


Appendix A: Methodology – Taxonomy, data and assumptions




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Table of Contents

Appendices

List of Figures

List of Tables

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1 Appendix A: Methodology – Taxonomy, data and assumptions

1.1 *Taxonomy of a technology*

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

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

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

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

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

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

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

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

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

1. Class
2. Segment
3. Product category

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

- Stationary air conditioning – AC
- Mobile air conditioning – MAC

- Domestic refrigeration – DR
- Refrigerated cold food chain – RCFC

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

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

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

For instance the stationary air conditioning class includes ‘Single split: non-ducted’ (AC2-1 and AC2-2) and ‘Single split system: Ducted (AC3-1), describing the two most numerous equipment formats where the indoor evaporator is mounted separately from the outdoor condenser and the two are connected by piping through which the refrigerant is pumped back and forth between them. AC1-1 is ‘Window Wall: Non-ducted unitary <10kWr, distinguishing this product category from the AC2 Segment because all of the elements of the vapor compression refrigeration system are integrated into a single device. Portable air conditioners are in the same segment as window wall units as they are also sealed unit (i.e. self-contained) and with similar refrigerating capacities.

Some numerous equipment types have two product categories, for instance:

- ‘Single split: Ducted single phase (AC3-1); and
- ‘Single split: Ducted three phase (AC3-2).

The two product categories AC3-1 and AC3-2 are distinguished by whether the equipment can be connected to single phase or three phase power. In this instance this distinction provides a direct correlation to the capacity of the compressors used and thus the refrigerating capacity range of the products in each product category.

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

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

The concept and framework of the taxonomy was developed in the early stages of researching and writing Cold Hard Facts 1 in 2006 and was then formalised and updated in 2013. Since that time additional data has come to light, and indeed some large populations of RAC equipment that were essentially not recognised in 2012, that has required some changes to be made to the taxonomy. The taxonomy below is the system of organising RAC technology that has been used in research and writing this report, Cold Hard Facts 2019 (CHF 2019).

Refer to *Appendix B1: CHF3 Taxonomy*.

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 the Environment and Energy) data on pre-charged equipment imports for 2005 and 2006;
- Commercial market research estimating the numbers of residential and small commercial split and packaged air conditioning systems sold in the few years prior to 2006 (by capacity and product type);
- Various sales datasets, some partial, from 2004 and going back as far as 1995 for domestic refrigeration, residential and small commercial air conditioning, collected from a number of importers, manufacturers and from published market research, constructed into the early years of the model and then released for industry comment and review;
- Personal communications and interviews with manufacturers and importers of commercial split systems and chillers, and
- Personal communications and interviews with manufacturers of commercial and domestic refrigeration systems.

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

Equipment retirement rates were developed using knowledge of manufacturers' warranty conditions, interviews with suppliers, designers and engineers.

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

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

- The latest issue the Department of the Environment and Energy data including bulk and pre-charged equipment import statistics by quantity, mass, species, licence holder, product category from 2006 to 2018 (DoEE 2019a); [1]
- Reviews of data included in regulatory impact statements and product profiles for air conditioning equipment (i.e. split systems, chillers, close control, portable, etc.) (E3 2017a), refrigeration display and storage cabinets (E3 2016), domestic refrigerators and freezers, non-domestic refrigeration (E3 2009), and other products such as high efficiency fans (E3 2017b);
- Reviews of data created for models of domestic energy production;
- Interviews with and surveys of manufacturers, importers and resellers of equipment, and with importers and wholesalers of refrigerant, parts, and tools for the purpose of other RAC industry related studies;
- Interviews with industry associations and professional bodies for the purposes of other industry and government programs;
- In-confidence industry wide surveys of major participants selling commercial refrigeration condensing units and compressors dissected by capacity and refrigerant;
- In-confidence industry wide surveys of suppliers, upstream processors and end-users of natural refrigerants to establish aggregate industry measures;
- Market intelligence reports with monthly sales ($ and quantity) of HCFCs and HFCs by species including refrigerant re-use;
- Market intelligence reports of refrigeration equipment sales (by type and capacity); and,
- Surveys of stock on the floor of domestic equipment retailers.

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

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

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

1.2.2 Product category stock models

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

[1] *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.*

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 N_{2000} (1-p), where N_{2000} is the number of units sold in 2000, and p is the proportion that have been scrapped between 2000 and 2012 inclusive and is given by the following function:

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

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

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

The historical sales data is dissected by refrigerant species to predict the refrigerant mix of the bank and in retiring equipment. This methodology has been refined further for end-of-life vehicles with a survival curve which is a normal distribution with a mean retirement age of 18.6 years and a standard deviation of 6.2 years up to age 27, then uniform distribution out to age 64 years where it hits 100% of retirements. This curve simulates actual vehicle registrations in ABS Census of Motor Vehicles, 2014, TableBuilder.

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

The average charge for the same type of equipment with roughly the same refrigerating capacity can be different by species. For example, the same capacity wall hung split air conditioning system contains an average charge of 1.7 kg of HCFC-22 as this is older technology, 1.45 kg of HFC-410A and 1.15 kg of HFC-32.

