



Cold Hard Facts 2



Prepared for the Department of Sustainability, Environment,
Water, Population and Communities

A study of the refrigeration and air conditioning
industry in Australia

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Industry associations

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Air Conditioning & Refrigeration Equipment Manufacturers Association of Australia
Air Conditioning and Mechanical Contractors' Association of Australia
Australian Refrigeration Association
ARCtick Australian Refrigeration Council
CAMBA – Convenience & Mixed Business Association
Consumer Electronics Suppliers Association
Refrigerated Warehouse and Transport Association
Refrigeration and Air Conditioning Contractors Association
Refrigerants Australia

Companies

Actrol Parts
A-Gas Australia
Airfrig Australia
Bitzer Australia
BOC Limited
Daikin Australia
Danfoss Australia
De Longhi Group
Electrolux Home Products
Engas Australasia
GreenFreeze
Heatcraft Australia
Hychill Australia
Nutrifaster (Desmon Coolrooms)
Orica Chemicals; Orica Australia
Patton Australia
Real Cold
Woolworths (Group Engineering)

Glossary

Ammonia Refrigerant	Anhydrous Ammonia (R717) has excellent thermodynamic properties, making it effective as a refrigerant, and is widely used in industrial 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.
Bottom-up model	A method of estimation whereby the individual appliances, equipment and product categories that make up the equipment bank are estimated separately. The individual results are then aggregated to produce an estimate of the refrigerant bank by refrigerant species. In the context of this study, consumption estimates (i.e. leakage plus local manufacture plus exports) is reconciled with the top down data (i.e. bulk imports), except in 2012 where stock piling occurred and adjustments were made to account for changes in industry behavior.
Cascade refrigeration system	A cascade system is made up of two separate but connected refrigeration systems, each of which has a primary refrigerant. The separate refrigerant circuits work in concert to reach the desired temperature. Cascade systems in operation today in Australia are R404A/R744 (CO ₂); R134a/R744 and R717 (ammonia)/R744. A cascade refrigeration system is also sometimes referred to simply as an 'advanced refrigeration system'.
CHF1	Cold Hard Facts 1, the original refrigeration and air conditioning (RAC) study undertaken by the authors in 2007 based on 2006 data.
CHF2	Cold Hard Facts 2, an updated study of the RAC industry in Australia with an expanded brief to encompass new application/equipment classes, new and emerging refrigerants, and report on the refrigerant bank.
Chlorofluorocarbons (CFCs)	Molecules containing carbon, fluorine, and chlorine. CFCs are the major ozone depleting substance phased out by the Montreal Protocol on Substances that Deplete the Ozone Layer. Many CFCs are potent greenhouse gases.
Coefficient of performance (COP)	The ratio of the heat extraction rate divided by the power consumed by the refrigeration compressor(s) and necessary ancillaries. The COP is dimensionless and is used to express the system efficiency.
Compressor	A device in the air conditioning or refrigeration circuit which compresses refrigerant vapour, and circulates that refrigerant through to its phases of condensation and evaporation, in order to produce the refrigeration effect. The compressor is available in many forms such as piston, scroll, or screw.
Compressor rack	The machine assembly which accommodates the main high pressure components of a refrigeration circuit in a single structure, allowing off site connection to associated pipe work and vessels.
Condensing unit	Condensing units exhibit refrigerating capacities ranging typically from 1 kW _r to 20 kW _r , they are composed of one (or two) compressor(s), one condenser, and one receiver assembled into a 'condensing unit'.
CO ₂ refrigerant	A widely used industrial refrigerant with high thermodynamic properties is suitable for process refrigeration applications, and automotive air conditioning use. In the past its high operating pressures have limited its use in small to medium commercial refrigeration applications. Technical innovation such as micro cascade systems and commercial availability of components such as compressors and other in line accessories is assisting its transition into smaller scale applications.
CO ₂ -e	Carbon dioxide equivalent to the number of tonnes of CO ₂ emitted.
Cumulative distribution function	Cumulative distribution function of the normal distribution with mean (μ) and standard deviation (σ) evaluated at a point in time (year x)
Direct emissions	Global warming effect arising from emissions of refrigerant, or any other 'greenhouse gas', from the equipment over its lifetime.
Energy Efficiency Ratio (EER)	The ratio of the cooling output (kW _r) divided by the total electric energy input. The EER is dimensionless and is used to express the air conditioning system cooling efficiency.
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)	Domestic, commercial or industrial device reaching the end of its useful lifespan. End-of-life (EOL) emissions are direct emissions from ozone depleting substance (ODS) and synthetic greenhouse

gases (SGG) refrigerants not recovered for destruction or reclamation.

Equivalent Carbon Price (ECP)	Under the Australian Government's Clean Energy Future Plan, synthetic greenhouse gases listed under the Kyoto Protocol have an equivalent carbon price applied through the Ozone Protection and Synthetic Greenhouse Gas Management legislation. Gases covered will include hydrofluorocarbons, perfluorocarbons (excluding gases produced from aluminium smelting) and sulfur hexafluoride, and any equipment or products which contain these gases.
E3	Equipment Energy Efficiency Committee of the Council of Australian Governments (COAG) operating under the Ministerial Committee on Energy and administered by the Equipment and Appliance Energy Efficiency Team in the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education.
Gas	A general term used throughout this report, referring to ozone depleting substances, synthetic greenhouse gases and natural refrigerants. The term can refer to refrigerants when the substance is used as a working fluid in equipment or used in other applications.
Gas Species	A gas species is defined as a refrigerant category based on its chemical family. For example CFCs, HCFCs and HFCs are all synthetic gases and are defined as different gas species. Similarly Hydrocarbon refrigerant is another gas species, and HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290) refrigerants are all part of this family. Other gas species include anhydrous ammonia and Carbon Dioxide.
Global Warming Potential (GWP)	A relative index that enables comparison of the climate effect of various greenhouse gases (and other climate changing agents). Carbon dioxide, the greenhouse gas that causes the greatest radiative forcing because of its abundance is used as the reference gas. GWP is also defined as an index based on the radiative forcing of a pulsed injection of a unit mass of a given well mixed greenhouse gas in the present-day atmosphere, integrated over a chosen time horizon, relative to the radiative forcing of carbon dioxide over the same time horizon. The GWPs represent the combined effect of the differing atmospheric lifetimes (i.e. how long these gases remain in the atmosphere) and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame.
Greenhouse Gases (GHG)	The Kyoto Protocol covers emissions of the six main greenhouse gases, namely Carbon dioxide (CO ₂); Methane (CH ₄); Nitrous oxide (N ₂ O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); and Sulfur hexafluoride (SF ₆). The scope of this study covers the equivalent in carbon dioxide due to indirect emissions from electricity generation, and direct emissions from HFCs.
GWh	Gigawatt hours is a unit of measurement for electricity use (1 watt hour x 10 ⁹).
Hydrocarbons (HCs)	The term hydrocarbon refers to the main types and blends in use in Australia including HC-600a, HC-290 and HC-436 (a blend of HC-600a and HC-290). HC-600a is the preferred hydrocarbon refrigerant in domestic refrigeration applications as it is suited to both refrigerator and freezer applications. HC-290 is the preferred hydrocarbon option for non-domestic stationary applications as its performance characteristics are more suited to medium temperature applications (i.e. greater than zero degrees Celsius). HC-436 is a hydrocarbon blend that is commonly used in mobile air conditioning retrofit applications.
Hydrochlorofluorocarbons (HCFCs)	Chemicals that contains hydrogen, fluorine, chlorine, and carbon. They do deplete the ozone layer, and have less potency compared to CFCs. Many HCFCs are potent greenhouse gases. HCFC-22 is the most common refrigerant in the Australian refrigerant bank.
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.
Hydrofluoroolefins (HFOs), and HFO blends	There are three classes of low GWP HFCs known as hydrofluoroolefins with low or reduced GWP values, the first is HFO-1234yf, with a GWP of around 4 that has been proposed as a replacement for R134a in mobile air conditioners (e.g. car air conditioners) and potentially many other RAC applications. The second class of refrigerant comprises azeotropes, which are blends of refrigerant gases for which the composition of the liquid and the vapor phase are the same, such as Opteon XP10 with a GWP value of about 600 which has aroused great interest in the supermarket industry. The third class of reduced GWP refrigerants includes, among others, DR-4 and DR-5. These developmental refrigerants are made up of mixtures (blends) of HFO-1234yf and other stable refrigerants, including HFCs. These refrigerants are in the early stages of development and there is no certain timeline for their testing, approval and release to the market.
HVAC&R	Heating, Ventilating, Air Conditioning and Refrigeration

Indirect emissions	Global warming effect of the CO ₂ emitted as the result of the generation of the electrical energy required to operate electrical equipment, sometimes also referred to as 'energy related emissions.'
Indirect emission factor	The indirect or CO ₂ emission factor is the mass of CO ₂ emitted by the power generator per kWh of electrical power supplied to the refrigeration installation taking in efficiency losses in generation and distribution.
Just-in-time (JIT)	Just-in-time is a production strategy that strives to improve a business return on investment by reducing in-process inventory and associated carrying costs. Items are created to meet demand, not created in surplus or in advance of need.
kWr	Refers to kilowatts of refrigeration capacity where as kW relates to kilowatts of electrical power.
KWh	Kilowatt hour (1 watt hour x 10 ³).
Kyoto Protocol	The Kyoto Protocol sets binding emissions limits for the six greenhouse gases listed in the Protocol. The Australian Government is committed to reducing emissions of the six main greenhouse gases, which includes the synthetic greenhouse gases (SGGs) listed under the Kyoto Protocol, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF ₆). PFCs and SF ₆ are excluded from the scope of this study, as they are not used in RAC applications.
Lifespan	Lifespan is the expected useful life of the equipment in years.
Low GWP substances or refrigerants	This term can and is used to refer to both the commonly referred 'natural' refrigerants, HFC substances with a GWP lower than those commonly used today and the near to commercial HFOs being scaled up by the major synthetic greenhouse gas manufacturers that are sometimes referred to as low GWP HFCs.
Low temperature refrigeration	Temperatures below 0°C that the general public would often think of as the point of 'freezing'.
Minimum energy performance standards (MEPS)	Regulatory requirements for appliances or equipment manufactured or imported to Australia to ensure a set level of energy efficiency performance is met or exceeded. In the RAC industry MEPS typically cover appliances such as domestic refrigerators, some refrigerated display cases, and a wide range of air conditioners (excluding portable, chillers below 350kWr, etc.).
Montreal Protocol	The Montreal Protocol on Substances that Deplete the Ozone Layer sets binding progressive phase out obligations for developed and developing countries for all the major ozone depleting substances, including CFCs, halons and less damaging transitional chemicals such as HCFCs.
Natural refrigerants	Hydrocarbons (R600a, R290 and R436), ammonia (R717) and carbon dioxide (R744) are commonly referred to as natural refrigerants. The term 'natural' implies the origin of the fluids as they occur in nature as a result of geological and/or biological processes, unlike fluorinated substances that are synthesised chemicals. However it has to be noted that all 'natural' refrigerants are refined and compressed by bulk gas manufacturers via some process and transported like other commercial gases so also have an 'energy investment' in their creation, storage and transport.
Operating hours per year	The number of hours the appliance, equipment or system operates at full input load or maximum capacity.
Ozone depleting substances (ODS)	Chemicals that deplete the ozone layer (e.g. HCFCs).
PJ	Petajoule (1 Joule x 10 ¹⁵).
Pre-charged equipment (PCE)	Pre-charged equipment is defined as air conditioning equipment or refrigeration equipment (including equipment fitted to a motor vehicle) that contains a hydrofluorocarbon (HFC) or hydrochlorofluorocarbon (HCFC).
RAC	Refrigeration and air conditioning.
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.
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 estimated 44 million mechanical devices using the vapour compression cycle in Australia.
Refrigerant charge	The original refrigerant charge of refrigerant used as the working fluid for heat transfer inside a

	piece of equipment.
Refrigerant leak rate	The annual leak rate is defined as the sum of gradual leakage during normal operation, catastrophic losses amortised over the life of the equipment and losses during service and maintenance expressed as a percentage of the initial charge per annum.
Refrigerant recovery	Removal of refrigerant from a system and its storage in an external container.
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 sited remote from the cabinet structure.
Self-contained RDC	Refrigerated display cabinet with its refrigerating machinery sited remotely from the cabinet structure.
Second Assessment Report (AR2)	Second Assessment Report of the United Nations Framework Convention on Climate Change, released in 1996. Australia's legally binding emission obligations under the Kyoto Protocol are calculated based on AR2 and therefore Australian legislation, including the <i>Ozone Protection and Synthetic Greenhouse Gas Management Act</i> , also cite GWPs from AR2.
Specific Energy Consumption (SEC)	Specific Energy Consumption is a measure of energy consumption intensity of a cold storage facility in kWh/m ³ per year.
Synthetic greenhouse gases (SGGs)	SGGs listed under the Kyoto Protocol, include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF ₆). PFCs and SF ₆ are excluded from the scope of this study, as they are not used in RAC applications.
Synthetic substances or synthetic refrigerants	HCFCs, HFCs and HFOs are commonly referred to as synthetic substances or synthetic refrigerants.
Technology segment	A term used by the authors to refer to a defined set of technologies within the heating, ventilation, air conditioning and refrigeration (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 modelling, an average charge size for each segment has been calculated.
Truck refrigeration unit (TRU)	TRUs are refrigeration systems powered by dedicated diesel internal combustion engines designed to refrigerate fresh and frozen perishable products (mostly food but also pharmaceuticals and other materials) that are transported on semi-trailers, rigid trucks and rail cars. Fresh is typically classed as 2°C and frozen -20°C.
Walk-in coolroom	A walk-in coolroom is a structure formed by an insulated enclosure of walls and ceiling, having a door through which personnel can pass and close behind them. The floor space occupied by this structure may or may not be insulated, depending on the operating temperature level.

Abbreviations

AC	Air conditioning
ACCC	Australian Competition and Consumer Commission
AR2	Second Assessment Report, similarly A4 is Forth Assessment Report
ABS	Australian Bureau of Statistics
ANZSCO	Australian and New Zealand Standard Classification of Occupations

BREE	Bureau of Resource and Energy Economics
BCA	Building Code of Australia
CBBS	Commercial Building Baseline Study (DCCEE 2012b)
CHF	Cold Hard Facts
CO ₂ -e	Carbon dioxide equivalent
DCCEE	Department of Climate Change and Energy Efficiency, now Department of Resources, Energy and Tourism (DRET)
DEWHA	Department of Environment, Water, Heritage and the Arts
DSEWPac	Department of Sustainability, Environment, Water, Population and Communities
EOL	End-of-life
GHG	Greenhouse Gas
GWh	Gigawatt hour
HVAC&R	Heating, ventilation, air conditioning, and refrigeration
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
kt	Kilotonnes, or thousand tonnes
LPG	Liquefied petroleum gas
L	Litre
MEPS	Minimum energy performance standards
MAC	Mobile air conditioning
MJ	Megajoule
Mt	Megatonne, or million tonnes
OPSGGMA	Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, including amendments.
ODS	Ozone depleting substances
OEM	Original Equipment Manufacturer
PJ	Petajoule
RAC	Refrigeration and air conditioning
RCFC	Refrigerated cold food chain
SEC	Specific Energy Consumption
SGG	Synthetic greenhouse gas
TAFE	Technical and Further Education
t	Metric tonne
UNFCCC)	United Nations Framework Convention on Climate Change

1 Executive summary

The refrigeration and air conditioning industry is an essential part of the Australian economy. Without its services our major cities and much of our agriculture, telecommunications sector and health sector would not be able to function as they presently do.

This report presents the findings of a detailed examination of the refrigeration and air conditioning (RAC) industry in Australia conducted in early 2013. *Cold Hard Facts 2* (CHF2) aims to provide policy makers, industry, and any of the general public who may be interested, with a broad view of the size and value of the industry. This report also establishes benchmarks for the industry that can be used in future years as reference points against which to measure growth and change.

At the same time CHF2 provides readers with detailed insights into many of the important applications of RAC systems in the Australian economy, focussed through the prism of the various forms of the technology itself. These product formats have evolved for specific functions, often in vital industries. By examining these end-use applications in detail, CHF2 can be used as the starting point for new research into the value that this technology creates for end users, and how these essential services can be delivered more efficiently.

The most obvious responsibility of the industry is the transport of nearly \$30 billion worth of perishable food per annum from farm to domestic refrigerator, using more than 28,000 refrigerated trucks. It also provides comfort conditions for millions of workers and visitors in more than 140 million square metres of non-residential buildings. It maintains tightly controlled operational temperatures for the thousands of computer packed bunkers that run our telecommunications, internet, banking and finance systems.

Specialised and energy intensive RAC services are vital for the operation of the country's hospitals and pharmaceutical supply lines, and are employed at essential steps in the production and delivery of all seafood, dairy products, meat and poultry products, beverages, confectionary and frozen foods. Air conditioning is now installed in the majority of the country's estimated 8 million homes and in the majority of the country's 16 million registered road vehicles.

Around 173,000 people are employed in more than 20,000 businesses operating in the RAC industry. Those employees are earning approximately \$13.3 billion in wages and salaries per annum. A large proportion of these wages are earned in the process of servicing the equipment, such as supermarket refrigeration systems, large commercial air conditioning systems and mobile air conditioning systems in vehicles. Other portions of this wages bill are earned driving the refrigerated transport fleet, servicing equipment in ships, on planes, in hospitals, data centres, supermarkets, and in laboratories and mortuaries.

However nearly \$5.9 billion was also spent purchasing and installing new equipment in 2012, and a further \$533 million (at 2013 prices) is estimated to have been spent on refrigerant gas. To avoid double counting expenditure, a 'discounted wages cost'¹ has been added to the cost of hardware purchases, gas purchases and the cost of energy consumed to arrive at an overall expenditure figure of some \$26.2 billion that was spent on RAC equipment and services in 2012.

¹ The 'discounted wages cost' was calculated by deducting the purchase price of all new equipment and refrigerant gases from the estimated direct employment costs as set out in Table 1.

Table 1: Main economic indicators of RAC industry activity 2012

Expenditure categories	Economic spend (\$ Billion)
New hardware costs installed	\$5.896
Annual refrigerant gas cost	\$0.535
Energy cost	\$14.061
Discounted wages cost	\$5.743
Total spend	\$26.235

As well as being vital to the delivery of fresh food and in the operation of our cities and industries, RAC technology in all its forms is the single largest electricity consuming class of technology in Australia. There are more than 45 million individual pieces of RAC equipment operating in Australia that consumed more than an estimated 59,000 GWh of electricity in 2012, equivalent to more than 22 per cent of all electricity used in Australia that year. Owners of RAC equipment spent an estimated \$14 billion dollars to pay for that electricity.

This vast stock of equipment, from small portable refrigerators and air conditioners to enormous commercial chillers and refrigeration plants, employ a bank of more than 43,000 tonnes of synthetic refrigerant gases, which have high greenhouse warming potential (GWP) and a current replacement value of around \$5.8 billion.² More than 4,800 tonnes of low GWP refrigerants are also found working in major refrigeration plants, most cold storage distribution facilities, in more than a million registered road vehicles, and an increasing number of supermarket refrigeration systems and domestic refrigerators.

As a result of the huge quantity of electricity used, and the significant bank of high GWP refrigerant gases employed, use of RAC equipment is also one of the largest single sources of greenhouse emissions in Australia.

Total indirect greenhouse gas emissions as a result of energy consumption to power RAC systems are estimated to be 57.1 Mt CO₂-e per annum, equivalent to more than 10 per cent of the Australian greenhouse emissions as calculated by the 2011-12 National Greenhouse Gas Inventory (NGGI).³

Combined with an estimated 4.1 Mt CO₂-e of Synthetic Greenhouse Gas (SGG) direct emissions from losses of refrigerant gas to air from operating RAC systems. RAC technology is responsible for greenhouse gas emissions equivalent to approximately 11.1 per cent of Australian emissions reported in FY2011-12.⁴


This total does not include approximately 1.3 Mt CO₂-e of direct emissions of earlier generations of refrigerant gas that are also strong ozone depleting substances, and that are being phased out of use under the Montreal Protocol on Substances that Deplete the Ozone Layer.

There is also a further significant quantity of refrigerant gas lost to air from RAC equipment that reaches the end of its useful life every year. In 2012 this could possibly have been equivalent to as much as an additional 1.9 Mt CO₂. If end-of-life emissions are this high, then direct and indirect greenhouse gas

² Based on Heatcraft Australia, April 2013 list prices, less typical contractor discounts plus mark-ups to end user.

