than 10, are referred to as reduced GWP refrigerants. For example, N40 (R-448A) with a GWP of 1387 is a zeotropic blend designed to serve as a replacement for HCFC-22 (GWP of 1810) and HFC-404A (GWP of 3922) in supermarket refrigeration retrofits, or in new systems. Refer to definition of High GWP Refrigerants and Low GWP Refrigerants.
refrigerant	Working fluid in the vapour compression refrigeration cycle.
refrigerant bank	The 'bank' of refrigerant gases is the aggregate of all compounds and substances employed as working fluids in the more than 50 million mechanical devices using the vapour compression cycle in Australia. Refrigerant in pre-charged imports is included in this value in the year of import. Refrigerant in equipment that is estimated to have retired from service in any year is not included. The 'Full Bank', or fully charged bank, is calculated based on the number of devices in the product category multiplied by the average original charge of that type of
	equipment when it is initially installed/purchased. The 'Partially Charged Bank' generally referred to in this report simply as 'the Bank',
	or sometimes as the 'working bank', will in practice, be less than the fully charged bank as the charge in individual pieces of equipment in the category declines over time until the equipment retires.
refrigerant charge	The original refrigerant charge of refrigerant used as the working fluid for heat transfer inside a piece of equipment.

Term	Definition		
refrigerant classifications	AS/NZS ISO 817: 2016 Refrigerants - Designation and safety classification assigns safety classification to refrigerants based on toxicity and flammability data; and provides a means of determining the refrigerant concentration limit.		
	Safety Group		
		Lower Toxicity	Higher Toxicity
	Higher Flammability	A3	B3
	Flammable	A2	B2
	Lower Flammability	A2L	B2L
	No Flame Propagation	A1	B1
	A1 group refrigerants inclu	de the majority of HFCs and I	HCFCs.
	A2L group refrigerants incl	ude HFO-1234yf and HFC-32	
	B2L group refrigerants inclu	ude R717 (Ammonia).	
	Refer to AS/NZS ISO 817, Su Installation Guidelines for f	upplier Material Data Sheets urther details.	and equipment supplier
refrigerant consumption	The Montreal Protocol definition of consumption is bulk imports plus refrigerant manufacture minus bulk exports. Australia has not manufactured refrigerant since 1996. Bulk refrigerant is imported and used largely for servicing the existing refrigerant bank of equipment, as well as charging new equipment not imported as pre-charged equipment (PCE) and in other applications including foams, fire protection, aerosols, export and other. Refer definition refrigerant usage.		
refrigerant decanting into tradable quantities	There are three significant import/decanting facilities in Australia. Gas is decanted at these sites into thousands of cylinders ranging in size through 10 kg, 18 kg, 60 kg and larger transportable tanks. Transportable tanks with a volumetric capacity of approximately 900 litres are commonly referred to as 'one tonners', and 'half tonners' for tanks with a 450 litres capacity. These transportable tanks can contain between 400 kg and 700 kg of product depending on the gas involved.		
refrigerant glide	The difference between the temperature at which all of saturated liquid temperatur to boil in the evaporator) is	saturated vapour temperatu the refrigerant has been con re (temperature at which a li referred to as the temperatu	rre (or dew point, the densed to liquid) and the quid refrigerant first begins rre glide of the refrigerant.
	At a given pressure, single of and are therefore azeotrope differently and have measur condense at a constant press 404A is a near azeotrope.	component refrigerants such es. Refrigerant mixtures (bler rable temperature glide whe esure. HFC-507A is an azeotro	as HFC-134a have zero glide nds) behave somewhat n they evaporate (boil) and opic blend whereas HFC-
refrigerant leak rate or effective leak rate	The leak rate referred to in charge lost per annum and operation plus: catastrophic during service and mainten mobile air conditioning equ from vehicle crashes, which	this report is expressed as a is calculated as the sum of gr c losses amortised over the li ance; and, gas lost along the ipment, the annual leak rate are classed as catastrophic l	percentage of the initial adual leaks during normal fe of the equipment; losses supply chain. In the case of takes into account losses osses.
refrigerant reclamation	Refrigerant reclamation ref specifications, most commo establishes purity specificat refrigerants to verify compo repackaged). The quality of analysis and meet or exceed required of virgin refrigeran	ers to the reprocessing of use nly by a process of fractional cions and specifies methods of osition regardless of source ( the reclaimed product must I AHRI 700 specifications wh nts.	ed refrigerants to AHRI 700 l distillation. AHRI 700 of testing for fluorocarbon new, reclaimed and/or be verified by chemical lich are the same standards
refrigerant recovery	Recovery refers to the remo approved recovery containe processing or analytical tes	oval of refrigerants from equi er. As defined by the AHRI, re ting.	ipment and collection in an ecovery does not involve
refrigerant species	A refrigerant species is defi For example CFCs, HCFCs a different gas species. Simila	ned as a refrigerant category nd HFCs are all synthetic gas rly hydrocarbon refrigerant	based on its chemical family. es and are defined as is another gas species, and