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

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

- Air conditioning chillers;
- Packaged air conditioning equipment;
- Window/wall units;
- Portable air conditioning;

- Splits systems (single and multi-head/variable refrigerant flow);
- Aircraft;
- Other heat pumps;
- Mobile air conditioning (vehicles less than and greater than 3.5t gross vehicle mass);
- Commercial refrigerated cabinets;
- Domestic refrigerators and freezers;
- Transport refrigeration (self and vehicle powered truck refrigeration); and,
- Other commercial refrigeration categories.

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

The average charge used in the table above is the average charge of the most common species found in that product category. Charges of other species used in the same product category may differ to some extent.

Refer to *Table 1: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan) for most common substance*, for average charges applied to all product categories in the taxonomy.

1.2.4 Small MAC refrigerant charges

The CHF2019 RAC Stock model uses both sales data (ABS 9314.0 2017 and FCAI 2019) and registration data (ABS 93090.0 2019) 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.

Small MAC: Average charge by year of manufacture

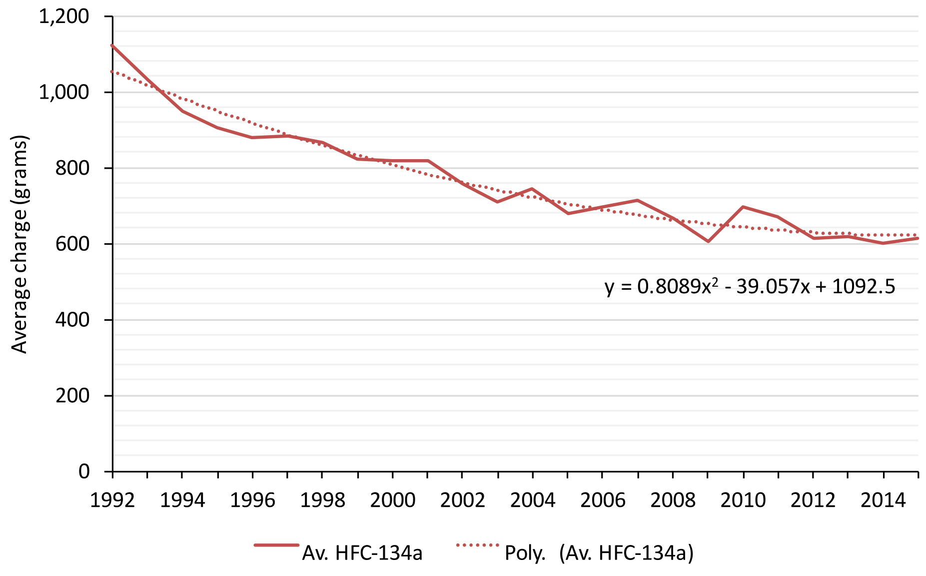

Figure 1: Polynomial used in RAC Stock model based on sample of more than 10,000 vehicles.

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 HC in 2002 is 50,000.
- Average age of vehicle converted is greater than 10 years.
- Attrition rate of vehicles greater than 10 years old is 10%.
- Annual leak rate is 10%.
- Proportion HC charge to 134a based on mass is 30%.
- Growth in aggregate supply beyond 2016 is 2% per annum.

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

1.2.6 Surveys of mobile air conditioner refrigerants

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

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

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

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

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; and,
- Refrigerant that is lost along the supply chain for the species of gas that the class of equipment requires while gas is being transported, decanted or handled.

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

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

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

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

Direct emissions from product category, in any one year, are always going to be greater than or, at the very best, equal to the service usage for that product category in that year. This is a conclusion from other data and research that shows that in the majority of product categories, particularly those categories that encompass smaller privately owned equipment, service is rarely comprehensive across the stock and at least some part of the stock of equipment in any category at any time, is operating on less than the full technical capacity of the refrigerant charge. This is discussed further in *Section 11.2.9* below.