³ Total Australian emissions reported by the NGGI for FY2011-12 were 550.8 Mt of CO₂-e. This value is the sum of the September 2011 Quarter, December 2011 Quarter, March 2012 Quarter and June 2012 Quarter (DCCEE 2012a). The models in CHF2 are based on calendar years.

⁴ Emission factors for energy consumption and direct emissions employed to arrive at these estimates are the same as the factors used in the NGGI. However estimates of greenhouse gas emissions from RAC equipment are built up from a model of the stock of equipment employed, and are not based on the IPCC methodology used in the NGGI. Comparisons of the quantum of greenhouse gas emissions from RAC with NGGI calculations of annual Australian emissions is to provide a measure of the scale of RAC emissions, not to declare that RAC emissions comprise an absolute percentage of the emissions reported in the NGGI.



emissions from RAC equipment could have totalled as much as 64.5 Mt CO₂-e in 2012, equivalent to 11.7 per cent of total Australian emissions reported in the latest NNGI.

We do not have sufficient data to be able to unequivocally declare how much RAC services contribute to Australia's \$1.57 trillion economy. The total spending estimated in *Table 1* for instance, is equivalent to 1.7 per cent of Australia's GDP. However the question of the value of the services that the RAC industry provides to its clients, such as the value added to agricultural produce moving through the cold food chain, is impossible to determine. Although that question is explored further in later sections of this report.

2 Introduction

This report presents a technological and economic snapshot of the refrigeration and air conditioning industry in Australia. The equipment that is used in this industry is often referred to as HVAC&R equipment (heating, ventilation, air conditioning and refrigeration equipment), and the industry itself is often referred to as the HVAC&R industry.

However this report, starting from a bottom-up analysis of refrigeration equipment and refrigerated air conditioning systems excludes gas heating and evaporative cooling from the analysis, and only includes ventilation in certain contexts.

CHF2 is the second edition of *Cold Hard Facts*. The first, *Cold Hard Facts* study (CHF1) was conducted in 2007. CHF1 included a brief written report, and an extensive database.

The genesis of CHF1 was in 2006 as part of a project conducted for the Ministerial Council on Energy examining ways to improve the energy efficiency of HVAC systems. In the course of the work an attempt was made to quantify the total economic value of the HVAC industry. This was later expanded into CHF1, the first attempt to put a value on, and determine employment across the entire RAC industry.

CHF1 also estimated energy consumed in delivery of RAC services, and the resulting greenhouse gas emissions from energy consumption. The CHF1 stock model was then used to estimate direct emissions of refrigerant gases in subsequent studies.

Since CHF1 was published, a great many requests have been received from researchers for assistance in understanding the database, and to use the data in further studies and presentations. Many of the requests were received from international researchers. The CHF1 report and database has been available for download from the Australian Government's Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC) website for over four years. Over that period it has been downloaded 45 times a month on average. To the best of our knowledge it would appear that there is no similar study of the RAC industry anywhere else in the world.

Since 2007 a number of other extensive research projects conducted by the authors and focusing on aspects of the RAC industry have provided further detail and insights into some of the many specialised segments within this sprawling and varied industry.

The CHF1 and CHF2 models have been built largely from primary data including equipment and refrigerant gas imports, manufacturer and sales surveys, licensing data and numerous other sources of data from various supply lines such as compressor and condensing unit sales.

The CHF2 model is built up from analysis of equipment stocks of more than 50 product types using parameters including refrigeration capacity, average gas charge, leak rates, hours of use based on location and climate zone, retirement rates, and energy use. As a result the CHF2 model can calculate the scale of the total bank of working gases employed in Australia, the total expenditure on electricity consumed, the total value of the equipment involved and several other outputs that ultimately allowed us to estimate the size of this industry.

Readers may well wonder what all the fuss is about. That would be an understandable response from those unfamiliar with the industry, as most people are. The services provided by RAC systems reach into the daily life of every Australian, yet this major industry is largely unknown to the public.

Refrigeration, like lighting and hot water services, is a 'cross cutting' technology that is present in, and facilitate every other industry and the daily life of every Australian. To some extent these technological systems are found in every building, home and industry. However, partly as a result of this ubiquitous presence in every corner of the economy, and because of the many and varied technological forms and styles in which it is deployed, RAC is not seen as an industry of its own.

Despite our reliance on refrigeration for essential services, such as the daily delivery and storage of fresh food, it is an industry that is effectively 'invisible' while in full view.

Even more invisible is the huge investment in air conditioning that makes the high rise towers of our cities habitable and keeps telecommunication centres and internet server farms in operation. Air conditioning has become almost as ubiquitous a presence in modern Australia as refrigeration.

Air conditioning is now present in nearly all commercial buildings, hotels, retail spaces whether they are single shops or huge shopping malls, in massive convention and conference centres, all hospitals and health centres and increasingly in universities and schools.

Nearly all modern vehicles have air conditioning as a standard feature. Air conditioning is now expected on all large passenger vehicles including commuter buses and passenger rail. All commercial aircraft have extensive air conditioning systems. Air conditioning is now becoming more common in off-road vehicles such as military vehicles, mining and earth moving equipment and harvesters. Modern luxury boats have air conditioning as standard.

The provision of refrigeration and air conditioning is clearly a major enterprise by any measure. Yet the Australian public has little knowledge of this industry, and does not relate to it as an industry in any meaningful way.

This obscurity is partly the result of the historical development of the technology and its role in almost every other enterprise or activity as a service, an input, is not generally the main economic game.

Agriculture is a good example. Despite the critical reliance on refrigeration for much of Australia's primary produce, refrigeration services are relatively modern phenomena that are just one input (of many) required in the production of food. No one thinks of the refrigerator when they eat the apple, they think of the tree, the farm, even the truck that carried it to them.

Similarly in the construction industry, many modern construction techniques and building designs rely on extensive and energy intensive air conditioning to make the buildings habitable. However the air conditioning is not the main objective of the endeavour.

This invisible role of RAC in the economy means that it has not fared well in the collection of economic data by government. The Australian Bureau of Statistics (ABS), responsible for measuring economic and social activity in Australia has, over the decades, evolved very well defined and tested methodologies for collecting and processing data on the many facets of the economy.

Much of the economic analysis of the ABS is about defining inputs and outputs and the value of activity that results in goods and services for domestic consumption or export, or activity that transforms materials.

But how do you measure the economic value of refrigeration and air conditioning? No one pays for refrigeration or air conditioning as a separate service. Transport is a service that is paid for and easily understood as it can be easily measured. Telephony, electricity and water consumption can be easily metered. The use of buildings by tenants or the rent returned to owners can be easily measured. The production and trading of commodities and their transformation into value added products can be measured. But there is no usual means or method of measuring the provision and value of refrigeration and air conditioning, nor of calculating the change in value of other goods or services as a result of RAC services. Yet without these services there is much we take for granted that would not be possible.

One measure that became immediately apparent from CHF1 was the extent to which refrigeration and air conditioning systems are major consumers of electricity in the economy and, when combined with the direct emissions of refrigerant gas, are significant sources of greenhouse gas emissions.

RAC equipment consume the most electricity of any single class of technology in the economy and, second only to 'transport related emissions', produce more greenhouse gas emissions than any other single energy end-use technology.

As you would expect, the national policy focus in recent years on reducing the greenhouse gas intensity of the economy has driven significant changes in the RAC industry. In the course of the last decade the energy efficiency of equipment and components has been a major focus of regulatory efforts, and of capital investment in product design and efficiency improvements.

More recently, with the implementation of the “Clean Energy Future Plan” by the Federal Government on July 1 2012, industry has had to work through a major economic adjustment when an equivalent carbon price was applied to synthetic greenhouse gases listed under the Kyoto Protocol.

This ‘equivalent carbon price’ (ECP) applied at the point of import or manufacture, is based on the global warming potential of the gas. The price increases resulting from the ECP had an immediate impact on the improved containment and increased reuse of high GWP gases, and the employment of low GWP refrigerants.

These significant environmental, technological and economic drivers for change have resulted in some adjustment stress across segments of the industry, however most of the industry has reacted positively with many readily accepting the inevitability and necessity of the transformations that are taking place.

For instance, the national professional body for the industry in Australia, the Australian Institute of Refrigeration, Air conditioning and Heating (AIRAH) has embarked on a multi-year program of consultation and planning to establish an industry roadmap. The roadmap will establish a framework for change through which priorities for industry development can be set and attained. This commitment to planning for change, instead of being driven by change, puts the Australian industry in a good position to prosper, and to meet their obligations to the community in a competent, professional and sustainable manner.

However all the data indicates that there is a great deal that can be done. AIRAH believes that efficiency and gas handling measures tailored to each equipment category could deliver emissions abatement of more than 12 Mt CO₂-e per annum. This includes, combining efforts on component efficiency, improved maintenance, documentation, data and performance monitoring, and improved refrigerant containment.

Given the scale of the RAC industry in the Australian energy economy, continuing efforts to increase the efficiency of energy use in RAC services, and to reduce the direct and indirect greenhouse gas emissions from RAC equipment, must be successful to drive the Australian economy to a low emissions future. Two major studies, the ‘*HVAC High Efficiency Systems Strategy*’, and ‘*In From the Cold*’ have previously outlined 10 year industry transformation strategies that would enable government and industry to achieve these goals (E3 2007 and E3 2009a).

As a first step to developing a more detailed understanding of the role of RAC in the energy economy, some parts of the industry should possibly be elevated to have a policy focus in their own right.

The cold food chain for instance, that refrigerates fresh food from the farm shed to the family kitchen (and to export), is so extensive and energy intensive, and is so vital to the functioning of our cities, it could be regarded as a piece of national infrastructure of the same scale and importance as roads and the distribution of water and electricity. Just like water reticulation, electricity distribution and transport networks, the cold food chain is not an option for our cities. It is an essential service.

This report will hopefully provide greater insight into the many aspects of the RAC industry so that its role and importance in the economy can be better understood, and receive the policy attention, planning and training resources that it deserves. This major measures of the industry reported here should also create something of a benchmark against which future studies can measure the rate of change, and the success or otherwise of changes implemented.

2.1 Structure of Cold Hard Facts 2

For readers who are not part familiar with the RAC industry, it may be effective to take the few minutes required to read the glossary which explain many of the terms commonly used in the RAC industry.

Following on from the *Introduction* and the *Executive Summary*:

Chapter 3, ‘Taxonomy of technology’ explains the way the many applications of refrigeration and air conditioning are broken up into categories (based on end-use).

Chapter 4, 'The stock of equipment', employs the taxonomy developed to describe the vast variety of equipment that delivers RAC services in some detail, describing all of the major equipment applications, the format and design features of the equipment in each of the major applications and the refrigerant gases predominantly used in each application.

Chapter 5, 'The bank in 2012', explores the dimensions and characteristics of the refrigerant gases that are essential to the operation of RAC equipment, examining the economic and technological forces that drive the growth in the bank of refrigerant and detailing the gas types most commonly used in the major equipment types.

Chapter 6, 'Energy and emissions', analyses the energy used to deliver RAC services and the greenhouse emissions that result from it and compares the outputs from the CHF2 bottom up stock model calculations with a major top down study of energy use in commercial buildings.

Chapter 7, 'Economics and employment', presents estimates of direct spending and employment in the industry.

Chapter 8, 'The dependent economy', looks at some of the elements of the wider economy that are effectively dependent on the delivery of RAC services.

Chapter 9, 'CHF1 and CHF2 Comparative measures', provides comparisons, where they can be made, between some of the findings of the original Cold Hard Facts report and this report.

3 Taxonomy of technology

The RAC Industry is comprised of a number of essential elements, without any one of which the industry would not function.

At its simplest level the industry relies on the physical goods and materials that deliver the end-user services. These are the stock of equipment, the refrigerant gas contained in the equipment that acts as a medium to transfer heat, and the electricity that is necessary to drive the compressors and fan motors that are the two main electromechanical elements of all RAC equipment.

The main gases in use today, and which are discussed in greater detail in *Chapter 5; The Bank in 2012*, are:

- HCFCs (hydrochlorofluorocarbons), once the most common species of refrigerant gas in use and a potent ozone depleting substance as well as having a high global warming potential (GWP). HCFCs are being phased out of use under the terms of the international Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol);
- HFCs (hydrofluorocarbons), a rapidly growing newer generation of Synthetic Greenhouse Gas (SGG) that do not have the same impacts on the ozone layer as HCFCs but that still have high GWP values;
- Natural refrigerants, a group of refrigerants including ammonia, hydrocarbons and CO₂, that have low GWP but have other properties, such as flammability, toxicity and high operating pressures that limit their use in some applications.⁵

The range of formats in which RAC equipment is manufactured is very wide. However this wide range of formats can be grouped into equipment types, based on end-uses and on main design features.

For the purposes of managing the mass of data while attaining reasonable resolution on various equipment types, CHF2 classifies all RAC equipment using a scheme that involves four broad ‘classes’ as a starting point, made up of eighteen ‘segments’, which cover fifty ‘product categories’.

The classes of RAC equipment are:

- **Stationary air conditioning**, a broad classification providing comfort conditions and technical services that includes small split air conditioning systems and portable units up to very large chiller driven systems used for space cooling, with extensive ducted distribution of air, including close temperature control and extremely fine air quality systems in infrastructure, laboratories, hospitals and other specialised environments;
- **Mobile air conditioning**, including air conditioning in private and commercial, registered and unregistered road, rail, marine and aviation transport;
- **Refrigerated cold food chain**, a fairly broad classification which captures all commercial, process and industrial refrigeration, as the overwhelming majority of these large devices are found in this supply chain; and,
- **Domestic refrigeration**, a broad category that ranges from the tiny portable refrigerators found in caravans, the small ‘bar fridges’ found in nearly every hotel room and workplace, to the ‘tub’ freezer and the sometimes very large double door fridge freezer combinations that are also found employed in the backs of restaurants, takeaways and sandwich shops.

These four classes are divided into the 18 technology or application segments and 50 product or equipment categories as set out in *Table 2*.

⁵ For further clarification on refrigerant properties by type refer to AS/NZS 1677-1998, *Refrigerating systems which outlines the current technical, safety, refrigerant classifications and refrigerant charge requirements*. ME006 Standards Committee is currently reviewing this standard and is evaluating ‘ISO 5149: 2009 Refrigerating systems and heat pumps’ and ‘IEC 60335-2-89, Household and similar electrical appliances – Safety’ as potential replacement.

Table 2: A taxonomy of RAC technology

Item no	Major class	Segments		Product categories	
STATIONARY AIR CONDITIONING					
1	Stationary air conditioning (AC)	AC1	Single split: non-ducted	AC1-1	Single split: non-ducted: 1-phase
2		AC1	Single split: non-ducted	AC1-2	Single split: non-ducted: 3-phase
3		AC2	Single split: ducted	AC2-1	Single split: ducted: 1-phase
4		AC2	Single split: ducted	AC2-2	Single split: ducted: 3-phase
5		AC3	Window/wall	AC3	Non-Ducted: Unitary 0-10 kW _r
6		AC4	Portable AC	AC4	Portable AC 0-10 kW _r
7		AC5	Chillers	AC5-1	<500 kW _r
8		AC5	Chillers	AC5-2	>500 & <1000 kW _r
9		AC5	Chillers	AC5-3	>1000 kW _r
10		AC6	Light commercial	AC6-1	RT Packaged systems
11		AC6	Light commercial	AC6-2	Multi split/VRF
12		AC6	Light commercial	AC6-3	Close control
13		AC6	Light commercial	AC6-4	HW heat pump: commercial
14		AC6	Light commercial	AC6-5	Pool heat pump
15		AC7	HW Heatpumps	AC7	HW heat pump: domestic
MOBILE AIR CONDITIONING					
16	Mobile air conditioning (MAC)	MAC1	Registered vehicles <3.5 GMV	MAC1-1	Passenger vehicles
17		MAC1	Registered vehicles <3.5 GMV	MAC1-2	Light commercial vehicles
18		MAC2	Registered vehicles ≥3.5 GMV	MAC2-1	Rigid truck and other
19		MAC2	Registered vehicles ≥3.5 GMV	MAC2-2	Truck: articulated
20		MAC2	Registered vehicles ≥3.5 GMV	MAC2-3	Commuter buses
21		MAC2	Registered vehicles ≥3.5 GMV	MAC2-4	Buses (> 7m)
22		MAC3	Rail	MAC3-1	Passenger rail

23		MAC3	Rail	MAC3-2	Locomotive
24		MAC4	Vehicles: other	MAC4	Off-road, defence and other (boat, etc.)
DOMESTIC REFRIGERATION					
25	Domestic refrigeration (DR)	DR1	Refrigerators and freezers	DR1-1	Domestic refrigerators
26		DR1	Refrigerators and freezers	DR1-2	Domestic freezers
27		DR2	Portable and vehicle refrigeration	DR2-1	Portable and vehicle refrigeration
28		DR2	Portable and vehicle refrigeration	DR2-2	Vehicle refrigeration
REFRIGERATED COLD FOOD CHAIN					
29	Refrigerated cold food chain (RCFC)	RCFC1	Unitary equipment	RCFC1-1	Refrigeration cabinets
30		RCFC1	Unitary equipment	RCFC1-2	Refrigeration beverage vending machines
31		RCFC1	Unitary equipment	RCFC1-3	Ice makers
32		RCFC1	Unitary equipment	RCFC1-4	Walk-in coolrooms: small
33		RCFC1	Unitary equipment	RCFC1-5	Walk-in coolrooms: medium
34		RCFC1	Unitary equipment	RCFC1-6	Walk-in coolrooms: large
35		RCFC1	Unitary equipment	RCFC1-7	Beverage cooling (post mix)
36		RCFC1	Unitary equipment	RCFC1-8	Beverage cooling (beer)
37		RCFC1	Unitary equipment	RCFC1-9	Water dispensers (incl. bottle)
38		RCFC1	Unitary equipment	RCFC1-10	Packaged liquid chillers
39		RCFC1	Unitary equipment	RCFC1-11	Milk vat refrigeration
40		RCFC1	Unitary equipment	RCFC1-12	Portable refrigerators (commercial)
41		RCFC2	Transport refrigeration	RCFC2-1	Mobile refrigeration: road: trailer - inter-modal
42		RCFC2	Transport refrigeration	RCFC2-2	Mobile refrigeration: road: diesel drive
43		RCFC2	Transport refrigeration	RCFC2-3	Mobile refrigeration: road: off engine
44		RCFC2	Transport refrigeration	RCFC2-4	Mobile refrigeration: marine
45		RCFC3	Supermarkets	RCFC3-1	Supermarket refrigeration: small
46		RCFC3	Supermarkets	RCFC3-2	Supermarket refrigeration:

					medium
47		RCFC3	Supermarkets	RCFC3-3	Supermarket refrigeration: large
48		RCFC4	Hospital refrigeration	RCFC4	Process and large kitchens
49		RCFC5	Industrial refrigeration	RCFC5-1	Cold storage and distribution
50		RCFC5	Industrial refrigeration	RCFC5-2	Process chilling

The CHF2 stock model has these 50 product categories at its base. For the purpose of modelling, some categories are further dissected in the database into ‘capacity bins’ to provide more precise energy consumption modelling (e.g. AC1-1: split systems: non-ducted: single-phase, is dissected into four capacity bins of 0 to 4 kW_r; 4 to 6.5 kW_r; 6.5 to 8.5 kW_r and >8.5 kW_r, as the stock levels are significant and the energy efficiency ratios vary depending on capacity).

Data in the majority of these product categories is discussed in *Chapter 4: The stock of equipment*. It is obvious to most observers that even with this number of categories, some are still quite broad, covering a large number of different formats and sizes of individual manufacturer brands and product models.

However this degree of resolution has taken some years to build up, based on available market data, and the common features, such as the condenser type (remote or self-contained), gas charge sizes, electricity requirements (single or three phase) and the physical formats of systems to be found in each product category.

Nonetheless the authors acknowledge that to further erode the uncertainty in the data, in some areas, more definitive stock surveys would be valuable. A list of representative applications where RAC systems are found across the Australian economy is provided in *Appendix C: End-use applications for RAC systems* as opposed to the various product and equipment categories modelled in this study.

4 The stock of equipment

4.1 The scale of events

The CHF2 stock model shows that RAC in all its forms is delivered in Australia via nearly 45 million individual pieces of equipment. The stock model also reveals that in recent years Australians have spent around \$5.8 billion every year buying and installing new devices across all classes of RAC equipment.

At the same time, every year an estimated 2 million devices containing refrigerant gas reach the end of their useful life, including more than 800,000 domestic refrigerators and freezers, 500,000 air conditioners, 600,000 vehicles of all types, and 90,000 commercial refrigeration units.

The calculations that have been used to arrive at these numbers involve calculating the average useful lifespan of various equipment categories, and arriving at a rate of retirements that looks reasonable in the context of manufacturer's information, warranty periods offered, and new sales. On that basis the stock in each class, segment and equipment category is believed to be a reasonable estimate.