Term	Definition
	HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290) refrigerants are all part of this family. Other gas species include anhydrous ammonia and carbon dioxide.
refrigerant usage	Refrigerant usage is the refrigerant used in the economy installing and manufacturing new equipment and maintaining existing equipment. Refer definition refrigerant consumption.
refrigerated cold food chain (RCFC)	The refrigerated cold food chain is part of the food value chain, which involves transport, storage, primary and secondary processors, distribution and retailing of chilled and frozen foods from farm gate to consumer. However, in this report domestic refrigeration and freezers are treated as a separate segment.
remote condensing unit	Condensing unit located remotely from the evaporator, typically outdoors (see condensing unit).
remote RDC	Refrigerated display cabinet (RDC) with its refrigerating machinery (condensing unit or refrigeration plant) sited remote from the cabinet structure that is located inside the supermarket or store.
RHL	Refrigerant handling licence
RRA	Refrigerant Reclaim Australia
RTA	Refrigerant trading authorisation
self-contained RDC	Refrigerated display cabinet with its refrigerating machinery sited inside the cabinet structure.
Second Assessment Report (AR2)	Second Assessment Report of the Intergovernmental Panel on Climate Change for the United Nations Framework Convention on Climate Change, released in 1996. Australia's legally binding emission obligations under the first Kyoto Protocol commitment period were calculated based on AR2.
Fourth Assessment Report (AR4)	Fourth Assessment Report of the Intergovernmental Panel on Climate Change for the United Nations Framework Convention on Climate Change, released in 2007. Australia's legally binding emission obligations under the second Kyoto Protocol commitment period are calculated based on AR4. AR4 GWP values are used throughout this report, unless stated.
specific energy consumption (SEC)	Energy consumption benchmark used in large cold storage facilities in kWh per m <sup>3</sup> per annum.
synthetic greenhouse gas (SGG)	SGGs listed under the Kyoto Protocol and regulated under the <u>Ozone Protection and</u> <u>Synthetic Greenhouse Gas Management Act 1989</u> , hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) sulfur hexafluoride (SF <sub>6</sub> ) and nitrogen trifluoride (NF <sub>3</sub> ).
synthetic substances or synthetic refrigerants	HCFCs, HFCs and HFOs are commonly referred to as synthetic substances or synthetic refrigerants.
TAFE	Technical and Further Education
technology segment	A term used by the authors to refer to a defined set of technologies within the HVAC&R industry sector. A segment of the broad family of technologies employed in the HVAC&R sector is defined by the application (i.e. mobile or stationary, commercial or residential) and then bounded by a range of size of the charge of working gas, although for the purpose of modeling an average charge size for each segment has been calculated.
tonne (t)	Metric tonne
truck refrigeration unit (TRU)	TRUs are refrigeration systems powered by dedicated diesel internal combustion engines designed to refrigerate fresh and frozen perishable products (mostly food but also pharmaceuticals and other materials) that are transported on semi-trailers, rigid trucks and rail cars. Fresh is typically classed as 2°C and frozen -20°C.
UNFCCC	United Nations Framework Convention on Climate Change
VRV/F	Variable refrigerant volume/flow
walk-in cool room	A walk-in cool room is a structure formed by an insulated enclosure of walls and ceiling, having a door through which personnel can pass and close behind them. The

Term

#### Definition

floor space occupied by this structure may or may not be insulated, depending on the operating temperature level.

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