1.2.8 OEM, service usage and service rates

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

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

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

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

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

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

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

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

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

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

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

Refrigerant mass flow concept diagram

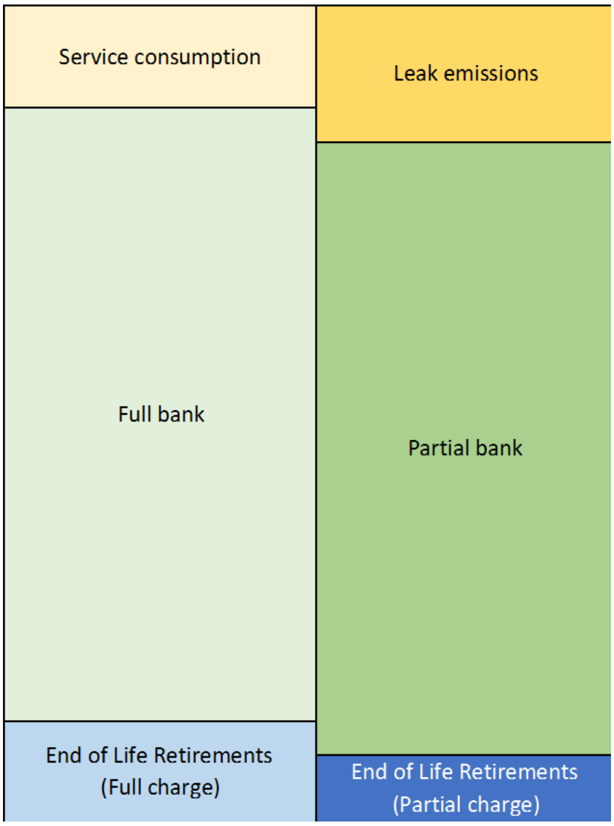

Figure 2: Refrigerant mass flow equation concept diagram.

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

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

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

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

The leak rate in the model depends on the assumptions, for example the theoretical rate of small AC: Split AC is 3.6% based on a 2% service rate, average lifespan of 12 years and EOL residual of 80%, and has a theoretical leak rate of 2.8% based on an EOL residual of 90%.

Figure 3 provides a graph of the mass balance elements for small MAC from 2016 to 2030. The full and partial bank axis is on the right in tonnes, and the annual flows axis is on the left. This modelling approach provides regulators with reconciled usage which is important from a Montreal Protocol perspective, and annual emissions (leak and end-of-life minus recoveries), essential for domestic emission reduction policy and understanding Kyoto Protocol elements.

Annual flows (left axis tonnes), banks (right axis tonnes)
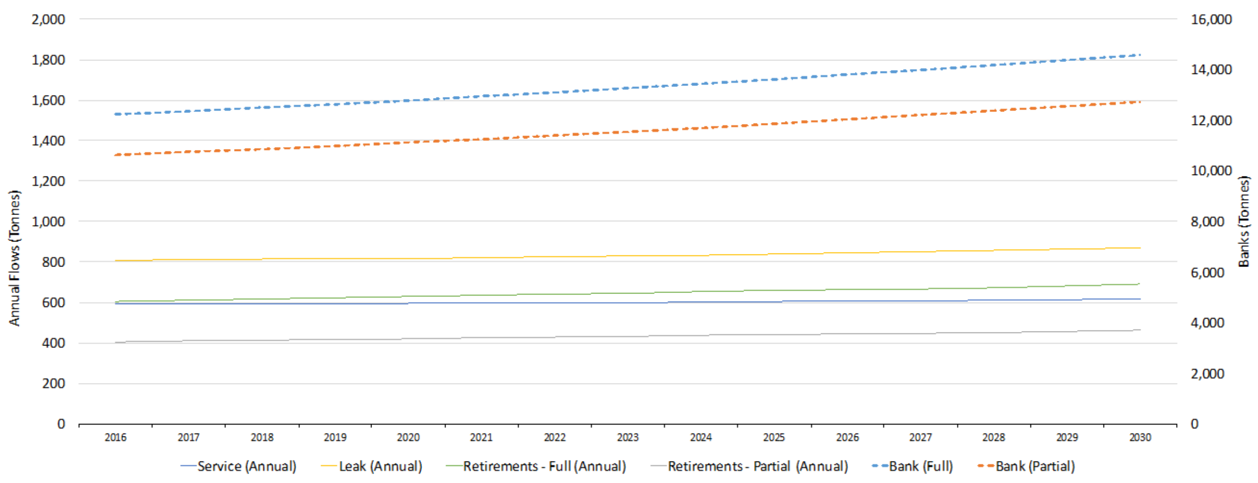
Figure 3: Small MAC Mass balance elements, annual flows and banks from 2016 to 2030 in tonnes.

Refer to *Table 1: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan) for most common substance*, for equipment service usage rates for each product category in the taxonomy.

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).

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

Table 1: Technical characteristics by product category (average charge, end-of-life factors, service rates, leak rates and average lifespan) for most common substances.

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2018	EOL[2]	Tech Rec[3]	Service rate (2018)	Theoretical leak rate (2018)	
Small AC: Sealed							
Non-ducted: unitary 0-10 kWr	0.75	0.65	85%	90%	2.0%	2.5%	12.0
Portable AC: 0-10 kWr	0.6	0.55			0.0%		8.0
HW heat pump: domestic	0.9	0.9			2.0%		15.0
Heat pump clothes dryers	0.46	0.47			2.0%		16.5
Small AC: Split							
Single split: non-ducted (1)	1.7 (HCFC-22)	1.15 (HFC-32)	80%	90%	2.2%	2.7%	12.0
Medium AC							
Split system: ducted	4.7	4.7	80%	90%	2.2%	2.7%	16.0
RT Packaged systems	12.2	15.0			2.2%		20.0
Multi split	3.0	3.0			2.2%		20.0
VRV/VRF split systems	11.0	9.0			2.2%		20.0
Close control	30.0	30.0			2.2%		12.5
HW heat pump: commercial	110.0	110.0			2.2%		20.0
Pool heat pump	2.8	2.8			2.2%		17.5
Large AC							
<350 kWr	40.0	40.0	85%	95%	4.0%	4.5%	20.0
>350 & <500 kWr	60.0	60.0			4.0%		25.0
>500 & <1000 kWr	210.0	210.0			4.0%		25.0
>1000 kWr (2)	670.0	670.0			4.0%		25.0