However the authors note frequent anecdotal reports of some categories of refrigeration and air conditioning equipment that have continued to operate for many decades, well beyond the estimated useful life used in the CHF2 database.

While these anecdotes do not provide a sufficient basis for adjusting the well reasoned assumptions on equipment life that are used, they are persistent, and frequently report similar types of equipment as being particularly long lasting. Many people for instance will be personally familiar with the 30 or 40 year old domestic refrigerator that still runs, possibly as a 'beer fridge' in someone's garage. Industry participants also report that sort of longevity in some well-made commercial refrigerators and in medium sized commercial space chillers.

Another indicator of some classes of long lasting equipment is the continuing presence of chlorofluorocarbons (CFCs) in the stream of waste gas delivered for destruction. The import and manufacture of CFCs were phased out and then banned from 1996, and while some of the waste CFCs delivered for destruction is reported to come in old 44 gallon drums, some of it is certainly being recovered from equipment only now being decommissioned at end-of-life (or in fact refurbished and having the gas charge replaced).

The phenomena of equipment in this industry to be hard working and long lasting was one of the factors identified in the *HVAC High Efficiency Systems Strategy* (HVAC HESS) in 2006/7 that often resulted in less than optimal performance of HVAC systems from an energy efficiency point of view (E3 2007). The HVAC HESS noted that the design of many of the components used in commercial air conditioning systems are generally so robust that, even when one component is compromised or its performance significantly degraded, such as having filters blocked by years of dust if not cleaned, that the balance of the system would simply work harder to compensate. This characteristic of HVAC&R systems means that comfort conditions are often delivered for a very long time after optimal energy efficiency is significantly degraded by failing and compromised components or a low refrigerant charge.

Having long lasting equipment should never be seen as a problem, except where it combines with a lack of maintenance to result in excessive energy use. This recurring theme of very long lasting equipment in some categories does however point to the possibility that stock calculations for some of the equipment categories is likely to be an underestimate. That would also imply that CHF2 calculations of quantities of end-of-life (EOL) equipment may be overestimated. This source of uncertainty is one of the reasons that potential EOL emissions are calculated and presented separately from lifetime direct and indirect emissions of RAC equipment.

To achieve greater accuracy and certainty on the calculated equipment stocks in future, field surveys conducted by a wide selection of service technicians could be conducted.

Each of the four main classes of equipment is discussed in detail in the sections that follow.

4.2 Stationary air conditioning

Stationary air conditioning equipment contains the largest portion of the bank of working gases, consumes the largest portion of annual bulk gas imports, and uses more electricity than any of the other classes of equipment in the RAC industry.

The seven segments and 15 product categories that make up this class contain approximately 63 per cent of the bank of working refrigerant gases in Australia, or around 27,200 tonnes, in more than 11.5 million devices that consumed an estimated 39 per cent (1,470 tonnes) of all bulk HCFCs and HFCs imported into Australia in 2012 to replace leaked gas.

Table 3: Stationary air conditioning taxonomy

Item	Major class	Segments (application/product)		Product/equipment categories	
STATIONARY AIR CONDITIONING					
1	Stationary air conditioning (AC)	AC1	Single split: non-ducted	AC1-1	Single split: non-ducted: 1-phase
2		AC1	Single split: non-ducted	AC1-2	Single split: non-ducted: 3-phase
3		AC2	Single split: ducted	AC2-1	Single split: ducted: 1-phase
4		AC2	Single split: ducted	AC2-2	Single split: ducted: 3-phase
5		AC3	Window/wall	AC3	Non-Ducted: Unitary 0-10 kW _r
6		AC4	Portable AC	AC4	Portable AC 0-10 kW _r
7		AC5	Chillers	AC5-1	<500 kW _r
8		AC5	Chillers	AC5-2	>500 & <1000 kW _r
9		AC5	Chillers	AC5-3	>1000 kW _r
10		AC6	Light commercial	AC6-1	RT Packaged systems
11		AC6	Light commercial	AC6-2	Multi split/VRF
12		AC6	Light commercial	AC6-3	Close control
13		AC6	Light commercial	AC6-4	HW heat pump: commercial
14		AC6	Light commercial	AC6-5	Pool heat pump
15		AC7	HW Heatpumps	AC7	HW heat pump: domestic

This class of equipment is a very broad group that includes equipment that can operate in reverse-cycle (heating and cooling) or cooling only, on single phase or three phase power, and range in size from a small 2 kW_r domestic portable air conditioner, with a refrigerant charge of less than 600 grams, to large 4,000 kW_r commercial space chillers containing more than a tonne of refrigerant in a single machine.

The stock and the energy consumption estimates of equipment categories in this report are generally consistent with the product profiles used in Australian government regulatory impact statements for split systems, close control air conditioning, chillers and hot water heatpumps. Portable air conditioner stock

levels are based on pre-charged equipment imports and consultation with suppliers of hydrocarbon charged models which allowed more accurate estimates of sales over the last decade. The stock estimates of the various product categories are listed in *Table 4*.

Table 4: Stationary air conditioning by category and stock numbers

Category code	Segment	Product category	Total (units)
AC1	Single split: non-ducted	Single split: non-ducted: 1 & 3 phase	7,145,000
AC2	Single split: non-ducted	Single split: ducted: 1 & 3 phase	1,304,000
AC3	Window/wall	Non-ducted: unitary 0-10 kW _r	1,915,000
AC4	Portable AC	Portable AC 0-10 kW _r	606,000
AC5-1	Chillers	<500 kW _r	20,200
AC5-2	Chillers	>500 & <1000 kW _r	7,200
AC5-3	Chillers	>1000 kW _r	1,100
AC6-1	Light commercial	RT Packaged systems	70,000
AC6-2	Light commercial	Multi split/VRF	276,000
AC6-3	Light commercial	Close control	11,500
AC6-4	Light commercial	HW heat pump: commercial	1,000
AC6-5	Light commercial	Pool heat pump	28,000
AC7	HW Heatpumps	HW heat pump: domestic	170,000
AC	Total stationary AC		11,555,000

(Sources: DSEWPaC 2013b, E3 2012, DSEWPaC 2011, IEA 2011, E3 2009b, E3 2008a, E3 2008b and industry informants)

The main product formats include:

- AC1-1, AC1-2: Non ducted split systems covering a broad class of equipment including single or multiple indoor units in a variety of styles such as wall hung, cassette, console and under ceiling;
- AC2-1, AC2-2: Ducted split systems used in domestic and light commercial applications where the indoor unit is connected to rigid or flexible duct which is ducted around the building to supply air to the conditioned space;
- AC3: Packaged room air conditioning units intended to be inserted through a hole in a wall or through a window aperture of a home, shop or worksite demountable. This product category is now predominately a replacement market;
- AC4: Portable air conditioning for domestic use and for spot cooling in commercial and industrial applications, or to provide temporary relief where normal air conditioning systems are inadequate or have broken down;
- AC5: Chillers that produce cold water across a wide range of refrigeration capacities, up to 4000 kW_r, mostly employed for space cooling of commercial buildings. These devices are the critical engines of

comfort in every city and town centre where summer temperatures would otherwise make many buildings simply uninhabitable;

- AC6-1: Roof top packaged air conditioning systems that use high static pressure fans which allow long duct runs. These systems are mostly sold now only as replacements for existing units where roof top packaged systems are already installed in commercial buildings with suspended tile ceilings;
- AC6-2: Variable refrigerant volume split systems with multiple indoor units. This format has emerged over the past decade as the preferred technology option for medium sized commercial buildings because of the flexibility and control options they provide;
- AC6-3: Close control or precision air conditioning systems that maintain very exact temperature in the air conditioned space are employed in many critical applications where air quality requirements are specified such as in computer rooms, data processing centres, telecommunication facilities, medical technology, clean rooms for production of electronic components and pharmaceuticals, and other industrial process areas; and,
- AC6-4, AC6-5, AC7: Other stationary equipment, hot water and swimming pool heat pumps for domestic and commercial applications that have been included in this sector.

Air conditioning units charged with HFC-410A are the fastest growing segment (by gas species) with more than 1,630 tonnes of HFC-410A gas imported in pre-charged equipment (PCE) in 2012 (around 60 per cent of all refrigerant imported in PCE). The demand for bulk HFC-410A was approximately 510 tonnes in 2010 and 700 tonnes in 2012 which, based on the bank of HFC-410A in the field of more than 14,300 tonnes, suggests the leak rates of HFC-410A split air conditioning equipment is between 4 per cent to 5 per cent per annum. This compares favourably with leak rates of 8 per cent per annum or more on the similar but older HCFC charged equipment.

In the early 2000's the large majority of all stationary air conditioning equipment contained HCFC-22, and in 2006 more than 30 per cent of refrigerant imported in pre-charged equipment was HCFC-22. The combined effects of technological advances, minimum energy performance regulations and the ban on HCFC pre-charged air conditioners announced in 2010, reduced the proportion of HCFC refrigerant imported in air conditioning equipment to just 3 per cent of total gas in PCE in 2010.

HFC-407C equipment imports are also in decline, with a slight increase in bulk imports to service existing stock and new installations. HFC-407C pre-charged air conditioning equipment enjoyed some popularity with the industry from 2003 through to about 2009 as it was relatively simple to substitute HFC-407C in HCFC-22 equipment designs to meet new efficiency ratings imposed during this period. Eventually the majority of stationary air conditioning applications migrated to HFC-410A and HFC-407C will only be consumed in small quantities to service existing equipment. One application where HFC-407C is commonly found is in precision controlled air conditioning.

HFC-134a has gained popularity in some large chillers for space cooling, and is also now used by the majority of local manufacturers of domestic hot water heat pumps in Australia.

As it is with most RAC equipment, Australia is largely a 'technology taker' of stationary air conditioning, driven almost entirely by product available from overseas suppliers, the vast majority of new equipment in any year (>90 per cent by refrigerant volume) is imported.

Local air conditioning manufacturers (Actron Air, Accent Air, Temperzone, GWA-Brivis, Air-Change and CommAir and a few others) produce about 15 to 20 per cent of total sales of split ducted systems and around 50 per cent of total sales of roof top packaged systems.

Extremely difficult trading conditions, which in large part resulted from cheaper imported product available from new investment in Chinese and Thai 'low labour cost' manufacturing capacity, have forced the closure of a significant proportion of Australian RAC manufacturing capacity in the last decade. The 2008 closure of the Carrier APAC factory in Western Australia removed demand for more than 75 tonnes per annum of mostly HFC-407C and HCFC-22 at the time, although some of this demand may have been picked up by new manufacturing capacity re-established under a new venture (CommAir) and other local manufacturers.

Emerson Network's close control air conditioning manufacturing operations in Regents Park in Sydney was relocated to Asia in mid 2011 to take advantage of the low labour cost environment, relaxed regulatory requirements and, at the time, the relatively high value of the Australian dollar.

Rheem, DUX and Quantum, and a few others manufactured around 20,000 to 25,000 hot water heat pumps in Australia in 2012 (requiring around 19 tonnes of HFC-134a). Hot water heat pump annual sales peaked at over 66,000 units per annum and have recently declined due to changes to the solar hot water rebate, product reliability issues and customer perception issues (i.e. not delivering hot enough water in low temperature climates).

Despite these tough conditions PowerPax, a local manufacturer of innovative high efficiency chillers has gone against this trend and has expanded its operations and grown export sales.

The remaining Australian air conditioning and heat pump manufacturers are operating in an increasingly tough environment, and in most product segments surviving the flood of cheaper imports by working in categories that require a high degree of bespoke design work, and where reliability and higher quality engineering are valued.

As an indication of the relative size of locally manufactured equipment, collectively they consume less than 300 tonnes of bulk refrigerant per annum, mostly HFC-410A and HFC-134a with some HFC-407C. This is around 7 per cent of total bulk HFC gas imports. Another measure of the relative scale of Australian manufacturing is to note that the gas consumed in local manufacturing is equal to 20 per cent to 25 per cent of the average annual volume of refrigerant gas imported in pre-charged stationary air conditioning equipment.⁶

⁶ Note: This proportion of local manufactured product is based on volume of refrigerant, and the proportion of units manufactured would be significantly less.

Table 5: Stationary air conditioning main metrics

Stationary air conditioning summary all categories	
Share of refrigerant bank:	63%
Size of refrigerant bank:	27,200 tonnes
Annual consumption to replace leaks (excl. OEM):	1,470 tonnes
Share of total annual bulk imports to replace leaks:	47%
Gas in pre-charged equipment imports over last five years (excl. 2012):	970 to 1,285 tonnes per annum
Estimated stock of equipment:	> 11.5 million units
Charge size:	500 grams to > 1 tonne ⁷
Estimated leak rate:	3% to 9% of charge per annum ⁸
Predominant gas species used by volume:	HCFC-22, HFC-410A, HFC-407C and HFC-134a
Annual expenditure on new equipment:	~\$3.35 Billion
Annual electricity consumption:	36,845 GWh
Share of HVAC&R Electricity consumption:	62%
Annual GHG indirect emissions:	33.67 Mt CO ₂ -e
Share of HVAC&R indirect emissions:	59%
Annual GHG direct emissions (ODS):	1.18 Mt CO ₂ -e
Annual GHG direct emissions (SGG):	1,14 Mt CO ₂ -e
Share of HVAC&R direct emissions:	44%
Share of HVAC&R total emissions (direct and indirect, not including EOL):	58%
Commercial Building stock serviced by AC:	143 million m ²

(Sources: DSEWPaC 2013a, DSEWPaC 2013b, E3 2012, DCCEE 2012b, DSEWPaC 2011, IEA 2011, E3 2009b, E3 2008a, E3 2008b and industry informants)

⁷ Most common devices are wall hung split system: 1.7 kg and split ducted system: 4.7 kg.

⁸ The actual leak rate depends on the type of equipment, maintenance and many other factors. This technology class ranges from hermetically sealed self-contained portable air conditioners with leak rates less than 1% to equipment with leak rates greater than 10% per annum. The majority of equipment by mass falls into the range of 4% to 9% per annum, refer to Appendices A and B for further information.

4.3 Mobile air conditioning

Mobile air conditioning includes equipment found in passenger vehicles, light commercial vehicles, buses, trucks, and in a number of unregistered and off road applications including locomotives, passenger rail, mining equipment, harvesters, forklift trucks, road making vehicles, mobile cranes, military vehicles and earthmoving equipment.

The four segments and nine product categories that make up this class contained approximately 21 per cent of the bank of working gases in Australia, or around 9,100 tonnes, in more than 16 million vehicles. The vehicle fleet also consumed an estimated 33 per cent (~1,048 tonnes) of all bulk HFCs imported into Australia in 2012 to replace leaked gas.

The large majority of this bulk gas was consumed servicing air conditioning systems in existing vehicles, which have an estimated leak rate of 10 per cent per annum. An additional allowance of 1.5 per cent per annum is included for passenger and light commercial vehicles to replace gas lost from vehicles that had some form of collision or catastrophic failure (i.e. compressor).

Table 6: Mobile air conditioning taxonomy

Item	Major class	Segments (application/product)		Product/equipment categories	
MOBILE AIR CONDITIONING					
16	Mobile air conditioning (MAC)	MAC1	Registered vehicles <3.5 GMV	MAC1-1	Passenger vehicles
17		MAC1	Registered vehicles <3.5 GMV	MAC1-2	Light commercial vehicles
18		MAC2	Registered vehicles ≥3.5 GMV	MAC2-1	Rigid truck and other
19		MAC2	Registered vehicles ≥3.5 GMV	MAC2-2	Truck: articulated
20		MAC2	Registered vehicles ≥3.5 GMV	MAC2-3	Commuter buses
21		MAC2	Registered vehicles ≥3.5 GMV	MAC2-4	Buses (> 7m)
22		MAC3	Rail	MAC3-1	Passenger rail
23		MAC3	Rail	MAC3-2	Locomotive
24		MAC4	Vehicles: other	MAC4	Off-road, defence and other (boat, etc.)

The majority of mobile air conditioning systems (95 per cent) are found in passenger vehicles. These systems generally contain 600 to 700 grams of refrigerant gas when fully charged. Due to the timing of the roll out of mobile air conditioning as a standard feature in passenger vehicles, and later in heavy vehicles and public transport, mobile air conditioning largely skipped the transition from CFCs to HCFC refrigerants in the 1990s. The vast majority of mobile equipment either transitioned from CFCs directly to HFC-134a, or it was manufactured with HFC-134a.

The registered vehicle stock levels by category, growth rates and lifespans (or vehicle attrition) used in CHF2 are consistent with the Australian Bureau of Statistics catalogues referenced in this report. This

simplified the methodology as the stock of equipment and retirements were derived by multiplying the ABS values by the estimated mobile air conditioning penetration for each product category.

Stock models of air conditioning systems in rail carriages and other mobile systems were developed based on consultation with key suppliers which have been on-going since the inception of CHF1. Stocks of the various product categories in this class of equipment are listed in *Table 7*.

Table 7: Mobile air conditioning by category and stock numbers

Category code	Segment	Product category	Total (units)
MAC1	Registered vehicles <3.5 GMV	Passenger vehicles	12,079,000
MAC1	Registered vehicles <3.5 GMV	Light commercial vehicles	2,487,000
MAC2	Registered vehicles ≥3.5 GMV	Rigid truck and other	422,000
MAC2	Registered vehicles ≥3.5 GMV	Truck: articulated	88,000
MAC2	Registered vehicles ≥3.5 GMV	Commuter buses	68,600
MAC2	Registered vehicles ≥3.5 GMV	Buses (> 7m)	22,000
MAC3	Rail	Passenger rail	6,800
MAC3	Rail	Locomotive	1,900
MAC4	Vehicles: other	Off-road, defence and other (boat, etc.)	32,800
AC	Total mobile AC		15,208,100

(Sources: DSEWPaC 2013a, DSEWPaC 2013b, FAPM 2013, ABS 9309.0 2012, ABS 9314.0 2012, DSEWPaC 2011, ABS 9208.0 2010 and industry informants)

Hydrocarbon is reported to be the second most widely used refrigerant in mobile air conditioning. It is thought to be employed most frequently in the service market for older second hand vehicles and is estimated to account for around 8 per cent of the refrigerant gas used in passenger and light commercial vehicles.

This equates to around 1,200,000 passenger and light commercial vehicles on the road. Other refrigerants found in mobile refrigeration applications include HFC-407C and HFC-410A which are more likely to be used in locomotive, passenger rail and off-road applications. The relatively rare HFC-124 can be found in extreme ambient applications such as in mobile cranes.

Consumption in automotive and truck manufacturing was estimated to be 180 tonnes in 2012. Automotive passenger vehicle manufacturing declined from 326,960 (including light commercial vehicles) in 2006 to 221,073 in 2012, partially due to the closure of the Mitsubishi factory in 2008. This decline removed demand of between 50 to 60 tonnes per annum from HFC-134a consumption. The recently announced closure of the Ford Motor Company manufacturing operations in Geelong and Broadmeadows in Victoria will have a similar effect between now and 2016.

Table 8: Mobile air conditioning main metrics

Mobile air conditioning summary all categories	
Share of refrigerant bank:	21%
Size of refrigerant bank:	9,100 tonnes
Annual consumption to replace leaks (excl. OEM):	1,048 tonnes
Share of total annual bulk imports to replace leaks:	33%
Gas in pre-charged equipment imports over previous five years (excl. 2012):	Vehicles with gross vehicle mass (GVM) < 3.5 tonnes = 359 to 507 tonnes Vehicles with GVM > 3.5 tonnes = 37 to 51 tonnes
Estimated stock of equipment:	> 16 million units
Charge size:	500 grams ⁹ to 10 kg (buses) Average charge (610 grams)
Estimated leak rate:	10% to 12% of charge per annum (incl. crash)
Predominant gas species used by volume:	HFC-134a and hydrocarbon in passenger and light commercial vehicles HFC-134a, HCFC-22, HFC-407C and HFC-410A in other MAC equipment categories
Annual expenditure on new equipment:	~\$560 Million
Annual GHG indirect emissions:	3.03 Mt CO ₂ -e
Share of HVAC&R indirect emissions:	5%
Annual GHG direct emissions (ODS):	0.01 Mt CO ₂ -e
Annual GHG direct emissions (SGG):	1.36 Mt CO ₂ -e
Share of HVAC&R direct emissions:	25%
Share of HVAC&R total emissions (direct and indirect, not including EOL)	7%
Number of registered vehicles serviced by AC	> 95% (passenger and light commercial vehicles)

(Sources: DSEWPaC 2013a, DSEWPaC 2013b, FAPM 2013, AIP 2013, DIT 2012, ABS 9309.0 2012, ABS 9314.0 2012, DSEWPaC 2011, ABS 9208.0 2010 and industry informants)

⁹ Hydrocarbon charge in mobile AC can be as low as 200 grams as the charge size is around 35% of HFC-134a charge.