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[2] *The EOL factor is used to calculate the residual EOL charge at end-of-life. The end-of-life factors are generally consistent with others cited internationally (e.g. ICF 2010) and in good practice guides by the IPCC.*

[3] *The calculated EOL charge in each segment has a maximum technical recovery factor that is uniformly set at 90%, except for air conditioning chillers, supermarket systems and commercial refrigeration with remote condensing units where the technical recovery rates are set to 95%.*

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2018	EOL[2]	Tech Rec[3]	Service rate (2018)	Theoretical leak rate (2018)	
Small MAC							
Passenger and LC Vehicle	0.629	0.622	67%	90%	5.3%	7.1%	18.6
Large MAC							
Registered buses (>12 GMT)	9.0	5.5	80% (3)	90%	8.6%	7.3% (7)	20.0
Registered buses (>4.5 & <12 GMT)	4.0	3.0			8.6%		20.0
Un-registered: passenger rail	15.0	15.0			8.6%		30.0
Un-registered: Locomotive	4.0	4.0			8.6%		30.0
RV and caravan	0.75	0.75	85%		2.0%		15.0
Un-registered: off-road, defence and other (boat, etc.)	2.75	2.75	80%		8.6%		15.0
Registered marine and pleasure craft	2.25	2.25			8.6%		15.0
Refrigeration cabinets: self-cont.	0.5	0.5	85%	90%	6.0%	7.2%	11.5
Refrigeration beverage vending machines	0.25	0.25			6.0%		12.0
Beverage cooling (post mix)	0.7	0.7			6.0%		8.0
Ice makers	1.0	1.0			6.0%		11.0
Water dispensers (incl. bottle)	0.05	0.05			6.0%		8.0
Other self-cont. refrigeration equipment	0.5	0.5			6.0%		12.0
Walk-in cool rooms: mini: Slid-in/Drop-in	0.75	0.75			6.0%		12.0
Walk-in cool rooms: small: Slid-in/Drop-in	1.4	1.4			6.0%		12.0

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2018	EOL[2]	Tech Rec[3]	Service rate (2018)	Theoretical leak rate (2018)	
Walk-in cool rooms: mini: remote	1.0	1.0	80%	95%	15.0%	15.7%	12.0
Walk-in cool rooms: small: remote	5.0	5.0			15.0%		12.0
Walk-in cool rooms: medium	17.0	17.0			15.0%		12.0
Walk-in cool rooms: large	23.0	23.0			15.0%		15.0
Walk-in cool rooms: warehouse	30.0	30.0			15.0%		20.0
Refrigeration cabinets: remote	10.0	10.0			15.0%		15.0
Beverage cooling (beer)	40.0	40.0	80%	95%	15.0%	15.7%	15.0
Milk vat refrigeration	40.0	40.0			15.0%		30.0
Packaged liquid chillers (incl. Milk vat)	40.0	40.0			15.0%		20.0
Process and mfg. (<40 kWr)	40.0	40.0			15.0%		20.0
Supermarket refrig: small	500.0	500.0	100%(4)	95%	11.8%	11.8%	15.0 (5)
Supermarket refrig: medium	900.0	900.0			11.8%		15.0
Supermarket refrig: large	1,100.0	1,100.0			11.8%		15.0
Mobile refrig: road: trailer - inter-modal	10.0	6.5	90%	95%	15.0%	15.7%	12.5
Mobile refrig: road: diesel drive	7.0	4.0			15.0%		12.5
Mobile refrig: road: off engine	4.0	2.2			15.0%		10.0

Product category	Average charge (kg)		EOL Factors (%)		Rates (% of original charge)		Nominal Av. Lifespan (Yrs)
	2012	2018	EOL[2]	Tech Rec[3]	Service rate (2018)	Theoretical leak rate (2018)	
Mobile refrig: marine	130.0	130.0	90%	95%	15.0%		25.0
Domestic refrig.							
Refrigerators and freezers (6)	0.140	0.133	90%	90%	0.25% (8)	1.7%	16.5
Portable refrig.	0.055	0.055	95%	0%	0.25%		12.0
Vehicle refrig.	0.035	0.035	95%		0.25%		12.0

Notes:

1. Charge for HFC-410A single split system is 1.45 kg.
2. The HCFC-123 charge is different with capacity range >500 & <1000 kWr = 180 kgs, and >1000 kWr = 670 kg as they are generally large capacity models.
3. Large MAC EOL percent adjusted to be consistent with commercial AC.
4. Supermarket refrigeration adjusted to 100%, consistent with high service levels, recovery and re-use.
5. Supermarket lifespan relates to average plantroom refurbishment lifespan.
6. Refrigerators and freezers average charge for HC is 0.55 grams. Portable and vehicle refrigeration rarely use HC.
7. The theoretical leak rate across Large MAC is lower due to the low leak rate of RV and caravans.
8. The service rate in 2018 has been lowered to 0.25% as the service of these appliances rarely involves refrigerant. If refrigerant is required, the unit is typically retired. The higher theoretical leak rate of 1.7% is due to the higher leak rates of older vintages in the stock model.