4.4 Domestic refrigeration

Domestic refrigeration and freezers are the visible and ubiquitous presence of refrigeration technology in everyday life. These highly refined, reliable and generally very efficient devices can be regarded as the necessary end point of the cold food chain infrastructure. As the ‘end point’ in the refrigerated cold food chain, domestic refrigeration and freezers provide probably the greatest labour saving and economic benefit for consumers who store fully value added produce in increasingly larger and more efficient appliances.

Table 9: Domestic refrigeration taxonomy

Item	Major class	Segments (application/product)		Product/equipment categories	
DOMESTIC REFRIGERATION					
25	Domestic refrigeration (DR)	DR1	Refrigerators and freezers	DR1-1	Domestic refrigerators
26		DR1	Refrigerators and freezers	DR1-2	Domestic freezers
27		DR2	Portable and vehicle refrigeration	DR2-1	Portable and vehicle refrigeration
28		DR2	Portable and vehicle refrigeration	DR2-2	Vehicle refrigeration

Domestic refrigeration in Australia (including domestic freezers and small portable refrigerators) is estimated to contain approximately 5.4 per cent (~2,200 tonnes) of the total refrigerant bank, consuming less than 0.7 per cent (~22 tonnes) of annual refrigerant imports to replace leaked gas, in a total stock of greater than 17,100,000 devices in 2012.

The large majority of the existing stock of domestic refrigeration contains HFC-134a (~93 per cent). Some very old products manufactured prior to the early 1990s contain CFC-12¹⁰ but it is estimated that in 2012 more than 1.1 million (~7 per cent) contain hydrocarbon HC-600a. This is a recent trend, though this number is growing rapidly with retailers and manufacturers reporting that more than half of all new sales of domestic refrigerators now carry a hydrocarbon refrigerant.

These millions of domestic refrigerators and freezers are largely used for food storage in Australian households, office and workplace kitchens, and in portable applications (approximately 1.4 devices on average per household). A small proportion of this stock can also be found being used for food storage in restaurants, takeaways, independent supermarkets, convenience stores, accommodation, and hotels, clubs and entertainment venues.

Typical storage volumes can range from 20 litre portable refrigerators, to large 850 litre units with ice and beverage dispensing features. The average size of the domestic fridge-freezer is increasing, however machines with beverage dispensing capability only represent a small fraction of existing stock.

A typical product contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system with refrigerant charges ranging from less than 50 grams to more than 200 grams, and around 40 per cent proportionally less if charged with hydrocarbons. Portable systems and passenger vehicle refrigerators include 240VAC/12VDC chest style fridge-freezers through to freestanding upright products suitable for caravans, camper trailers, motor homes, boats, buses, four wheel drives, etc.

¹⁰ This older stock of equipment is just one of the sources of the 30 to 40 tonnes of CFCs still being returned every year to the RRA destruction program, the gas most likely being recovered from fridges being repaired by dealers of second hand white goods.

New sales in 2012 amounted to more than 1.2 million devices with new sales having averaged close to 1.1 million devices every year for the past decade.

More than 75 per cent of new sales by unit volume are imported as pre-charged equipment. The 2008 closure of Fisher & Paykel's domestic refrigerator manufacturing plant in Cleveland, Queensland displaced Australian demand for 36 tonnes of HFC-134a bulk imports per annum. It is expected that a similar volume of gas in equipment imports replaced this reduction in demand for bulk gas. Consumption from the only remaining domestic refrigerator manufacturers, Electrolux Appliances based in Orange, NSW is declining as the remaining models are converted to HC-600a.

There were 94 tonnes of refrigerant imported in pre-charged domestic refrigerators in 2010, and a further 13 tonnes in portable refrigerators in that year.

Leak rates are very low for the majority of these tightly engineered and completely self-contained systems. The decades of product development and the huge volume manufactured have produced a class of equipment that is so reliable that most people never have to get one repaired.

More than 100,000 portable and passenger vehicle refrigerators are imported each year; major suppliers include Dometic Group (Waeco brand) and Engle Australia. Evercool, Norcoast and OzeFridge manufacture small quantities of portable 12V refrigerators in Australia.

It is estimated that nearly 900,000 domestic and portable devices, still likely to contain as much as 98 tonnes of HFCs, reached the end of their useful life in 2012. That quantity of HFCs is the equivalent of 127,400 tonnes of CO₂-e.

The main metrics are provided in *Table 10*, which includes an electricity consumption estimate of 7,374 GWh for domestic refrigerators and freezers, plus an additional 100 GWh for portable appliances. This estimate is consistent with other research in this area including the *Evaluation of Energy Efficiency Policy Measures for Household Refrigeration in Australia 2010* (E3 2010c) that provided an estimate of 6,206 GWh to 7,773 GWh in 2012 for domestic refrigerators and freezers, depending on which policy measures were adopted.

Table 10: Domestic refrigeration main metrics

Mobile air conditioning summary all categories	
Share of refrigerant bank:	5%
Size of refrigerant bank:	2,205 tonnes
Annual consumption to replace leaks:	22 tonnes per annum
Share of total annual bulk imports to replace leaks:	< 0.5%
Gas in pre-charged equipment imports over previous five years (excl. 2012):	85 to 142 tonnes per annum
Estimated stock of equipment:	> 17 million appliances
Charge size:	50 to 200 grams, average 140 grams
Estimated leak rate:	< 1% of charge per annum
Predominant gas species used by volume:	HFC-134a and HC-600a
Annual expenditure on new equipment:	< \$1.2 Billion
Annual electricity consumption:	7,474 GWh
Share of HVAC&R electrical consumption:	13%
Annual GHG indirect emissions:	6.83 Mt CO ₂ -e
Share of HVAC&R indirect emissions:	12.0%
Annual GHG (SGG) direct emissions:	0.03 Mt CO ₂ -e
Share of HVAC&R direct emissions:	0.5%
Share of HVAC&R total emissions (direct and indirect, not including EOL):	11%

(Sources: DSEWPaC 2013a, DSEWPaC 2013b, DSEWPaC 2011, E3 2010b, E3 2010c and E3 2008d and industry informants)

4.5 Refrigerated cold food chain

More than almost any segment of the RAC industry, the refrigerated cold food chain is essential to the maintenance of our modern way of life. Australia's reliance on the cold food chain extends to its economic well being as a nation.

While total farm gate production of food in Australia were estimated to be worth some \$52 billion in 2010-11, more than 60% of that, worth more than \$32 billion was exported, contributing to the diets of more than 60 million people around the world.

Total production of perishable foods that require an unbroken chain of refrigeration from the point of production to the point of consumption was worth more than an estimated \$28 billion at the farm gate. Approximately \$11 billion was earned from export of perishable foods in 2010-11. At the same time Australian's dined out on more than \$10 billion worth of food imports in 2010-11, at least half of which was likely to be refrigerated.

Operation of the refrigerated cold food chain is the original purpose for which the underlying technology was developed. Refrigerating systems for maintaining food stuffs and perishable products have been in constant technological development and innovation for more than 125 years. As such it is no surprise that, while this is not the largest class of equipment employed, it is characterised by having more variety of formats and mechanical styles for delivery of the cooling services than any of the other classes. Part of the reason for this is due to the wide range of application temperatures ranging from water coolers dispensing water at around 10°C to blast freezers operating below -35°C.

The five segments and twenty four product categories that make up this class contained approximately 11 per cent of the bank of working gases in Australia, or around 5,000 tonnes, in more than one million installations and pieces of equipment that consumed an estimated 19 per cent (614 tonnes) of all bulk HFCs imported into Australia in 2012 to replace leaked gas.

Table 11: Refrigerated cold food chain taxonomy

Item	Major class	Segments (application/product)		Product/equipment categories	
REFRIGERATED COLD FOOD CHAIN					
29	Refrigerated cold food chain (RCFC)	RCFC1	Unitary equipment	RCFC1-1	Refrigeration cabinets
30		RCFC1	Unitary equipment	RCFC1-2	Refrigeration beverage vending machines
31		RCFC1	Unitary equipment	RCFC1-3	Ice makers
32		RCFC1	Unitary equipment	RCFC1-4	Walk-in coolrooms: small
33		RCFC1	Unitary equipment	RCFC1-5	Walk-in coolrooms: medium
34		RCFC1	Unitary equipment	RCFC1-6	Walk-in coolrooms: large
35		RCFC1	Unitary equipment	RCFC1-7	Beverage cooling (post mix)
36		RCFC1	Unitary equipment	RCFC1-8	Beverage cooling (beer)
37		RCFC1	Unitary equipment	RCFC1-9	Water dispensers (incl. bottle)
38		RCFC1	Unitary equipment	RCFC1-10	Packaged liquid chillers
39		RCFC1	Unitary equipment	RCFC1-11	Milk vat refrigeration

40	RCFC1	Unitary equipment	RCFC1-12	Portable refrigerators (commercial)
41	RCFC2	Transport refrigeration	RCFC2-1	Mobile refrigeration: road: trailer - inter-modal
42	RCFC2	Transport refrigeration	RCFC2-2	Mobile refrigeration: road: diesel drive
43	RCFC2	Transport refrigeration	RCFC2-3	Mobile refrigeration: road: off engine
44	RCFC2	Transport refrigeration	RCFC2-4	Mobile refrigeration: marine
45	RCFC3	Supermarkets	RCFC3-1	Supermarket refrigeration: small
46	RCFC3	Supermarkets	RCFC3-2	Supermarket refrigeration: medium
47	RCFC3	Supermarkets	RCFC3-3	Supermarket refrigeration: large
48	RCFC4	Hospital refrigeration	RCFC4	Process and large kitchens
49	RCFC5	Industrial refrigeration	RCFC5-1	Cold storage and distribution
50	RCFC5	Industrial refrigeration	RCFC5-2	Process chilling

The disproportionate level of bulk gas consumption, compared to the portion of the working bank employed in this class is to some extent because of the nature of the task. Machinery in the cold food chain is generally very hard working and operates the majority of hours of the day, if not 24 hours a day. Generally much lower temperatures need to be attained and maintained than in any air conditioning applications.

The industry does acknowledge that leak rates are high in this sector of the industry and a renewed focus on gas containment, leak detection and prevention is sweeping through some parts of the sector.

While being one of the smaller classes in terms of the portion of the bank employed, and being the smallest in terms of the stock of equipment, the refrigerated cold food chain is thought to be the largest source of employment in the sector, including the people employed in the refrigerated transport task.

Stocks of the various product categories in this extensive class of equipment are listed in *Table 12*.

Table 12: Refrigerated cold food chain by category and stock numbers

Category code	Segment	Product category	Total (units)
RCFC1-1	Unitary equipment	Refrigeration cabinets	447,000
RCFC1-2	Unitary equipment	Refrigeration beverage vending machines	134,000
RCFC1-3	Unitary equipment	Ice makers	66,000
RCFC1-4	Unitary equipment	Walk-in coolrooms: small	65,700
RCFC1-5	Unitary equipment	Walk-in coolrooms: medium	20,200
RCFC1-6	Unitary equipment	Walk-in coolrooms: large	12,200

RCFC1-7	Unitary equipment	Beverage cooling (post mix)	37,000
RCFC1-8	Unitary equipment	Beverage cooling (beer)	12,200
RCFC1-9	Unitary equipment	Water dispensers (incl. bottle)	235,000
RCFC1-10	Unitary equipment	Packaged liquid chillers	10,000
RCFC1-11	Unitary equipment	Milk vat refrigeration	6,800
RCFC1-12	Unitary equipment	Portable refrigerators (commercial)	5,000
RCFC2-1	Transport refrigeration	Mobile refrigeration: road: trailer - inter-modal	6,300
RCFC2-2	Transport refrigeration	Mobile refrigeration: road: diesel drive	5,000
RCFC2-3	Transport refrigeration	Mobile refrigeration: road: off engine	17,600
RCFC2-4	Transport refrigeration	Mobile refrigeration: marine	420
RCFC3-1	Supermarkets	Supermarket refrigeration: small	2,048
RCFC3-2	Supermarkets	Supermarket refrigeration: medium	985
RCFC3-3	Supermarkets	Supermarket refrigeration: large	333
RCFC4	Hospital refrigeration	Process and large kitchens	120
RCFC5-1	Industrial refrigeration	Cold storage and distribution	13.05 Million m ³
RCFC5-2	Industrial refrigeration	Process chilling	-
RCFC	Total RCFC		1,083,900

(Sources: DSEWPaC 2013a, DSEWPaC 2013b, AMSA 2013, ABARES 2012, DSEWPaC 2011, EG 2011, E3 2009a, MC 2012, WF 2013, WOW 2013, Convenience World and industry informants)

Overall confidence in the data relating to this class of equipment has improved for a number of reasons.

A confidential survey that covered more than 95% of the commercial refrigeration market was undertaken as part of this study. Participants supplied 2010, 2011 and 2012 annual sales data for refrigeration compressors and condensing units in up to 8 capacity categories, and provided a dissection of refrigerant type for each capacity bin where practical. This data was provided exclusively to market participants in aggregate to assist them with improved market intelligence on the market size and make up, and therefore is not published in this report. The data from the survey provided the authors with invaluable information to improve the quality of the stock model and verify prediction of proportions of refrigerant species sold and installed.

Stock of food retail outlets was updated from previous studies using the latest public data published by major supermarket chains, and information from other targeted sources such as Convenience World for statistics on convenience stores by brand and ABS data on business types.

The dairy industry, which is a big user of refrigeration services across nearly all of its product lines, has seen a lot of farm consolidation over the last two decades with farm numbers declining from 21,994 in 1980 to 6,770 in 2012.¹¹ The number of operating dairy farms is well known, and this product category was dissected into proportions of the two main equipment types (i.e. Direct expansion, or 'DX' cooling; and

¹¹ Source: Dairy Australia, Statistics and Markets, Cows and Farms data provided by State Milk Authorities.

indirect cooling systems). Electricity consumption and refrigerant models were then developed for both of these equipment types based on their specific technical characteristics.

The number of fishing vessels with commercial scale refrigeration systems is estimated to be around 400 to 450 vessels which was significantly scaled down from previous studies including CHF1, and *'In from the Cold'*. The revision downwards is based on an improved understanding of the proportion of the registered fishing fleet that is active. Interviews with industry stakeholders indicate that only about 40% of the 2,109 fishing vessels registered with the Australian Maritime Safety Authority are active. Research for this study has also improved our understanding of the size of vessel on which commercial refrigeration systems are typically found. Essentially only registered fishing vessels of greater than 15 meters in length are likely to have a substantial refrigeration system. Smaller vessels were assumed to either collect ice at the wharf, and/or have portable refrigeration systems.

The electricity consumption of cold storage facilities was calculated by multiplying the total storage capacity of 13.05 million m³ (95% ammonia and 5% HFC/HCFC) by the specific energy consumption (SEC) in kWh per m³ per year. The SEC of individual cold storage facilities can vary significantly ranging from around 30 kWh/m³/year to greater than 200 kWh/m³/year, depending on the type of facility (i.e. cold store or blast freeze, storage temperatures, and combination of these types), the overall efficiency of the refrigeration system and efficiencies of individual components, lighting technologies, geographical climate, thermal insulation and sealing (i.e. automatic doors) of structure, maintenance, and many other factors. The industry average was estimated to be 51 kWh/m³/year for ammonia systems and 15% higher for synthetic refrigerant systems, however an industry specific source suggested the average SEC could be 10% to 15% higher with typical ammonia systems consuming around 60 kWh/m³/year.¹²

The estimate of total cold storage capacity in Australia was based on the latest Refrigerated Warehouse Transport Association member data for independent third party logistics and retail facilities plus an allowance of 33% for non RWTA members.

When it was published in 2009, *'In from the Cold: Strategies to increase energy efficiency of non-domestic refrigeration in Australia and New Zealand'* (E3 2009a), predicted energy consumption of 15,300 GWh per annum in 2012. CHF2 has revised this value down slightly to 14,700 GWh per annum of electricity consumption by this class of equipment in 2012. This is consistent with more recent findings as, since *'In from the Cold'* was published there have been significant signs of improved energy efficiency in this industry sector.

4.5.1 Self-contained commercial refrigeration

Several of the equipment categories in the unitary equipment segment are referred to in the trade as 'self-contained refrigeration'. Self-contained commercial refrigeration equipment typically contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system employing relatively small refrigerant charges, ranging from just 40 grams in a bottle water cooler, to up to three kilograms in a refrigerated display case.

Many of these equipment categories are very familiar to the average citizen, being common in supermarkets, grocery and butcher stores, cafes and other food retail outlets, restaurants, takeaways, hotels and clubs.

The main product categories include:

- RCFC1-1: Refrigerated display cabinets, sometimes referred to as 'self-contained merchandisers' covering plug-in-type food retail and supermarket cabinets, including; sandwich-pizza preparation and display counters; kitchen and service storage and preparation equipment; glass door merchandisers and upright cabinets; chest cabinets commonly used for ice cream display; ice cream makers; blast chiller freezers; wine, drink and glass chilling cabinets for bars, restaurants and hotels. RCFC1-1 also picks up a small number of specialised cabinets for pharmaceutical applications;

¹² Gabor Hilton, *Refrigerated Warehouse and Transport Association*.

- RCFC1-2: Refrigerated beverage vending machines often purchased by major food manufacturers such as Coca-Cola, Pepsi and Schweppes, and also independent vending suppliers located at airports, railway stations, offices, factories, warehouses, universities and schools, etc.;
- RCFC1-3: Ice makers commonly used in cafes, hotels/bars and food courts. These are generally packaged freestanding, bench-top or under-bench units, and may have a small storage basket or bin with access door, or dispense ice and beverages automatically;
- RCFC1-4, RCFC1-5: Drop-in and slide-in packaged refrigeration units used in walk-in coolrooms and extensively used throughout the food chain to refrigerate fresh, chilled and frozen produce;
- RCFC1-7: Post-mix beverage cooling and dispensing equipment that transforms concentrated syrup, typically supplied in ‘bag-in-box’ casks, mixed with water that is circulated through an ice bank cooler to serve carbonated drinks in all sorts of hospitality venues including clubs, hotels, large restaurants with bars and entertainment venues;
- RCFC1-9: Bottle water coolers and water dispensers found in offices, factories, gymnasiums, etc.; and,
- RCF1-12: Portable refrigerators for commercial applications.

Refrigerant employed in non-domestic refrigeration is often selected based on the two main temperature ranges used for the conservation or freezing of fresh food and beverages. These are referred to in the industry as either; medium temperature (where produce is refrigerated to temperatures above zero degrees Celsius), and low temperature, (where food is frozen and refrigerated to zero degrees and below).

The majority of the existing stock of self-contained non-domestic refrigeration contains HFC-134a which is the refrigerant of choice for medium temperature applications. A smaller portion of the stock of equipment operates on HFC-404A, mostly in low temperature applications or when greater refrigerating intensity is required.

The use of hydrocarbons (HC-600a and HC-290) and CO₂ refrigerants is emerging in new equipment in Australia, however the installed base is very small and estimated to be just 2 per cent, at best in some equipment classes and non-existent in others. Examples of equipment using hydrocarbon refrigerants include freezer cabinets commonly used in Aldi supermarkets, wine coolers and chest freezers.

Consumption of bulk imported synthetic refrigerant is declining in this segment, mostly due to the decline in domestic manufacturing and as more and more equipment is imported as PCE. The main local manufacturers include Williams Refrigeration, Hoshizaki Lancer, IMI Cornelliuss, Zip Industries, Aquacooler, and Stoddart Manufacturing. The closure of Orford Refrigeration’s commercial refrigeration manufacturing operations in Toowoomba, Queensland and Frigrite Refrigeration in Victoria removed at least 15 tonnes of HFC-134a from bulk imports per annum, although the majority that was replaced by and equivalent increase in PCE imports.

4.5.2 Commercial refrigeration (excluding self-contained)

Much of the rest of the refrigerated cold food chain is built on categories of equipment that are broadly referred to as ‘remote condensing units’, and ‘centralised refrigeration systems’ and include:

- RCFC1-5, RCFC1-6: Medium and large walk-in-coolrooms;
- RCFC1-8: Beverage cooling systems for beer in which beer from kegs is circulated through an ice bank cooler to serve beer from taps in all sorts of hospitality venues including clubs, hotels, large restaurants with bars and entertainment venues;
- RCFC1- 11: Milk vats used exclusively in the dairy industry for rapid chilling of fresh milk;
- RCFC3: Supermarkets that typically have advanced centralised refrigeration systems for low, medium and high temperatures, plus individual condensing units as required; and,
- RCFC 4: Hospitals that have large kitchens typically comprising multiple individual condensing units.

These categories of commercial refrigeration equipment cover a wide range of medium to large refrigeration capacity (>1 kW_r), and include remote condensing units; centralised refrigeration systems commonly used in supermarkets; packaged liquid chillers; process refrigeration applications in industry and centralised systems for large cold storage facilities. Each of these important commercial applications is discussed in more detail in the sub-sections that follow.

Remote condensing units

Remote condensing units typically range from 1 kW_r to 20 kW_r in refrigerating capacity, and are composed of either one or two compressors, one condenser, and one receiver. These components are assembled into a 'condensing unit', which is typically located outdoors, or 'remote' from the trading floor or refrigerated space.

Refrigeration systems with remote condensing units are used in a variety of applications including on large refrigerated display cabinets such as the rear loading wine and beer refrigerators, walk-in cool rooms, beverage cooling (e.g. beer and soft drinks), milk vat refrigeration on dairy farms and chilling and freezing applications in industry.

The term walk-in coolroom is used to describe an enclosed storage space that is either refrigerated to temperatures above zero degrees Celsius (walk-in-cooler), or is refrigerated to zero degrees and below (walk-in freezer). Some older walk-in-coolers use HCFC-22, however HFC-404A has been the refrigerant of choice for walk-in-coolers and freezers for over a decade. Smaller walk-in-coolers typically with self-contained systems are inclined to use HFC-134a. Walk-in coolrooms are estimated to account for around 330 tonnes of the refrigerant bank and consume approximately 110 to 120 tonnes of refrigerant per annum making them the stand out leakiest equipment category in the sector.

Beverage cooling systems are a surprisingly large category employing approximately 470 tonnes of gas, due to the large refrigerant charge required for beer chilling applications. An average installation can have 40 kilograms of refrigerant. Older systems use HCFC-22, however HFC-404A has been the refrigerant of choice for over a decade, with a small portion of systems operating on HFC-134a.

Milk vat refrigeration units are used by dairy farmers to rapidly chill fresh milk from 34°C to 4°C prior to pick up by bulk tankers. There are two common milk cooling methods used on dairy farms, 'direct expansion' cooling and 'indirect cooling' systems. Indirect cooling uses a specialised water chiller. More than half of the existing fleet of direct expansion milk vat units use very old belt drive technology charged with HCFC refrigerants. These systems employ drive shaft seals that high refrigerant leak rates of 25 per cent or more per annum. Milk vat refrigeration units are estimated to employ around 360 tonnes of refrigerant per annum and consume approximately 80 tonnes of gas every year to service that bank.

Supermarkets

Modern supermarkets are entirely reliant on the use of RAC systems with as much as 75% of all energy used in a supermarket likely to be consumed by either refrigeration or air conditioning services. Supermarkets also generally contain a wide variety of refrigeration equipment including central plant 'rack systems', remote condensing units servicing display cases and walk-in coolrooms, and self-contained merchandisers (discussed in the *Chapter 4.5.1*) located throughout the store. The refrigerant bank contained in supermarkets (excluding self-contained devices) is estimated to account for around 7 per cent (~3,200 tonnes) of the total refrigerant bank and consume approximately 140 to 150 tonnes of annual refrigerant imports.

A centralised supermarket refrigeration system will typically include 8 to 12 compressors ranging in capacity from 7.5 to 22.5 kW_r serving both low and medium temperatures, built onto a rack system located in a separate plant room. Large supermarkets employ centralised equipment requiring refrigerant charges greater than 900 kilograms, with medium and small supermarkets generally requiring 600 kilograms and 160 kilograms of gas on average respectively. The large majority (85 per cent to 90 per cent) of refrigerant in supermarkets is HFC-404A. Where practical, the supermarket industry and many other medium temperature refrigeration applications are switching from HFC-404A to HFC-134a, partly because of the lower GWP of the HFC-134a refrigerant. Other recent trends in this category include the retrofitting of

HFC-404A systems with HFC-407F (GWP of 1,824) because of its lower GWP. With more than a 100 tonnes of HFC-407F imported in 2012 the authors estimate that around 40 tonnes of HFC-404A has been replaced.

The main local manufacturers of refrigeration rack systems include Bitzer and supermarket contractors including McAlpine Hussmann (a subsidiary of Ingersoll Rand), Austral Refrigeration (a former division of the defunct Hastie Group) and regional players such as John A Gordon, Contract Refrigeration, A.J. Baker and Alkar. Other notable changes in the industry include the closure of a major supermarket contractor Frigrite Refrigeration and the relocation of Heatcraft condensing unit manufacturing operations to China.

4.5.3 Industrial refrigeration, process chilling and cold storage

Industrial refrigeration (RCFC5), or process refrigeration, are terms commonly used to describe refrigeration applications in manufacturing processes, and those using a heat exchanger and secondary refrigerant such as water, brine or glycol20 to create the refrigerating effect.

Cold storage facilities and food manufacturers with in-house engineering expertise generally use industrial refrigeration systems with screw compressors or large reciprocating compressors operating on anhydrous ammonia (R717). There are a few industrial systems charged with HFC-404A, and some older HCFC-22 charged systems in operation, however these are rare. Ammonia charged systems dominate this equipment category with 90 per cent to 95 per cent of applications based on refrigerant volume using ammonia.

Small packaged liquid chillers (RCFC1-10) are used in process applications in laboratories, some food and drinks processing, and in other applications in manufacturing and research laboratories in a variety of industry sectors. They can have refrigerating capacities ranging from 10 kW_r to more than 1,000 kW_r. Refrigerant types used in these rare and specialised packaged liquid chillers vary significantly depending on the temperature range, size, application and design. Refrigerants used include HFC-134a, HFC-404A, HFC-407C, HFC-410A and HCFC-22.

4.5.4 Refrigerated transport

Around 42 per cent of all of Australia's 'non-bulk' road transport is for moving food and groceries (DAFF 2012). The majority of refrigerated transport (RCFC2) includes road, rail and intermodal containers, commonly referred to as 'transport refrigeration'. Refrigeration systems on fishing vessels and coastal shipping are simply called 'marine'. The majority of marine systems are on fishing vessels.

The transport refrigeration bank is estimated to comprise less than 0.4 per cent (~170 tonnes) of the refrigerant bank and consumes approximately 1 per cent (~50 tonnes) of annual synthetic refrigerant consumption, mostly in service and replenishment following system failures.

Transport refrigeration technology is made up of:

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

The large majority of equipment in service has shaft seals and vibra-sorber hoses (i.e. stainless steel braided flexible hoses). Over the equipment's lifespan it is typical to see at least one compressor replacement, shaft seal failure and a vibra-sorber failure. The shaft seal and hose failures would most likely result in the total loss of refrigerant charge. Compressor replacement would typically involve reclaim and reuse of the refrigerant.

The trailer/intermodal and diesel drive units are imported fully charged, tested and ready to be fitted. Off-engine units are imported with a nitrogen holding charge to keep the system pressurised and clean as they have to be ‘plumbed’ up with piping and a compressor by the installer. Refrigeration systems for trucks, trailers and intermodal refrigerated containers are predominantly charged with HFC-404A with a typical charge of between 6 and 10 kilograms. Some smaller systems can use HFC-134a with charges below 4 kilograms.

The existing stock is prone to high leak rates estimated at around 20 per cent per annum, however much attention in recent designs has been focused on the elimination of as many joints as possible. As a result fully sealed systems without shaft seals or flexible hoses are now available.

Marine refrigeration is estimated to comprise around 0.1 per cent (~55 tonnes) of the refrigerant bank yet involving very high annual consumption of around 2 per cent of all bulk imports (~16 tonnes) as a result of the often extremely high leak rates that are observed in fishing vessels of between 25 per cent and 30 per cent per annum.¹³ Fishing vessel systems are very hard working systems in very difficult environments with normal machine vibration exacerbated by the high vibration and sometimes relatively violent movement of the vessel, combined with high humidity plus the corrosive effects of salt.

Marine refrigeration as defined in this report is for fishing vessels that contain specialised chilling and blast freezing equipment on vessels typically over 20 metres in length, however some refrigeration can be found on vessels of between 10 and 20 metres long.

An unknown number (certainly in the tens of thousands) of refrigerated shipping containers commonly known as “Reefers” enter and leave Australian ports every year, primarily carrying perishable foods. Most of the refrigerant consumption in manufacturing and service of Reefers occurs overseas.

¹³ Industry source: Austral Fisheries, leak rates greater than 30% per annum can be experienced on old open drive equipment.

Table 13: Refrigerated cold food chain main metrics

Refrigerated cold food chain summary all categories	
Share of refrigerant bank:	11%
Size of refrigerant bank:	5,000 tonnes
Annual consumption to replace leaks (excl. OEM and charging new equipment):	614 tonnes per annum
Share of total annual bulk imports to replace leaks:	< 19%
Gas in pre-charged equipment imports over previous five years (excl. 2012):	60 to 90 tonnes per annum
Estimated stock of equipment:	> 1 million devices
Charge size:	40 grams (water cooler) to > 1 tonne (large supermarket or system)
Estimated leak rate:	3% to 25% of charge per annum ¹⁴
Predominant gas species used by volume:	HFC-404A, HFC-134a, HCFC-22, HFC-407F, CO ₂ , hydrocarbons and ammonia
Annual expenditure on new equipment:	~\$0.782 Billion
Annual electricity consumption:	14,657 GWh
Share of HVAC&R electrical consumption:	25%
Annual GHG indirect emissions:	13.6 Mt CO ₂ -e
Share of HVAC&R indirect emissions:	24%
Annual GHG direct emissions (ODS):	0.12 Mt CO ₂ -e
Annual GHG direct emissions (SGG):	1.59 Mt CO ₂ -e
Share of HVAC&R direct emissions:	24%
Share of HVAC&R total emissions (direct and indirect, not including EOL)	24%

(Sources: DSEWPaC 2013a, DSEWPaC 2013b, AMSA 2013, ABARES 2012, DSEWPaC 2011, EG 2011, E3 2009a, MC 2012, WF 2013, WOW 2013, Convenience World and industry informants)

¹⁴ The actual leak rate depends on the type of equipment, maintenance and many other factors, and equipment can range from small self-contained water coolers with leak rates of around 1% per annum to more than 25% on fishing vessels that operate in extremely harsh conditions, refer Appendices A and B for further details.

5 The bank in 2012

The common denominator of all air conditioning and refrigeration, in all of its forms and applications, is the working gases that are employed in them as the medium for transferring heat. The sum of all gas contained in RAC equipment is referred to as ‘the bank’ of working gas.

The total bank of high GWP working gas installed in RAC equipment in Australia at the end of 2012, is estimated at approximately 43,500 tonnes of ODS and HFCs.

This bank of gas, if lost to air, has a potential for global warming equivalent to approximately 71.4 Mt CO₂-e. This is roughly equivalent to 13 per cent of Australia’s total annual greenhouse gas emissions.

The end user replacement cost of this bank is roughly estimated to be \$5.8 billion based on current market prices.

At any time a small portion of the bank is in equipment that is not yet installed and operating. For instance, in the course of 2012 a total of more than 2,557 tonnes of refrigerant gas was imported in more than 3 million individual pieces of pre-charged equipment. While throughput in the supply chains for RAC equipment is high, it is reasonable to expect something between 20 per cent and 30 per cent of that equipment is still in the supply chain, and not in operation.

Additionally there is a stock of bulk gas in the supply chain that is available at any time for servicing this bank. Normally the annual imports would all be counted as forming part of the bank in the year of import. However the totality of bulk gas imports in 2012 were not automatically counted as being part of the working bank because of the extent of stockpiling of gas that occurred prior to the introduction of the ‘equivalent carbon price’ (ECP) on HFCs.

The bank of gas is comprised of two main species, HCFCs that are subject to an increasingly rapid phase out under the terms of the Montreal Protocol, and HFCs that on 1 July 2012 became subject to an ECP at the point of import. While there were already a number of inflationary influences in the HFC supply chain that were causing prices to rise, the introduction of the ECP had the effect of dramatically increasing retail prices of HFCs.

As the date for the introduction of the ECP approached imports of HFCs rose to 9,179 tonnes in 2012. Based on average imports for the five years prior to December 31, 2011, it is estimated that more than 2.7 years of average supplies of HFCs were imported in the 12 months before the implementation of the ECP.

An estimate of the bulk imports that would normally have been required in 2012 to service the bank, and for use in new equipment is included in the calculation of the total bank. The calculated ‘normalised’ values for 2012 are 3,328 tonnes of HFC bulk gas imports, 903 tonnes of HCFCs bulk gas imports¹⁵ and a further 2,557 tonnes contained in pre-charged equipment (PCE). These are the values used in the CHF2 model and throughout this report when referring to 2012 HFC imports.

The balance of the unusually high imports in 2012, of more than 5,800 tonnes, has not been included in the bank, but is noted as being ‘carried in stock’. These stockpiles will be incorporated as part of the bank in the course of the next year or two.

As a result of the stockpiling it is expected that bulk gas imports will be lower than average for at least two years following the implementation of the ECP on 1 July, 2012, as the gas in stock is consumed by the market.

Data available to date confirms this trend with bulk gas imports for the period from 1 July 2012, to 31 December, 2012 of only 15 tonnes of HFCs for RAC applications and 572 tonnes of HCFCs. The HFC imports for this 6 month period were less than 1% of what might have been expected in the absence of the ECP introduction.

¹⁵ This estimate is the volume required to meet HCFC consumption demand, not what was actually imported under the Montreal cap.

5.1 GWP of components of the bank

This report often refers to the global warming potential (GWP) values of the gases that are the subject of this study. The range of GWP across all gases that can be found in the stock of equipment ranges from zero (ammonia) to 10,900 for the now uncommon and phased out CFC-12.

For the purposes of this report the bank of working gases has been differentiated into 'high GWP' refrigerants and 'low GWP' Refrigerants. The delineation is made at a GWP of 1,000.

The vast bulk of all working gases in use (~90 per cent) are high GWP gases. The term low GWP gas is used to refer to the natural refrigerants, ammonia, hydrocarbons and CO₂, and HFC substances with a GWP lower than those commonly used today. This includes the near to commercial HFOs being scaled up by the major synthetic greenhouse gas manufacturers that are sometimes referred to as low GWP HFCs (refer to *Chapter 5.2.9* for further details on the development of HFO substances).

While ammonia has a GWP of zero, CO₂ is the benchmark with a GWP of 1. Commonly used hydrocarbon refrigerants such as HC-600a and HC-290 have a GWP of around 3, HFC-32 has a GWP of 650 and HFO1234yf is commonly cited with a GWP of 4. All these gases satisfy our criteria as being 'low GWP'.

The GWP values used in this report are based on the Second Assessment Report (AR2) of the International Panel on Climate Change (IPCC) except where specifically referenced to the Fourth Assessment Report (AR4).

While many of the GWP's originally calculated in AR2 have been updated, and in many cases increased, in the AR4, the legislation in Australia under which the ECP was introduced is referenced to the AR2 values that were in use in 1997, at the time of the Kyoto Protocol being signed.

The AR4 values will be adopted by the Australian government in 2017. The Fifth Assessment Report is well advanced, however is not publically available at the time of writing this report.

For information *Table 36* in *Appendix B* lists the AR2 and AR4 GWPs of refrigerant gases and substances in use in Australia.

5.2 Refrigerant bank 2006 versus 2012

In a dramatic phase of growth the bank of working gas has expanded by more than 45 per cent in just 6 years, from an estimated 30,169 tonnes in 2006 to a total bank of 43,500 tonnes in 2012.

However it also has to be noted that the baseline figure for the bank in 2006, calculated as part of CHF1, may have been underestimated as a result of a general underestimation of the stock of equipment made at that time. Numerous studies have been conducted since the completion of CHF1, many of which have extended the data in the stock model, finding some larger 'pools' of gas in stocks of equipment that were previously underestimated. These include walk-in coolrooms and some categories of commercial refrigeration equipment.

As a result of these other research projects the 2012 model also includes more accurate assumptions about retirement rates of certain equipment categories that has had the effect of increasing the estimated average life of some equipment categories, and therefore increasing the number of pieces of equipment expected to still be in operation, a change that adds to the bank of gas working in that category.

Even with the improved data and assumptions available in the 2012 model, upon reviewing the underlying data used in CHF1 the authors concluded that the 2006 bank is likely to have been underestimated by no more than 10 per cent. If we assume that as the worst case, and the 2006 bank was actually equivalent to 33,185 tonnes, then the bank has still grown by some 32 per cent in the period. The reality is likely to be something between those numbers, with the range of growth of the bank in the period from 2006 being at least 32 per cent, and being no more than 45 per cent. The range, and the total tonnes in the bank at the 2006 starting point do not have a significant impact on the observable trends in the composition of the much expanded bank in 2012.

The rapid growth in the working bank, particularly between 2006 and 2010, is a phenomenon that was largely underpinned by the vast increase in air conditioning equipment.

The overall rate of growth of this high GWP bank of gas appears to have slowed in the last two years. Growth of only 5 per cent, per annum, at most, has been recorded between 2010 and 2012, from around 41,100 tonnes to the present level. This recent rate of growth may be even lower because some of the same data improvements that led us to consider a possible underestimation of the 2006 bank would also flow through to a (much smaller) possible underestimation of the 2010 bank.

Irrespective of the exact rate of growth, the observed flattening in growth of the bank could possibly be a result of some saturation in the air conditioning market, coupled with slightly cooler summers in 2010 and 2011 than during previous years. Other factors that could contribute to this trend include the general tightening in consumer spending, resulting in delayed purchasing decisions in both residential and commercial equipment, a trend that has been widely observed across the economy during the period.

Some of this flattening in growth of the high GWP bank may also be attributed to accelerated migration of some product categories to the use of low GWP gases in the lead up to the introduction of the ECP on July 1, 2012. These technological trends include the retrofitting of registered passenger vehicles with hydrocarbons, a shift by manufacturers of new domestic refrigerators to hydrocarbon refrigerants, and a move of some larger supermarket systems to technology driven by CO₂ refrigerant.

However it is too early to say if this slowing in the overall growth rate of the high GWP bank is a long term trend.

5.2.1 The bank by high GWP species

The total bank of high GWP working gases in refrigeration and air conditioning equipment in Australia in 2012 is estimated at approximately 43,500 tonnes of HCFCs and HFCs as listed in *Table 14*.

Table 14: High GWP refrigerant bank at the end of 2012 by mass in tonnes

Species	Bank (t)
HCFC-22 ⁽¹⁾	11,227
HCFC Mix	201
HFC-134a	13,432
HFC-404A	3,306
HFC-407C	1,017
HFC-410A	14,341
Total	43,523

1. CFCs, now estimated to be less than 450 tonnes and rapidly declining, are included in HCFC-22 estimates, and some HCFC blends used in air conditioning applications are counted as HCFC-22.
2. The values in the table are estimates from the CHF2 stock model.

The relative proportions of the main high GWP HCFCs and HFCs that make up the bank have changed dramatically since 2006 as illustrated in *Figures 1* and *2* (Sources: CHF2 stock model, DSEWPaC 2007).