1.2.12 Hydrocarbons and equivalent refrigerant charge

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

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

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

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

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

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% in the National Greenhouse and Energy Reporting Act 2007. Current market intelligence and reconciling usage shows leak rates of HFC-404A less than half this within the main supermarket chains. Supermarkets, and other segments of the industry that employ equipment that is maintained by engineers, have improved leak rates substantially since the introduction of the equivalent carbon tax in 2012. Even though this tax was only in place for two years, it appears to have substantially changed behavior in several sectors of the industry.

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 were generally consistent with those used by the IPCC and ICF International in a variety of technical papers (ICF 2010).

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

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

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 2019 RAC Model has new sales mix inputs for all equipment types and aggregated outputs for product categories (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 ≥ 800 grams and < 2.6 kg.

Predicted new sales mix by new equipment type: Input units

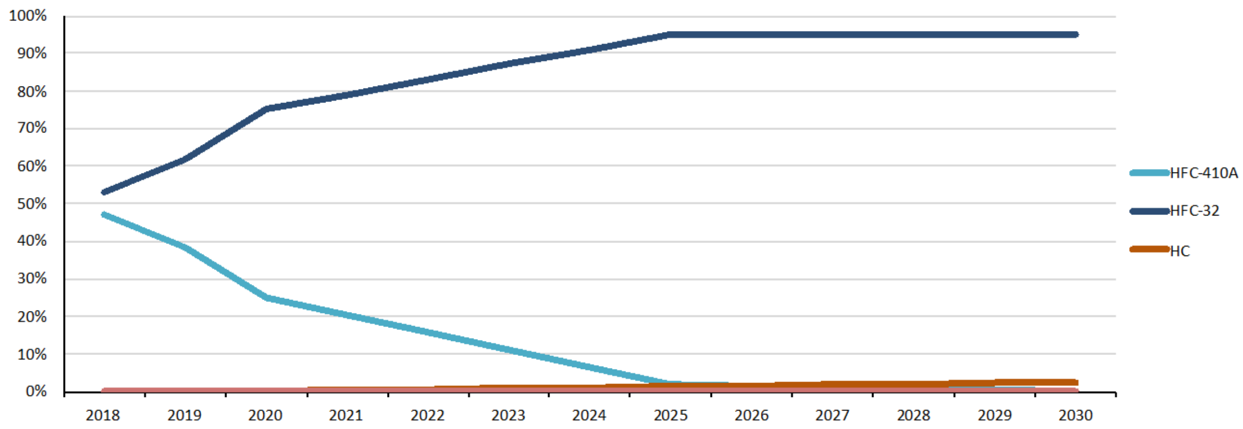

Figure 4: New sales mix by units for Small AC: Split

Predicted new sales mix by new equipment type: Refrigerant mass output

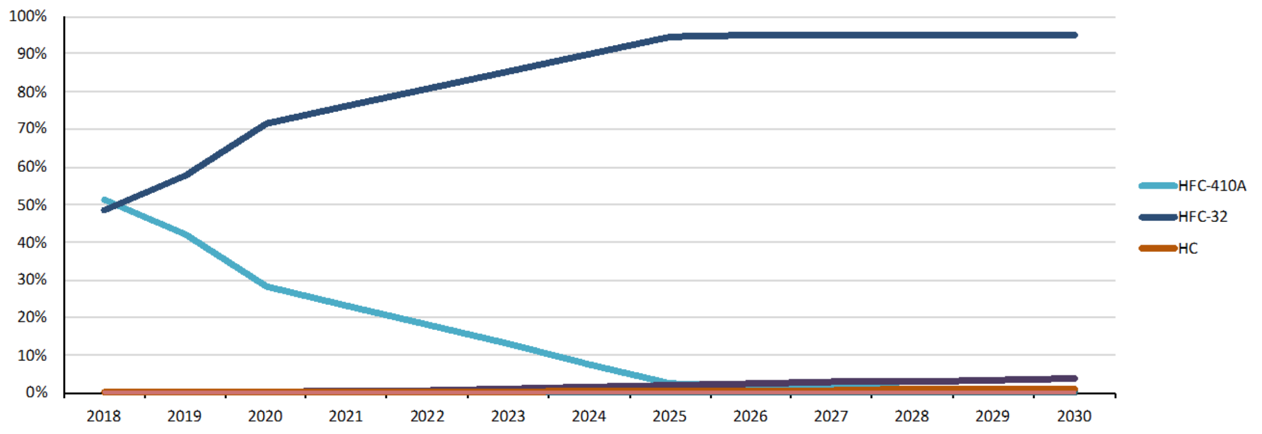

Figure 5: New sales mix by refrigerant mass for Small AC: Split.