The bank 2006 versus 2012

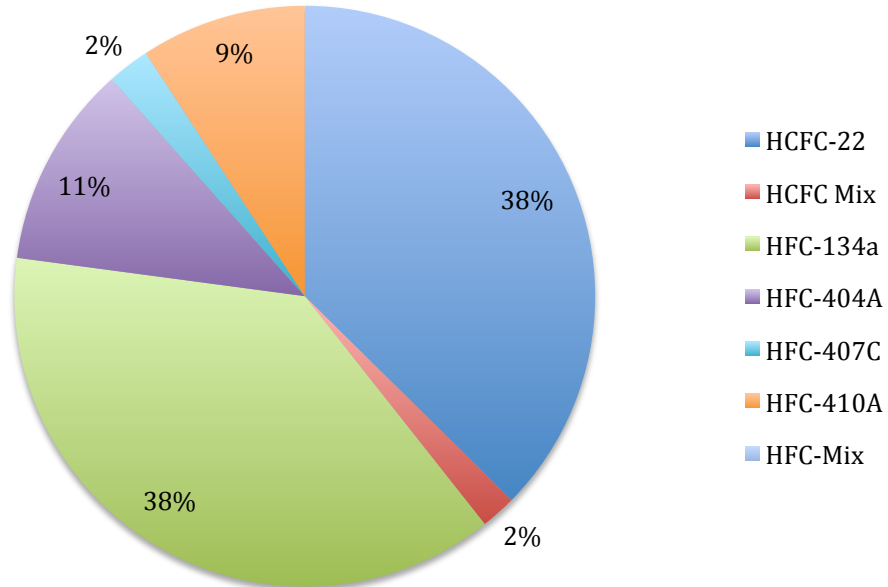


Figure 1: Bank of main high GWP HCFCs and HFCs in Australia 2006

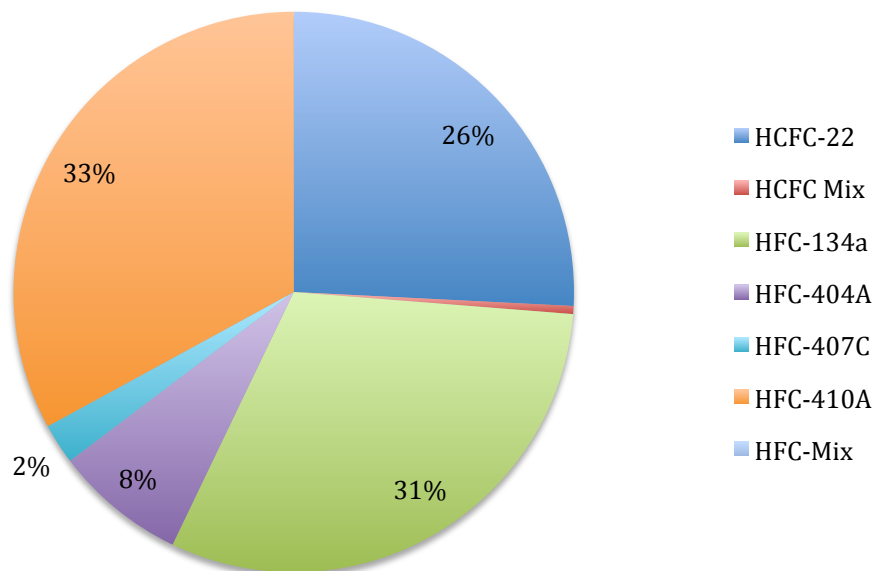


Figure 2: Bank of main high GWP HCFCs and HFCs in Australia 2012

Comparing the composition of the 2012 bank, with the working bank as it was in 2006, reveals some dramatic changes. The rapid increase in the use of HFC-410A from 9 per cent (2,782 tonnes) of the bank in 2006 to 33 per cent in 2012 (13,966 tonnes), driven by the explosive growth in stationary air conditioning and the use of HFC-410a to replace HCFC-22, means that HFC-410A is now the largest component of the entire bank, edging out HFC-134a.

A corresponding decline in the proportion of HCFC-22 in the bank, from 38 per cent of the bank in 2006 (11,280 tonnes) to 26 per cent in 2012 (11,227 tonnes), demonstrates the effect of the Australian industries commitment to the accelerated phase out of HCFC-22 under the Montreal Protocol. Australia is now four years ahead of the agreed international timetable. The phase out of HCFCs is discussed in more detail in *Chapter 5.2.6*.

While the quantity of HCFCs in the bank is almost identical in 2006 and 2012, the comparison masks the strength of the trend against HCFCs. Previously HCFC-22 was the refrigerant of choice in air conditioning applications. Its use peaked in 2010 when it was estimated that more than 12,800 tonnes of HCFCs made up just over 30 per cent of the bank in that year. In what is quite a sharp fall, the bank of HCFCs is already down nearly 1,600 tonnes from that high point in just two years.

Predicting the future rate of change in the bank of HCFCs is complicated by several factors including the current prices of HCFC-22 which is similar to its most likely replacement HFC-410A, the amount of HCFC-22 reuse, stock piling used refrigerant from old systems, and the cost of maintaining old equipment. However the impact on prices of the next Montreal Protocol cap step down from 40 ODP tonnes to 10 ODP tonnes in 2014 is expected to accelerate equipment retirements.¹⁶

HFC-134a is now the second most abundant gas in the bank. It has been growing steadily at around 3 per cent per annum, and now accounts for 31 per cent (13,811 tonnes) versus 38 per cent in 2006 (11,389 tonnes).

HFC-404A has remained relatively steady in overall tonnes, however has declined from 11 per cent of the bank in 2006 to 8 per cent in 2012.

HFC-407C comprises just 2.3 per cent of the bank and has grown steadily from around 700 tonnes in 2006 to slightly more than 1,000 tonnes in 2012, mostly as a result of the similar refrigeration characteristics of HCFC-22 and HFC-407C. A comparison of the 2006 and 2012 bank by species in tonnes is provided in *Table 15*.

Table 15: High GWP refrigerant bank 2006 and 2012 by mass in tonnes

Species	2006 (t)	2012 (t)
HCFC-22 ⁽¹⁾	11,280	11,227
HCFC Mix	595	201
HFC 134a	11,389	13,432
HFC-404A	3,412	3,306
HFC-407C	711	1017
HFC-410A	2,782	13,966
Total	30,169	43,523

¹⁶ The ODP multiplier for HCFC-22 is 0.055, therefore 40 ODP tonnes is equivalent to 727.3 metric tonnes of HCFC-22.

1. CFCs, now estimated to be less than 450 tonnes and rapidly declining, are included in HCFC-22 estimates, and some HCFC blends used in air conditioning applications are counted as HCFC-22.

5.2.2 Stockpiles

While it appears that the working bank of gas has stabilised in recent years, the announcements in mid-2011 of the impending introduction of the ECP resulted in a significant increase in bulk imports in 2012, and strong growth in stocks held by businesses throughout the supply chain.

DSEWPac data indicates that total imports of all species of refrigerant gas in 2012 were equivalent to more than two and a half years of average supply of HCFCs and HFCs, or a total of more than 12,511 tonnes of HCFCs and HFCs.

This was at a time when general activity in the sector was slower than previous years due to cool summers in 2010 and 2011, sluggish economic activity which led to reduced building and construction activity, and a slow-down in spending and investment during the 2011-12 financial year.

Total imports in 2012 were made up of 9,179 tonnes of bulk HFCs, 775 tonnes of bulk HCFCs, and 2,557 tonnes of refrigerant contained in pre-charged equipment. The majority of HFC bulk imports were made up of 4,185 tonnes of HFC-134a, 2,155 tonnes of HFC-404A and 2,065 tonnes of HFC-410A.¹⁷ In the previous corresponding period only 3,152 tonnes of HFCs and 1,297 tonnes of HCFCs had been imported in bulk.

These additional stock piles of gas (equivalent to more than 25 per cent of the working bank) should see much lower than average imports for at least the 2012-13 and 2013-14 financial years, with a volume recovery likely during 2014-15. However to some extent that prediction depends on other trends in the industry including the impact on losses of improved refrigerant containment, increase in reuse of gas recovered from EOL equipment and during routine equipment service, and the overall level of economic activity, building and construction work, and refurbishment and equipment replacement rates.

5.2.3 The bank employed

The period of extremely rapid growth in the bank corresponds with the latter stages of a decade long boom in installation of smaller commercial and domestic air conditioning systems, and a continued roll out of air conditioning across other areas of the economy such as in schools and universities, public and community buildings and in retail and industrial environments.

Overall demand for air conditioning increased at a rate much faster than the economy for most of the past decade with imports of pre-charged air conditioning equipment averaging around a million new air conditioning units each year in Australia for the past decade. This compares with average imports of only a couple of hundred thousand units per annum during most off the 90s. The effect of the demand for new air conditioning services can be viewed in *Figure 3* which illustrates the employment of the bank in the various major classes of technology.

This distribution of the bank of working gases across the major classes of equipment has changed dramatically since 2006, almost entirely because of the near doubling in the proportion of the bank contained in stationary air conditioning systems, rising from around 37 per cent of the bank previously to an estimated 63 per cent in 2012.

¹⁷ The import data quoted in this report will vary slightly from Senate estimates as some Ozone Depleting Substances (i.e. Halons, Carbon Tetrachloride and Methyl Chloroform, and CFCs used for medical applications) and Synthetic Greenhouse Gasses (i.e. SF₆ and PFCs) are not used in RAC applications.

2012 bank by major segment

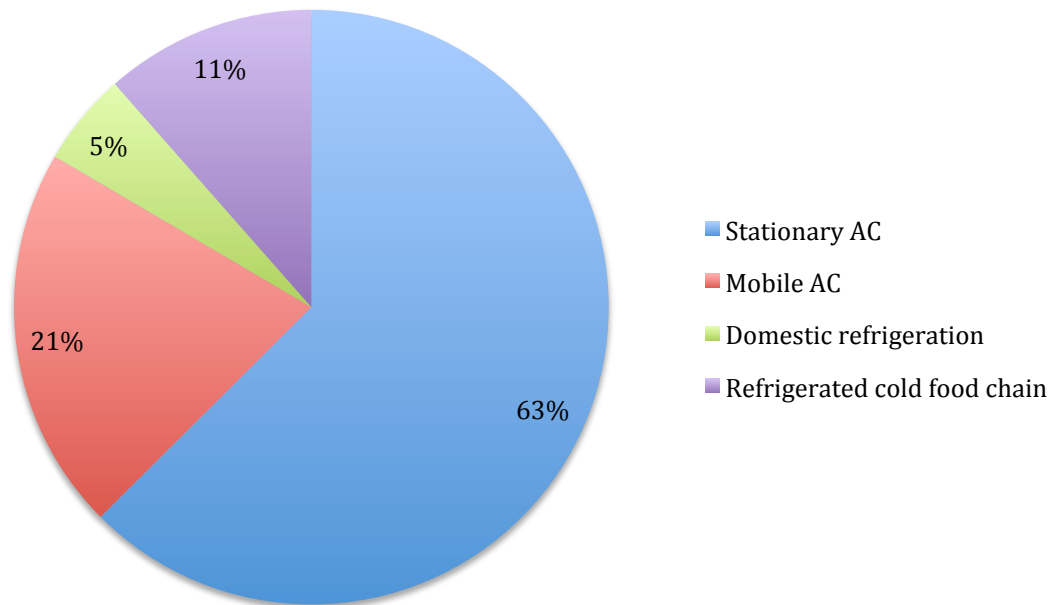


Figure 3: Bank of refrigerants by major segment 2012

(Source: CHF2 stock model)

The second largest portion of the bank is mobile air conditioning, comprising approximately 21 per cent of the total in 2012. This gas is predominantly contained in a rolling stock of around 16 million registered vehicles of all types containing HFC-134a (ABS 9309.0, 2012; ABS 9314.0, 2012).

Local manufacturing of mobile air conditioning systems is estimated to consume 160 tonnes of gas, a level of demand which has declined by around 50 to 60 tonnes per annum since the closure of the Mitsubishi factory in Adelaide in 2008, and is expected to decline further with the imminent closure of Ford Motor Company manufacturing operations in 2016.¹⁸ The larger use of gas (~80 per cent) in this sector was consumed servicing air conditioning systems in existing vehicles, which have an estimated leak rate of 10 per cent per annum, plus in replacement of gas lost from vehicles that had some form of collision or compressor failure.

The refrigerated cold food chain accounts for just 11 per cent of the total refrigerant bank, with domestic refrigerators and freezers containing a further 5 per cent. Thus all the refrigeration equipment essential in the transport and maintenance of food supplies and food quality, employ only 16 per cent of the total bank of gas.

¹⁸ Federation of Automotive Products Manufacturers reported 221,073 passenger vehicles were produced in Australia in 2012, 221,776 in 2011 and 243,031 in 2010.

5.2.4 Bulk gas imports

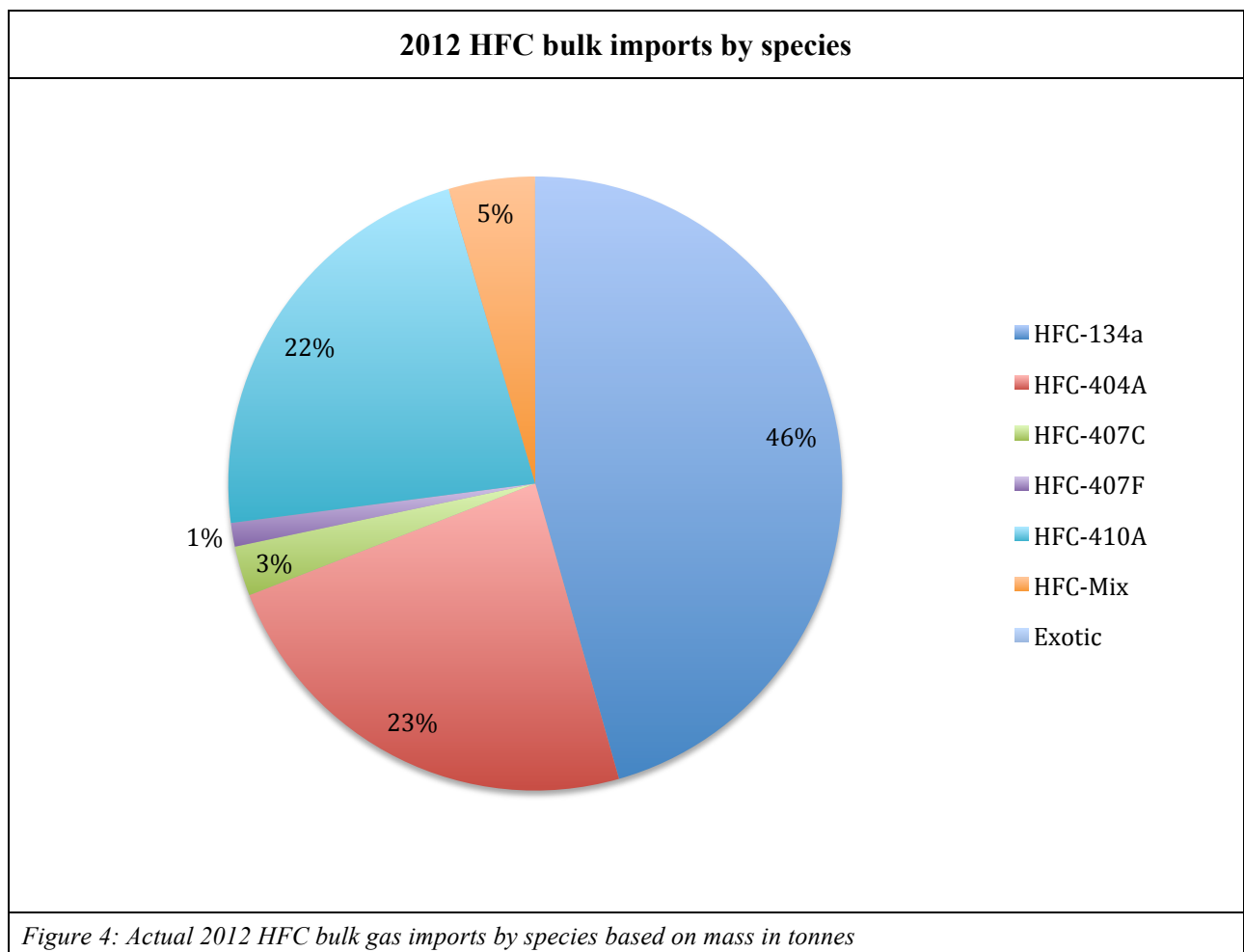
One of the two sources of growth in the bank is via the import of bulk refrigerant gases. Yet a surprising proportion of bulk imports do not add to the working bank, but are instead consumed replacing gas lost through leaks and during equipment service.

On average around 4,500 tonnes of both HCFCs and HFCs bulk gas were imported per annum from 2006 to 2011, of which it is estimated that around 70 per cent (~3,150 tonnes) was consumed to maintain the existing stock of equipment. In other words more than two thirds of annual bulk imports are being used to replace gas that is lost to air from working equipment every year.

The rest of the annual bulk imports (around 30 per cent) is used to charge new equipment manufactured in Australia, to charge equipment imported without a charge of working gas (i.e. pre-charged with nitrogen), or consumed in other applications such as foam blowing, fire protection and aerosols. A small proportion, (~20 to 30 tonnes) is re-exported for servicing shipping vessels and supplying wholesalers located in the Pacific Islands.

Stationary air conditioning is the single largest end-use for bulk imported gas. Servicing air conditioning and replacing gas that has been lost through leaks, and charging new air conditioning equipment, is estimated to account for approximately 1,470 tonnes, or 35 per cent of all bulk imports in 2012.

Figure 4 illustrates the actual mix of HFC species imported in bulk (this chart does not include imports of HCFCs). *Figure 5* provides a six year trend of imports of HFCs in kilo tonnes of CO₂-e.



(Sources: DSEWPaC 2013a)

Trend of HFC bulk imports in kt CO₂-e

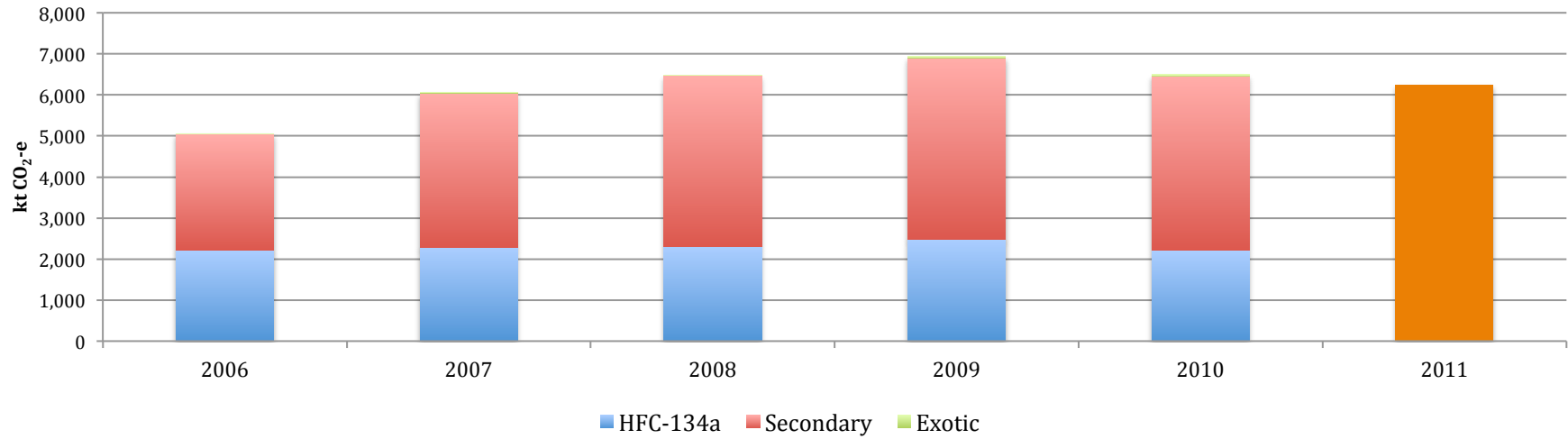


Figure 5: Six year trend of HFC bulk imports as reported in major SGG categories in kt CO₂-e

(Source: 2013a)

Bulk imports of refrigerants occur in tanks containing as much as 18 tonnes each. Bulk imports are bought into the country by only 17 licensed importers who decant the gases into smaller tanks, ranging from 5 tonne mobile road tankers, to 12 kg cylinders used by tradesmen and technicians.¹⁹

A controlled substances licence is required to import bulk HCFCs and HFCs, and holders of these licences are required to report all imports.

HFC bulk imports have grown from an estimated 2,660 tonne in 2006 to 3,150 tonne in 2011 (an 18 per cent increase in volumes but down from the peak in 2009). Changes in the mix of HFC substances imported in bulk between 2006 and 2010 illustrate some of the changes in the underlying bank. A significant rise in imports of HFC-410A, and a steady increase in imports of HFC-404A, is testament to the effect of restrictions on HCFC-22 imports (widely used in stationary air conditioning equipment) and the migration of some other technology segments away from HCFCs to the non-ozone depleting HFC gases. (The phase out of HCFCs is discussed in more detail in *Chapter 5.3.6*).

During this period the import of HFC-134a, by far the most commonly used HFC, maintained a steady trend over the period, growing at approximately 3 per cent per annum. Various economic and technological trends capped demand for bulk HFC-134a imports, including the closing down of some Australian vehicle manufacturing capacity, and the closure, or move off-shore, of more than half of the domestic refrigeration and commercial manufacturing capacity that existed at the beginning of the century. At the same time, some uses of HFC-134a have also been migrated to alternative working gases, such as the use of hydrocarbon refrigerants in the majority of domestic refrigeration and in some retrofitting of as much as 8 per cent of registered vehicles with mobile air conditioning.

Bulk imports of refrigerants by species are illustrated in *Figure 6* for 2006, 2010 and 2012 in tonnes. 'HFC Mix' comprises HFCs with smaller consumption volumes typically used in foam applications (HFC-365mfc, HFC-245fa and HFC-227ea), fire protection (HFC-227ea) and as HCFC drop-in refrigerant replacements (HFC-427A, HFC- 422A, HFC-422D and HFC-417A).