1.2.16 GWPs and refrigerant compositions

Global Warming Potential

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

Australia's original legally binding emissions obligations under the Kyoto Protocol (1997 to 2013) were calculated based on the GWP values published in the Second Assessment Report (AR2) of the International Panel on Climate Change (IPCC) released in 1996. Therefore Australian legislation, including the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* (the OPSGGM Act), cited GWPs from AR2.

Revised GWP values were reported in the Fourth Assessment Report (AR4) in 2007. The 2nd Kyoto Protocol commitment period is based on AR4 values. The Australian Government adopted AR4 from July 2017.

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

Table 2 below 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.

Table 2: GWP factors of main refrigerant species.

Common substances	AR2 GWP-100 Year	AR4 GWP-100 Year
Substances controlled by the Montreal Protocol		
CFC-11 (1)	3800	4750
CFC-12 (1)	8100	10900
HCFC-123	90	77
HCFC-22	1500	1810
HCFC-141b	-	725
HCFC-142b	1800	2310
HCFC-406A	-	1943
HCFC-408A	-	3152
HCFC-409A	-	1585
HCFC-225ca (3)	-	122
HCFC-225cb (3)	-	595
Hydrofluorocarbons (HFCs)		
HFC-125	2800	3500
HFC-134a	1300	1430
HFC-152a	140	124

Common substances	AR2 GWP-100 Year	AR4 GWP-100 Year
HFC-236fa	6300	9810
HFC-32	650	675
HFC-404A [2]	3260	3922
HFC-407C	1526	1774
HFC-407F	1824	2107
HFC-410A	1725	2088
HFC-417A	1955	2346
HFC-428A	2930	2265
HFC-438A	1890	3667
HFC-507A	3300	3985
HFC-227ea [3]	2900	3220
HFC-245fa [3]	-	1030
HFC-365mfc [3]	-	794
HFC/HFO Blends		
R448A	-	1387
R449A	-	1397
R452A	-	2141
R452B	-	676
R454B	-	466
R454C	-	148
R466A	-	733
R513A	-	631
Nil or <10 GWP alternatives		
HC-600a [4]	-	3
HC-290	-	3
CO_2 (R744)	-	1
Ammonia (R717)	-	0
HFO-1234yf [5]	-	5
HFO-1234ze(E)	-	5
HFO-1233zd	-	5
HFO-514A	-	2

Notes:

1. No longer in common use, banned in 1996. GWP values of blends such as HFC-404A and others are calculated based on the mass composition of substances listed in the IPCC assessment reports.
2. All references to HFC-404A throughout the report include both HFC-404A with a chemical composition of HFC-125/143a/134a (44.0/52.0/4.0) and HFC-507A with a chemical composition of HFC-125/143a (50.0/50.0) as they are very similar in mass composition and service the same applications.

3. Not used as refrigerant in RAC applications, substances used for foam blowing applications, fire protection and as solvents.
4. HC-600a and HC-290 are not published in the AR2 or AR4.
5. These are new substances and were not reviewed, included or published in the IPCC, Fourth Assessment Report published in 2007. The GWP values of HFO substances are those cited by the manufacturers as based on AR4. The GWPs of HFOs has recently re-evaluated by the UN with HFO-1233zd and HFO-1234ze with a GWP of 1; and HFO-1234yf with a GWP of less than 1. This report uses previous cited values to maintain consistency. The ASHRAE refrigerant mass chemical compositions are used to calculate the GWP values of these blends.
6. *Table 3* provides the refrigerant mass composition of common blends used in Australia.

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

ASHRAE Refrigerant designation	Refrigerant composition (Mass %)
Refrigerant blends: Zeotropes	
R404A	R125/143a/134a (44.0/52.0/4.0)
R406A	R22/600a/142b (55.0/4.0/41.0)
R407C	R32/125/134a (23.0/25.0/52.0)
R407F	R32/125/134a (30.0/30.0/40.0)
R408A	R125/143a/22 (7.0/46.0/47.0)
R409A	R22/124/142b (60.0/25.0/15.0)
R409B	R22/124/142b (65.0/25.0/10.0)
R410A	R32/125 (50.0/50.0)
R422D	R125/R134A/R600A (65.1/31.5/3.4)
R427A	R32/R125/R143a/R134a (15.0/25.0/10.0/50.0)
R436A	R290/600a (56.0/44.0)
R438A	R125/R32/R134A/R600/R601a (45.0/5.0/45.0/4.0/1.0)
R436B	R290/600a (52.0/48.0)
R448A	R1234yf/R1234ze/R32/R125/R134a (20.0/7.0/26.0/26.0/21.0)
R449A	R1234yf/R32/R125/R134a (25.3/24.3/24.7/25.7)
R452A	R1234yf/R32/R125 (30.0/11.0/59.0)
R454B	R-32/1234yf (68.9/31.1)
R454C	R-32/1234yf (21.5/78.5)
Refrigerant blends: Azeotropes	
R507A	R125/143a (50.0/50.0)
R513A	R1234yf/R134a (56.0/44.0)
R514A	R-1336mzz(Z)/1130(E) (74.7/25.3)

1. The contents of this table are from ANSI/ASHRAE 34-2016, Designation and Safety Classification of Refrigerant, published on the ASHRAE website.
2. https://www.ashrae.org/technical-resources/standards-and-guidelines/ashrae-refrigerant-designations

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 the Environment and Energy.

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[4] 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 AC RIS prepared for DoEE in 2016. However by combining some of the categories used in CHF3, a comparison of the stocks used in both studies has been made below.

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

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

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

Notes:

1. "*Decision and Consultation Regulation Impact Statement Air conditioners, Chillers and Close Control Air Conditioner: Energy Modelling & Cost Benefit Analysis*" prepared by EnergyConsult on behalf of the trans-Tasman Equipment Energy Efficiency (E3) programme, 2015 to 2017 (E3 2017a).
2. Domestic and commercial hot water heat pumps; swimming pool heat pumps; and heat pump clothes dryers.
3. The energy consumption calculations for stationary AC includes fan energy for equipment where the fan is incorporated into the equipment, which includes all residential and light commercial AC equipment. Large AC such as space chillers have separate ventilation systems and ancillaries including pumps and motors. An allowance of 50% for ancillary equipment is included in the calculation for both air cooled and water cooled chillers.
4. No allowance is made for fan energy for residential, commercial and industrial ventilation that includes a diverse range of applications such as domestic exhaust fans, kitchen exhaust fans for residences and commercial kitchens, carpark ventilation systems to monitor and control carbon monoxide levels, and ventilation systems for industrial processes.
5. CHF3 and the AC RIS 2015 use similar average capacities and efficiencies (i.e. AEER and ACOP) in the energy consumption calculations.

Residential AC electricity use calculations

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

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

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

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

Business electricity use calculations

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

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

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

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

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

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

Close Control AC

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

Proportion of residential and commercial

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

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

Table 5: Estimated air conditioning proportion of use in commercial applications.

Product category	Commercial (%)
1Ph Non ducted split 0-4kW	5%
1Ph Non ducted split 4-6kW	15%
1Ph Non ducted split 6-10kW	20%
1Ph Non ducted split>10kW	30%
3Ph Non ducted split 0-20kW	95%
1Ph Ducted	20%
3Ph Ducted 0-20kW	80%
3Ph Ducted 20-40kW	95%
3Ph Ducted >40kW	100%
1Ph Non ducted unitary 0-10kW	30%
1Ph Non ducted unitary>10kW	100%
Portable AC 0-10kW	5%
3Ph Non ducted 20-40kW	100%
3Ph Non ducted >40kW	100%
Chillers	100%
Multi Splits	20%

Product category	Commercial (%)
VRV/VRF split systems	75%
Close control air conditioning	100%
HW heat pump: commercial	100%

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 ABS 3101.0, Australian Demographic Statistics, June 2012 (ABS 3101.0 2017). The calculated national average for CHF2 in 2012 was 0.914 kg CO_2e/kWh.

In CHF3 the latest national estimate Scope 2 and 3 emissions factors - consumption of purchased electricity by end users (Table 41, NGA Factors DoEE 2018) was used, a value of 0.80 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.

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

Fuel type	Energy content factor (GJ/kL)	Emission factors (kg CO_2e/GJ)		
		CO_2	CH_4	N_2O
Gasoline (petrol)	34.2	67.4	0.02	0.2
Diesel oil	38.6	69.9	0.01	0.6

(Source: Table 4, Post-2004 Vehicles, NGA Factors, DoEE 2018)

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

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

Average State based prices were sourced from AEMO National Electricity and Gas Forecasting, Neutral Scenario, 1981 to 2037 by State, wholesale and retail prices, Australian Energy Market Operator, 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.

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; and,
- **End-of-life emissions** from the entire stock of equipment and from some classes and segments of the stock.

As a result of all of the above the RAC Stock model can also be used to generate projections of the working banks of refrigerant by class, and, in some cases by equipment segment. The model also produces projections of annual service use by refrigerant type from 2016 to 2030. Projections are calculated in metric tonnes and in millions of tonnes CO_2e. This enables the model to be used to estimate and analyse the future refrigerant bank in an economy as compared to the bank required under international agreements to phase down HFCs and an overall reduction in greenhouse gas emissions.

An example is shown below of the small MAC bank in tonnes and millions of tonnes of CO_2e based on the equivalent bank.