¹⁹ *List of licenses and exemptions granted under the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, issued February 2012.*

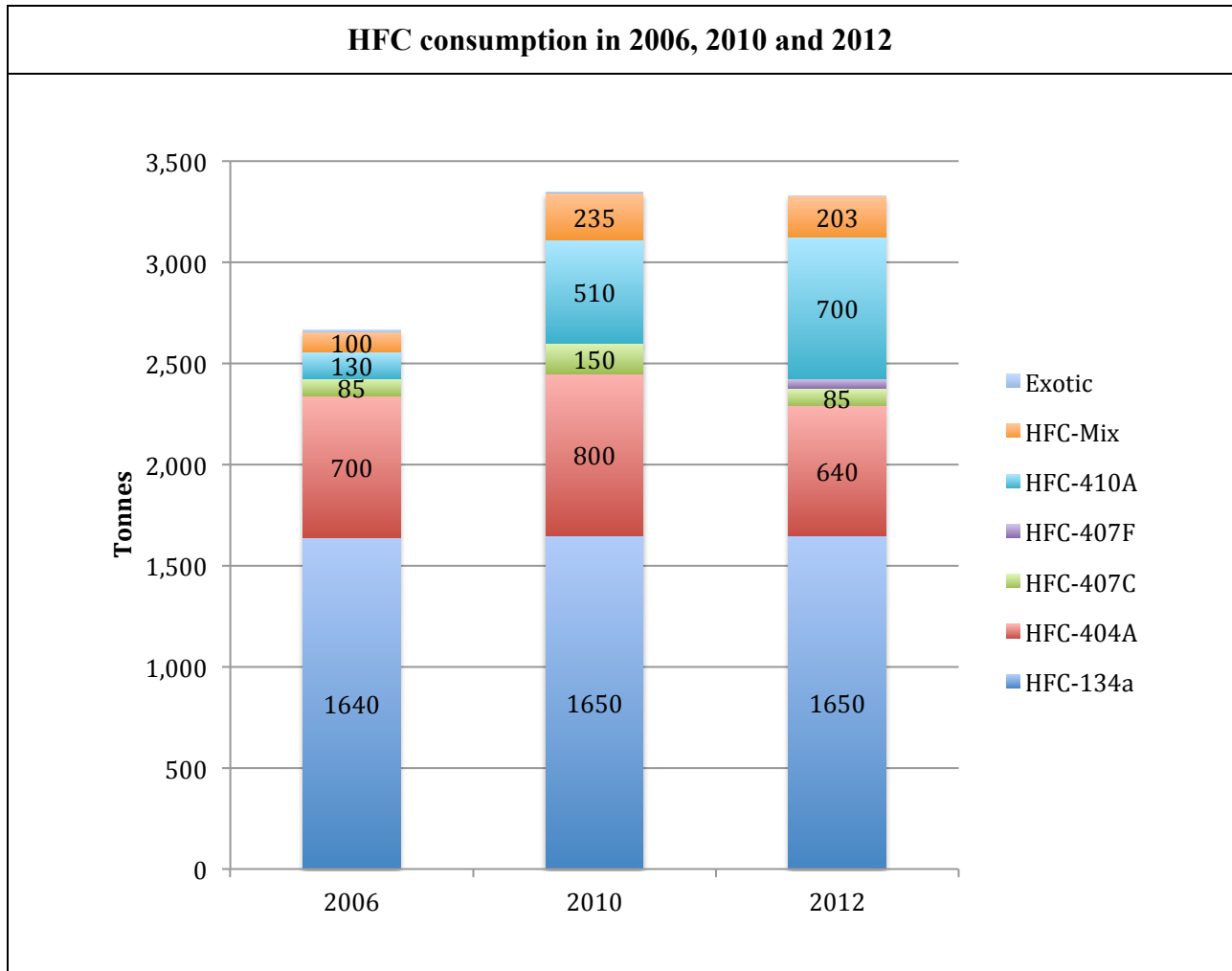


Figure 6: Estimated HFC consumption in 2006, 2010 and 2012 based on mass in tonnes

Note: Consumption estimates are based on top down (imports) versus bottom up (stock model) reconciled except for 2012 where top down consumption was derived from 2011 imports adjusted to account for industry changes in behaviour (i.e. transition to other refrigerants, recycling, improved containment, etc.).

The bulk imports of HFC-410A seen here, even if running at the higher rate of more than 500 tonnes per year for the years 2007, 2008 and 2009, provide only a small part of the more than 10,000 tonne growth of the bank of HFC-410A in the period. This demonstrates how much of the dramatic growth in the bank of HFC-410A was driven by imports of equipment pre-charged with HFC-410A.

This PCE driven addition to the bank of HFC-410A is almost entirely as a result of imports of pre-charged air conditioning systems, as the market moved away from the previously large imports of HCFC pre-charged air conditioning equipment, during a period when Australia saw an average of 1.1 million domestic and small commercial air conditioning systems imported every year.

Around 6 per cent of bulk imports are consumed in applications that are not for refrigeration or air conditioning and do not form part of the working bank, such as for foam blowing (manufacture of insulating ‘styrofoam’ blocks), in fire protection systems and in aerosols. Additionally it is estimated that around 100 to 120 tonnes of HFCs are exported, mostly in shipping vessels and in pre-charged equipment (i.e. 53 tonnes in 87,156 motor vehicles in 2012).

Figure 7 illustrates the dissection of HFC consumption and the refrigerant bank for 2012 by application in tonnes, and Table 17 provides a summary of estimated consumption volumes to service leaks.

HFC consumption in 2012 by major class

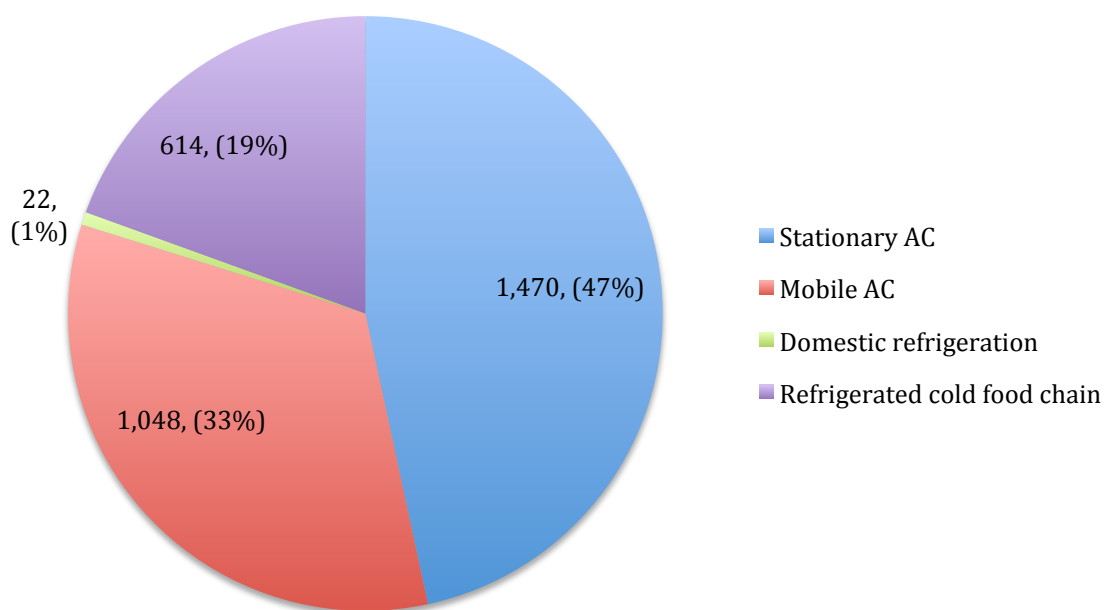


Figure 7: Estimated HFC consumption in 2012 by major class based on mass

(Source: CHF2 stock model)

Table 16: Estimates of 2012 HCFC and HFC gas consumption and refrigerant bank by major class

End-use	2012 Consumption (t)	2012 Bank (t)
Domestic refrigeration	30	2,200
Refrigerated cold food chain	955	5,000
Stationary air conditioning	1,769	27,200
Mobile air conditioning	1,214	9,100
Foams	150	-
Fire protection	50	-
Other (incl. aerosols, R&D, direct export)	72	-
Total	4,240	43,500

(Source: CHF2 stock model)

5.2.5 Pre-charged equipment (PCE) imports

The second means by which the bank of refrigerant gas grows is through the import of ‘pre-charged’ equipment (PCE). Imports of PCE have been running at historically high levels for the last decade, almost entirely as a result of the demand that occurred for small wall hung split air conditioning systems. This growth in demand was driven by dramatically lower prices for small split air conditioning systems as a result of new manufacturing capacity coming on line, largely in China and Thailand.

In total, in 2012, there were more than 3 million devices pre-charged with HFCs or HCFCs imported into Australia and containing, in aggregate, a total of around 2,557 tonnes of working gases.²⁰

There were well over a million stationary air conditioning devices imported in 2012, accounting for more than 64 per cent of imported refrigerant contained in equipment in that year.

Unfortunately a change in the system of collecting data on pre charged equipment in 2012 has now made it impossible to compare imports of equipment types from prior to 2012, with later imports. Equipment reporting categories were aggregated, so much of the detail is not available. A detailed breakdown of pre-charged air conditioning equipment from 2005 to 2011 is presented in *Table 17*. This information demonstrates the scale of stationary air conditioning imports and details of other devices imported for 2012 is provided in *Figures 8 and 9*.

Split system air conditioners made up 64 per cent of all air conditioning devices, with single indoor units containing an average charge of 1.7 kilograms, resulting in the import of more than 1,080 tonnes of HFCs in total.

Almost 32,000 multi head units with an average charge of 4.9 kilograms collectively contained more than 156 tonnes of HFCs at import. Air conditioning chillers accounted for less than 4 per cent of refrigerant imported in equipment, as many units are charged on site from bulk refrigerant imports.

There were more than 132,000 window/wall air conditioning units imported in 2010 with an average charge of 720 grams, accounting for around 3 per cent of the total refrigerant imported in equipment. Sales of this product category have declined to around 70,000 in 2012.

Portable air conditioners contained only 2 per cent of refrigerant imported in equipment, mostly due to the relatively small charge in each device, typically around 600 grams. Although imports of portable air conditioning grew strongly to more than 130,000 in 2009, sales in 2011 have declined equally, with total units imported down by more than half to 48,810.

Window/wall and portable air conditioning devices imported in 2010 contained slightly more than 166 tonnes in total, mostly with HFC-410A and some HFC-407C.

²⁰ A ban on imports of equipment containing HCFCs was implemented in July 2010.

Table 17: Stationary air conditioning pre-charged equipment imports in Australia 2005 to 2011

PCE type	2005	2006	2007	2008	2009	2010	2011
Chillers	1,291	504	804	1,169	722	1,476	1,096
Packaged	21,042	16,900	19,785	18,631	16,217	20,485	19,907
Packaged: window/wall	147,987	176,850	107,257	124,414	131,352	132,159	72,639
Portable refrigerated	25,188	77,940	87,009	117,344	137,611	129,781	48,810
Split system: multi head/vrf	30,625	37,312	43,093	49,900	35,128	30,955	29,655
Split system: single head	700,233	801,460	886,572	779,184	741,118	968,107	797,043
Total AC	926,366	1,110,966	1,144,520	1,090,642	1,062,148	1,282,963	969,150

(Sources: DSEWPaC 2013a)

While such a detailed breakdown is not available for 2012, the total equipment numbers imported up to 2011 confirms the trend seen in bulk gas imports, levelling off in demand from the highs of 2010.

The next largest class of equipment imported was more than 896,000 mobile air conditioning systems, each with an average charge of 625 grams, containing in aggregate around 560 tonnes of refrigerant and accounting for around 19 per cent of imported HFCs.

There was 94 tonnes of refrigerant imported in domestic refrigerators, and a further 13 tonnes in portable refrigerators in 2010.

The five year average for refrigerant gas volume for all pre-charged equipment imports is 2,470 tonnes per annum. The main refrigerant types involved changed significantly over that period, largely due to the Montreal Protocol initiatives driving the phase out of HCFCs. In 2006 HFC-410A represented 35 per cent of gas contained in PCE imports. By 2010 it had grown to over 1,300 tonnes to represent more than 50 per cent. In contrast HCFC-22 has declined from around 30 per cent of gas in PCE in 2006 to just 3 per cent in 2010.

HFC-134a imports have remained relatively steady with a five year average of 736 tonnes which equates to around 30 per cent of total PCE imports. On average, HFC-404A makes up only 1 per cent of PCE imports over the last five years, as applications using this substance are mostly charged on site with gas provided by bulk importers. The only major exception to this is for self-powered refrigerators, used for refrigerated road transport, which were imported containing, in aggregate, around 7 tonnes of HFC-404A.

Figures 8 and 9 provide a dissection of pre-charged imports by equipment and refrigerant type for 2010 based on metric tonnes.

2012 PCE imports by reporting category

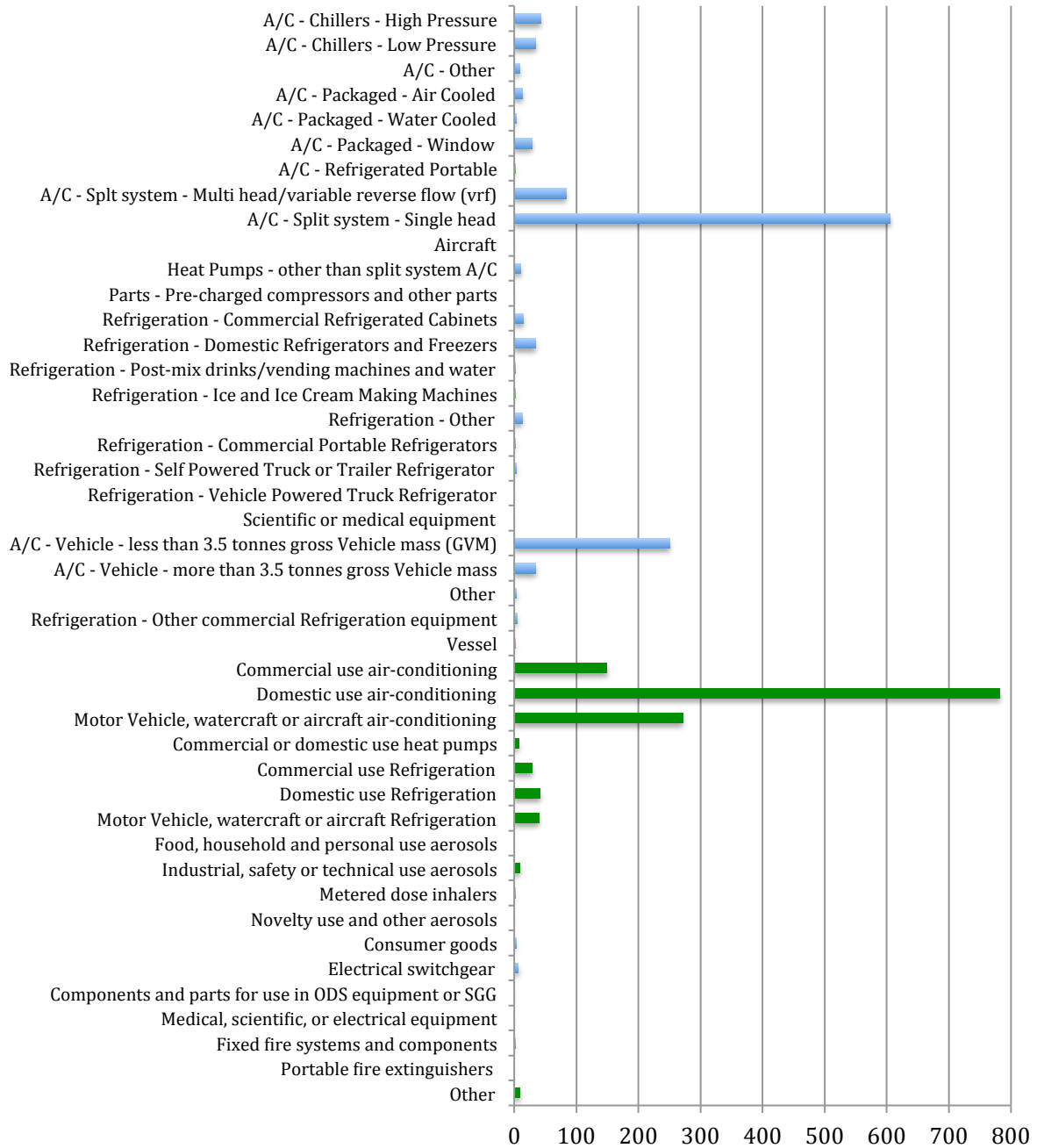


Figure 8: 2012 pre-charged imports by reporting category in tonnes

Note: The equipment reporting categories on 1st July 2012 (Pre in blue and post in green).

(Sources: DSEWPaC 2013a)

2012 PCE imports by refrigerant

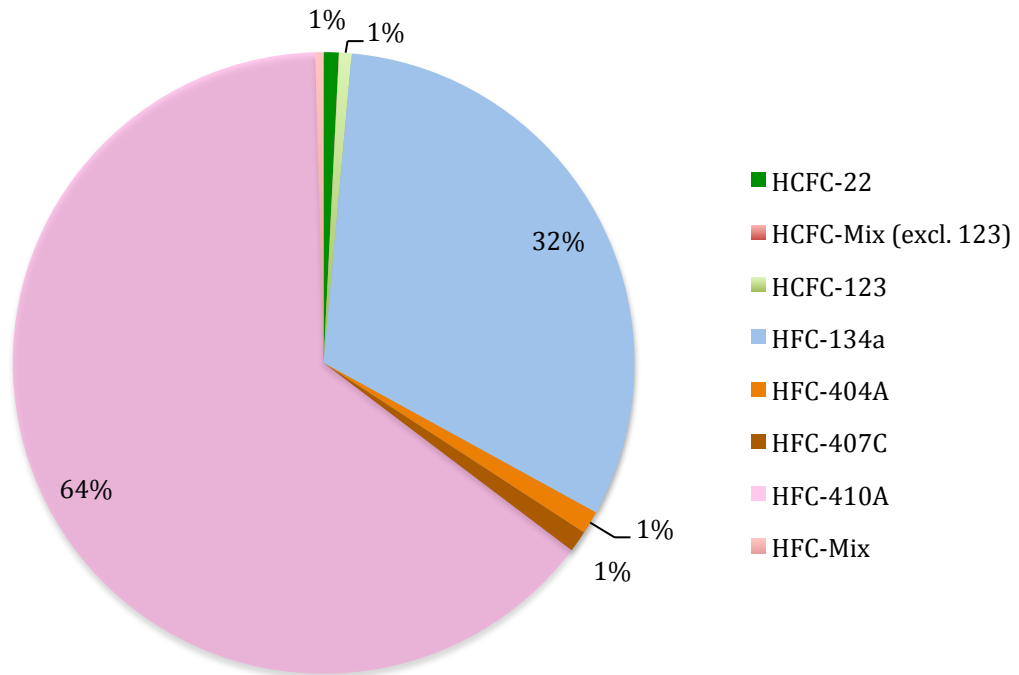


Figure 9: 2012 refrigerant by species in pre-charged imports based on tonnes

(Sources: DSEWPaC 2013a)

This mass of equipment has been a major source of growth in the working bank of refrigerant gas, introducing an average of about 2,500 tonnes gas per annum during the last 6 years as illustrated in *Figure 10*.