Bank (tonnes): 2018 to 2030
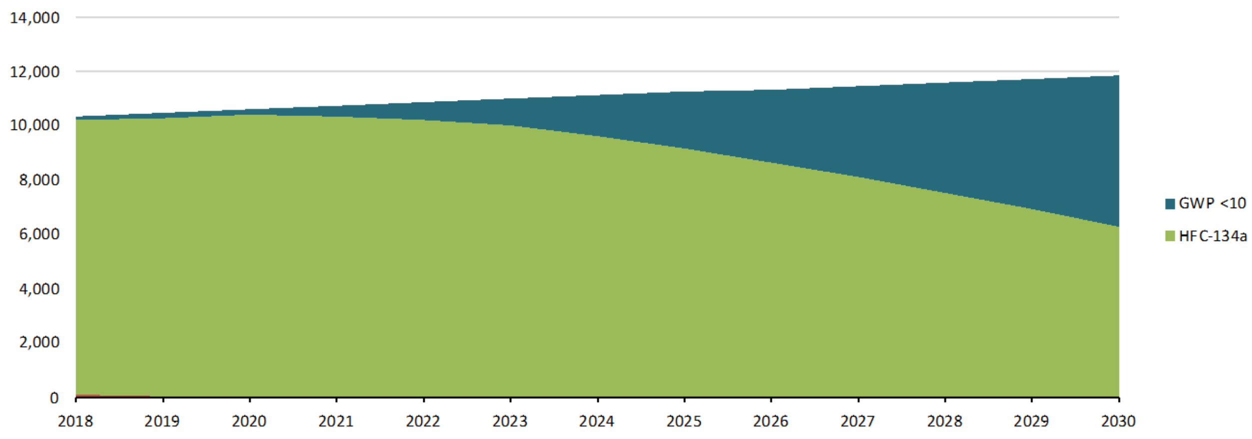
Figure 6: Small MAC refrigerant bank in tonnes from 2018 to 2030.

Bank (Mt CO_2e): 2018 to 2030
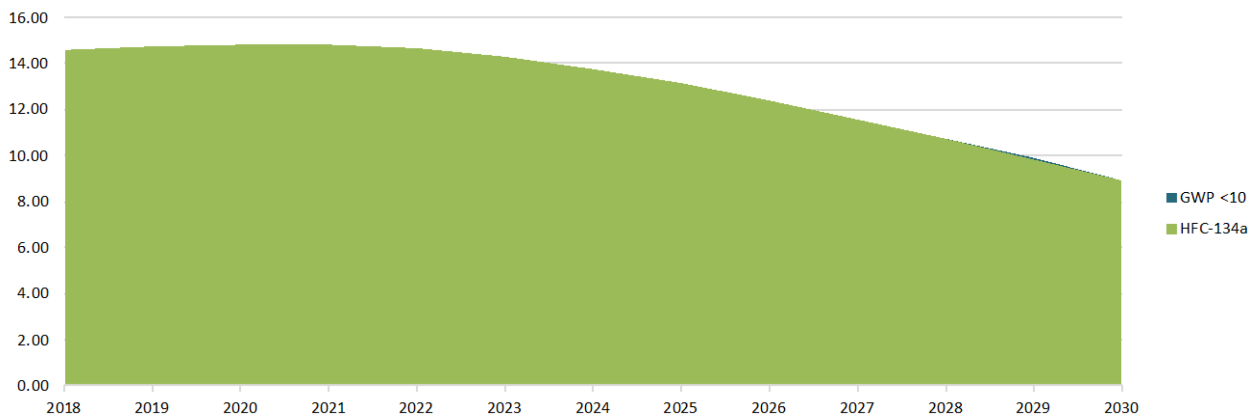
Figure 7: Small MAC refrigerant bank in Mt CO_2e from 2018 to 2030.

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. *Table 7* below provides a list of businesses that are considered part of the HVAC&R industry. A list of end use applications is provided on the following page. Equipment and services suppliers to these end use applications are generally considered part of the industry sector.

Table 7: Types of businesses in the HVAC&R supply chain.

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

End use applications

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

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

Stationary air conditioning systems

Non-residential buildings ventilation and air conditioning systems:

- Commercial and government office accommodation
- Education (all generally also including some larger format refrigeration) such as schools, universities and TAFEs
- Community buildings
- Hospitals and health facilities including mortuaries
- Hotels and accommodation
- Industrial
- Convention centres, retail malls and food courts
- Entertainment, restaurants, swimming pools, gyms
- Transport hubs, underground train stations, airports

Close Control facilities:

- Computing, server farms and UPS
- Telecommunications switching, PABX and UPS
- Museums, galleries, archives and specialised storage
- Pharmaceutical
- Labs and testing

Mobile air conditioning systems

Air conditioned and refrigerated transport:

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

Aviation:

- Commercial passenger airlines

- Military aviation
- Private and charter aircraft

Maritime systems:

- Fishing fleet
- Specialised sea freight
- Passenger liners
- Luxury boats and private charter
- Defence field systems and emergency services

Refrigerated cold food chain, industrial and process systems

Commercial refrigeration:

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

Process chillers & industrial refrigeration:

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

Industrial chiller applications:

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

Other large chiller deep freeze applications:

- Water cooling for medical or chemical equipment such as SEM, MRI and X-Ray units
- Petro-chemical/gas & chemical
- Medical/pharmaceutical/serum/plasma

- Co-generation/tri-generation
- Mining and tunnels
- Liquefaction and cryogenics

Power generation industry:

- Mobile plant

Other applications:

- Water coolers
- Heat pump pool heaters