PCE trend by species from 2006 to 2012

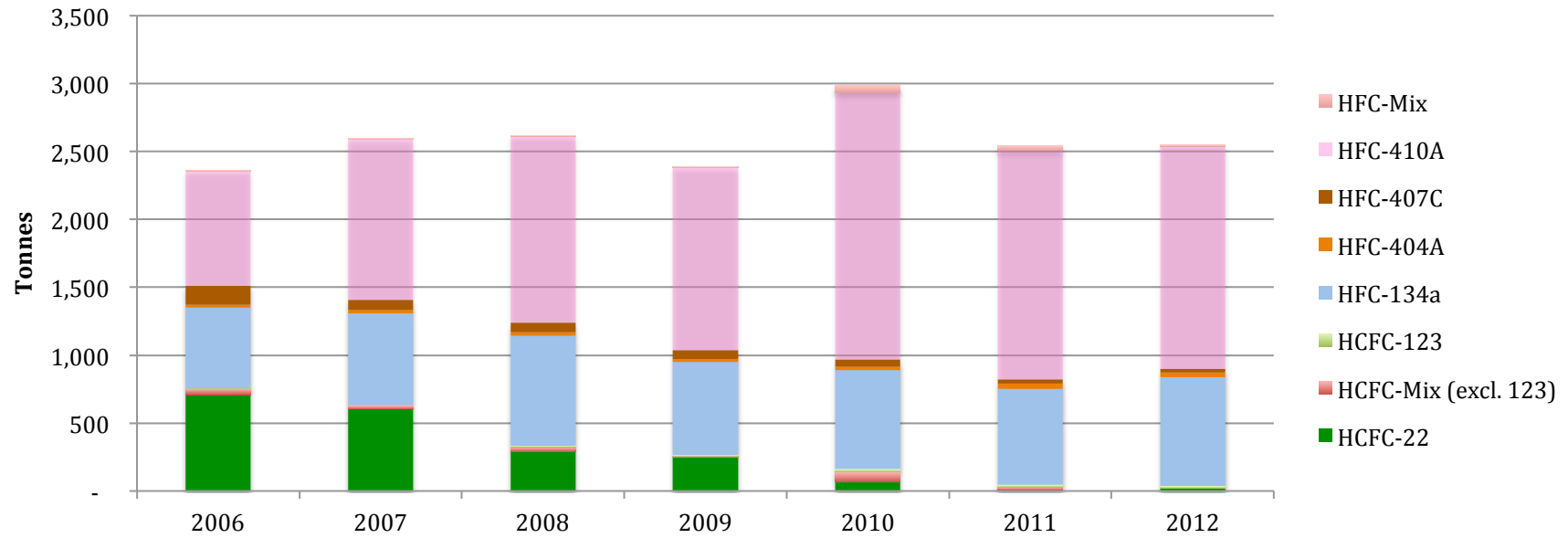


Figure 10: HCFCs and HFCs in pre-charged equipment 2006 to 2012 by species in tonnes

(Source: 2013a)

5.2.6 HCFCs in the refrigerant bank

Imports of HCFCs followed a predictable trend downwards as the Australian industry and importers continued to deliver on the timetable for the phase out of HCFCs they committed to in the 1990s under the Montreal Protocol.

Figure 11 illustrates the decline in HCFCs imported in bulk imports since 2006. The ban on the import of HCFCs contained in pre-charged air conditioning equipment came into force on the 1 July 2010. The decline in HCFC pre-charged imports is shown in *Figure 12*.

The import of HCFCs can also be reported in terms of the ozone depleting potential (ODP) of the gas (its ozone depleting effect being the reason it has been phased out). The trend in imports of ODP tonnes against the industries agreed cap is reported in *Figure 13*.

Under the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989, from 1 January 2014 the cap on HCFC imports will be reduced to 10 ODP tonnes annually (equivalent to around 180 metric tonnes of HCFC-22) before declining in 2016 to the 'service tail' of 2.5 ODP tonnes (equivalent to around 45 tonnes of HCFC-22 per annum), before the final global phase out of HCFCs in 2026.

HCFC import trends from 2006 to 2012

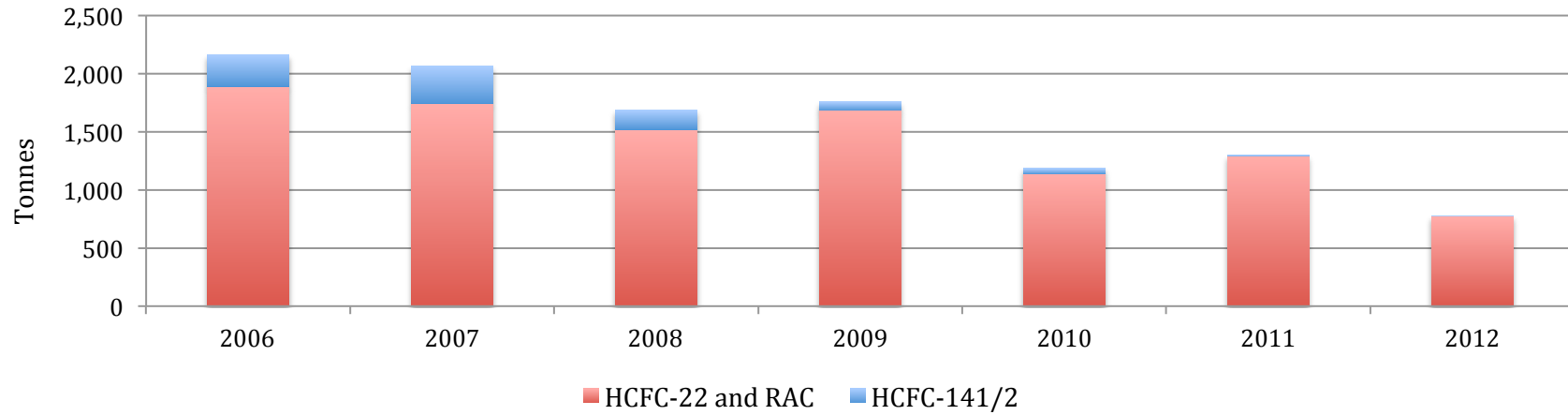


Figure 11: HCFC Bulk import trend from 2006 to 2012 in tonnes

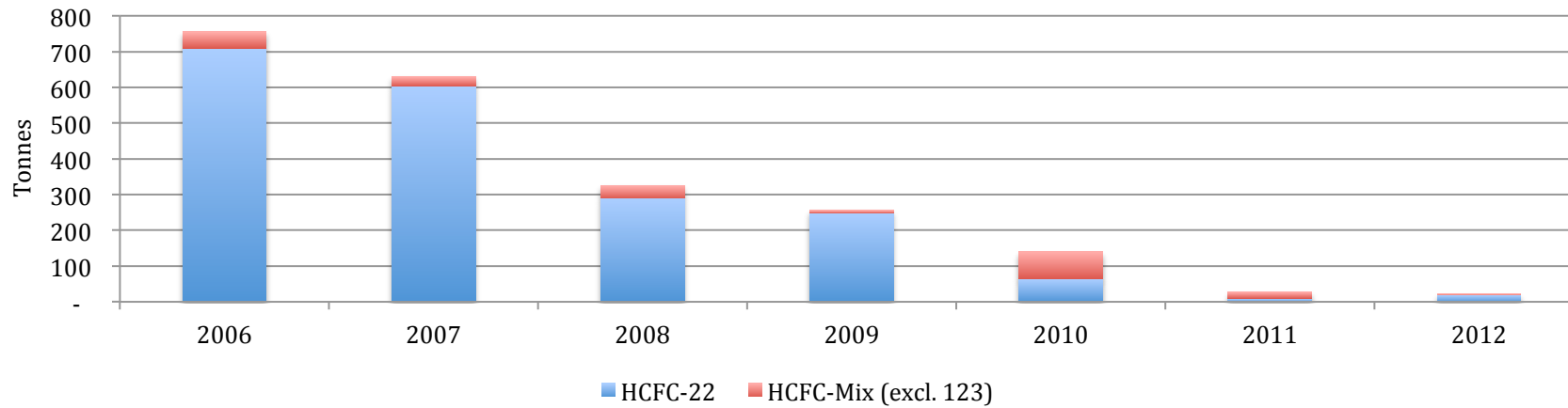


Figure 12: HCFC Pre-charged equipment import trend from 2006 to 2012 in tonnes

(Source: 2013a) Note HCFC-123 PCE imports in 2012 were 16.3 tonnes, down from 20.6 tonnes in 2010.

HCFC bulk imports and future projections in ODP tonnes

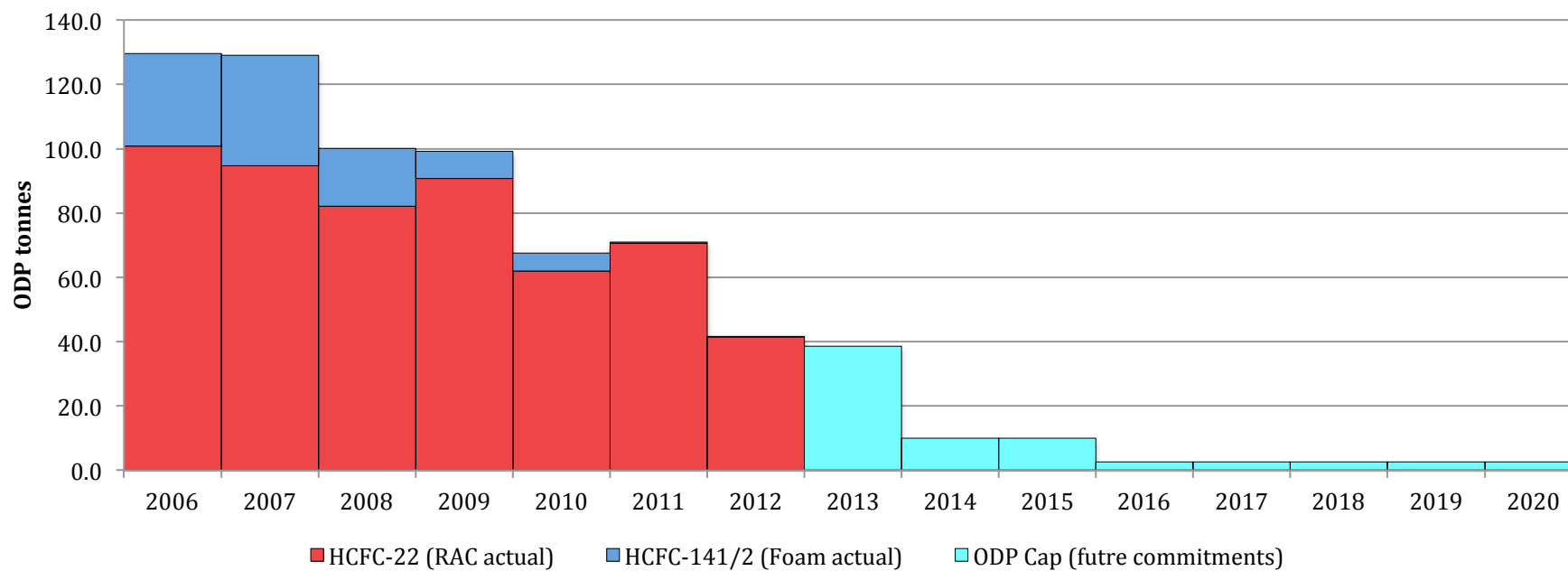


Figure 13: HCFC bulk imports from 2006 to 2012, and future projections based on future commitments in ODP tonnes

(Sources: DSEWPac 2013a, OPSGGMA and Montreal Protocol)

HCFC PCE

The sharp drop in the HCFC bank since 2010 should continue as a result of larger numbers of HCFC charged air conditioning units that were installed between 10 and 20 years ago, reaching the end of their useful life and being retired.

Despite the ban on imports and manufacture of HCFC air conditioning equipment, small quantities of HCFC pre charged equipment are still being imported under special exemptions (i.e. high static ducted split system air conditioners, one-off specialised low volume imports, replacement parts and space chillers charged with HCFC-123). This trickle of new equipment, and the large numbers of HCFC PCE imported up until as recently as 2008-09 indicates that the long tail of HCFC-22 bulk imports, at 45 tonnes per annum, may not be sufficient to meet the expected demand to service and repair the remaining installed HCFC charged equipment. Additional bulk HCFCs will be required for service and maintenance until at least 2025. In the case of HCFC-123 which is employed in long lasting large and expensive chillers, the service tail is likely to continue until possibly 2035. As such it is expected that more of the HCFCs recovered from EOL equipment will be stockpiled for reuse.

At least one new business has been established in the last 18 months that facilitates technicians recovering HCFC-22 from equipment at end-of-life, and returning the gas to be cleaned and resold. As the HCFC import restrictions tighten, reducing the allowable imports towards zero, this is expected to become a more common business practice.

Based on analysis of gas collected for destruction, the bank is estimated to also still include a remnant of some 300 to 400 tonnes of CFCs.²¹

5.2.7 Low GWP refrigerants

Early vapour compression refrigeration systems in the 19th century relied on the use of ammonia, methyl chloride and sulphur dioxide, gases that are toxic if inhaled.

By the beginning of the 20th century however, most large refrigeration plants, commonly used in meat packing works, were operating using ammonia.

With the invention of synthetic refrigerants based mostly on chlorofluorocarbon (CFCs and some HCFCs) in the 1920s, safer refrigerators were possible for home and consumer use. In the 1970s, the compounds were found to be reacting with atmospheric ozone, an important protection against solar ultraviolet radiation, and their use as a refrigerant worldwide was curtailed in the Montreal Protocol of 1987.

The main CFC replacements, HFCs, have since been regulated under the Kyoto Protocol due to their high global warming potential.

As a result, around the world the RAC industry and the manufacturers of industrial gases are moving towards two new streams of low GWP refrigerant gases, including 'natural' refrigerants, and low GWP synthetics.

5.2.8 Natural refrigerants

Strong growth from a low base in some classes of low GWP refrigerants has been observed in the past three years, particularly in the use of Hydrocarbons (HC-600a, HC-290 and HC-436). This trend has coincided with the introduction of the equivalent carbon price on the import and manufacture of synthetic greenhouse gases.

²¹ CFCs continue to be returned for destruction every year through the RRA recovery program, although a large proportion of the returns are reported as having been returned in 44 gallon drums, having been stored for servicing equipment when CFCs were first phased out. Given the cessation of use of CFCs in any new equipment in the early 1990s it is to be expected that the rate of retirement of CFC charged equipment must accelerate rapidly in the next few years until there is essentially none left.

Suppliers of low GWP refrigerants, and equipment that employs these refrigerants, have been operating in the market for many years prior to the development of these policies. Some suppliers in this market provide engineering services on very large ammonia charged systems used in the cold food chain, while others are focused on development of the market for HC charged equipment. All of these businesses have seen strong growth in customer enquiries and sales since it was announced that the high GWP HFC refrigerants would have an equivalent carbon price applied to them based on their GWP.

The total mass of low GWP refrigerants employed in the bank provides refrigeration and air conditioning services that would otherwise require approximately 5,000 tonnes of high GWP gases, equivalent to as much as 11.5 per cent of the high GWP bank.

Table 18: Low GWP refrigerant bank at end 2012 by mass in tonnes

Species	Bank (t)
CO ₂	80
Ammonia (R717)	4,400
Hydrocarbons	320
Total ⁽¹⁾	4,800

1. Sources: In-confidence market survey of all major participants provided actual 2012 market volumes, which was used to derive estimates of the natural refrigerant bank by type.

Ammonia

The main applications where ammonia²² systems are found include cold storage facilities (typically 5,000 to 250,000 m³), large chilling, freezing and ice making systems in the primary and secondary stages of the cold food chain, and some chemical processes and mining air conditioning applications.

There is an estimated 12.4 million m³ of cold storage space operating on ammonia systems. Assuming a benchmark obtained from industry sources of 31 kg per 1,000 m³ of storage space, this equates to around 380 tonnes of ammonia in cold stores.²³

Other applications where large charges of ammonia can be found in single installations are in high volume blast freezing applications that are extremely refrigeration intensive, requiring snap freezing of large masses of perishable goods such as in meat processing, poultry processing and other primary and secondary processes in the refrigerated cold food chain (i.e. vegetables, dairy, beverages, frozen foods).

Some individual meat processing facilities are known to contain up to 150 tonnes of ammonia. There are more than 2,100 meat/poultry processing facilities in Australia that employ more than 200 people. A survey of suppliers of bulk ammonia estimated 545 tonnes was delivered to customers in 2012. Based on the research undertaken on existing facilities the present estimate on the ammonia bank is 4,400 tonnes in total, however based on historic and 2012 supply volumes it is likely this estimate is very conservative and further research is required to improve the accuracy of this estimate.

²² Ammonia used in refrigeration systems is anhydrous Ammonia meaning it does not contain water, the chemical symbol is NH₃ and the ASHRAE refrigerant number is R717.

²³ Industry source: Gabor Hilton, Refrigerated Warehouse and Transport Association.

Hydrocarbons

The majority of hydrocarbons are employed in small charge systems such as domestic refrigerators and automotive systems.

Hydrocarbons are reported to be a widely used refrigerant in mobile air conditioning. It is thought to be employed most frequently in the service market for older vehicles and is estimated to account for around 8 per cent of passenger and light commercial vehicles. This equates to around 1,200,000 on road passenger and light commercial vehicles. In addition there is one very small manufacturer (i.e. OKA) of special purpose 4WD on/off road vehicles that has switched to hydrocarbon refrigerants.

It is estimated that in 2012 more than 1.1 million domestic refrigerators in Australia (~7 per cent of the total) contain hydrocarbon HC-600a. Trends point to this number growing rapidly with retailers and manufacturers reporting that more than half of all new sales of domestic refrigerators now carry a hydrocarbon refrigerant.

The only remaining domestic refrigerator manufacturer, Electrolux Appliances based in Orange, NSW has converted the majority of its product lines to HC-600a and has plans to convert the remaining models soon.

Although the expansion of the HC-600a charged stock of equipment is underway, a trend that is expected to accelerate, it will take a long time before the majority of domestic equipment is no longer charged with a fluorocarbon gas. A small survey of 66 fridge-freezers in a large retail outlet was undertaken at the end of 2010. Fifty-one products were found to contain HFC-134a (Fisher & Paykel, Samsung, LG, Kelvinator and Westinghouse). Fifteen products (29 per cent) contained HC-600a (Electrolux, Westinghouse, Hisense and some larger LG models).

In a follow up survey in 2013 of seventy-six products in the same store 54 per cent of products contained hydrocarbon refrigerant. Notably more brands had converted to HC-600a, including Electrolux, Westinghouse, Hisense, Fisher & Paykel, Sharp, Panasonic and some larger LG models.

Self-contained refrigeration display cabinets containing small charges of hydrocarbon refrigerant can be found in the majority of the 300 Aldi supermarkets currently operating in Australia. Other HC charged applications include small volumes of stationary RAC, and some small hot water heatpumps.

CO₂ systems

There are an estimated 160 supermarket refrigeration systems containing CO₂, the majority of these (>90 per cent) are cascade systems with charges of around 200 kilograms. Other CO₂ systems can be found in small numbers in large licensed clubs and food process applications. Although aggregate supplies of CO₂ were estimated to be 70 tonnes in 2012, the installed base of equipment suggests that a significant portion of this gas is carried in the supply line, and on site as back-up supplies in manifolded cylinder pallets (i.e. Manpacks) to cover catastrophic failures (i.e. compressor failures or ruptures of gas lines). CO₂ systems have very high operating pressures and suppliers of CO₂ refrigerant claim the systems occasionally suffer gas line failures and lose their entire charge. These factors allow the authors to estimate a relatively small working bank of CO₂ refrigerant of around 80 tonnes. It should be noted that whilst a loss of charge is very inconvenient for the end user, the environmental impact is relatively insignificant as the refrigerant has a GWP of 1. As designs and practices advance

Recent innovations developed by equipment suppliers for the supermarket industry include micro cascade air cooled condensing units available in capacities from 2.5 kW_r upwards. These units offer hybrid refrigeration (HFC-134a/CO₂) systems for use in smaller sites and have potential for application across a broad range of commercial refrigeration applications.

CO₂ refrigerant technology and expertise is rapidly emerging in a wide range of applications including large food processes, truck and automotive air conditioning (see next section), refrigerated vending machines, hot water heat pumps, and refrigerated containers known as Reefers. One such example is the

EcoCute technology widely available in Europe and Japan that uses CO₂ refrigerant technology on hot water heat pumps to achieve high efficiencies and lowering running costs.²⁴

5.2.9 Low GWP synthetic refrigerants

Driven largely by legislative changes in Europe that will soon require all new cars to have low GWP refrigerants in their air conditioning systems, new classes of synthetic refrigerant, known as olefins, have been in trials in European automotive air conditioning systems in recent years.

The species that is expected to be widely available in the next few years is HFO-1234yf with a GWP of 4, although several vehicle manufacturers have reportedly refused to employ it because of flammability issues. Volkswagen, Daimler, Audi, BMW and Porsche have recently announced plans to develop CO₂ technology. However many others are apparently preparing to replace HFC-134a with HFOs by 2015.

As well as being marketed for use in mobile air conditioning systems, HFO-1234yf is being promoted by international suppliers as being suitable for beverage vending machines and domestic refrigeration.

A related gas HFO-1234ze with a GWP of 6 is considered to be a suitable replacement for use in chillers and cascade refrigeration systems as well as in aerosol and foam blowing applications. HFO-1234ze has recently been approved by the Australian Government National Industrial Chemicals Notification and Assessment Scheme for use in Australia. A third new olefin, HFO-1234zd with a GWP of less than 5 is said to be suitable for centrifugal chillers.

Importantly blends of both the HFOs with proprietary mixes of other gases, mostly blends of HFCs, are being trialled in stationary RAC applications. These new blends with GWPs of 200 to 500 are still relatively high, but a great improvement on the current HFC refrigerants where the most common products have GWPs ranging from 1,300 to as high as 3,260.

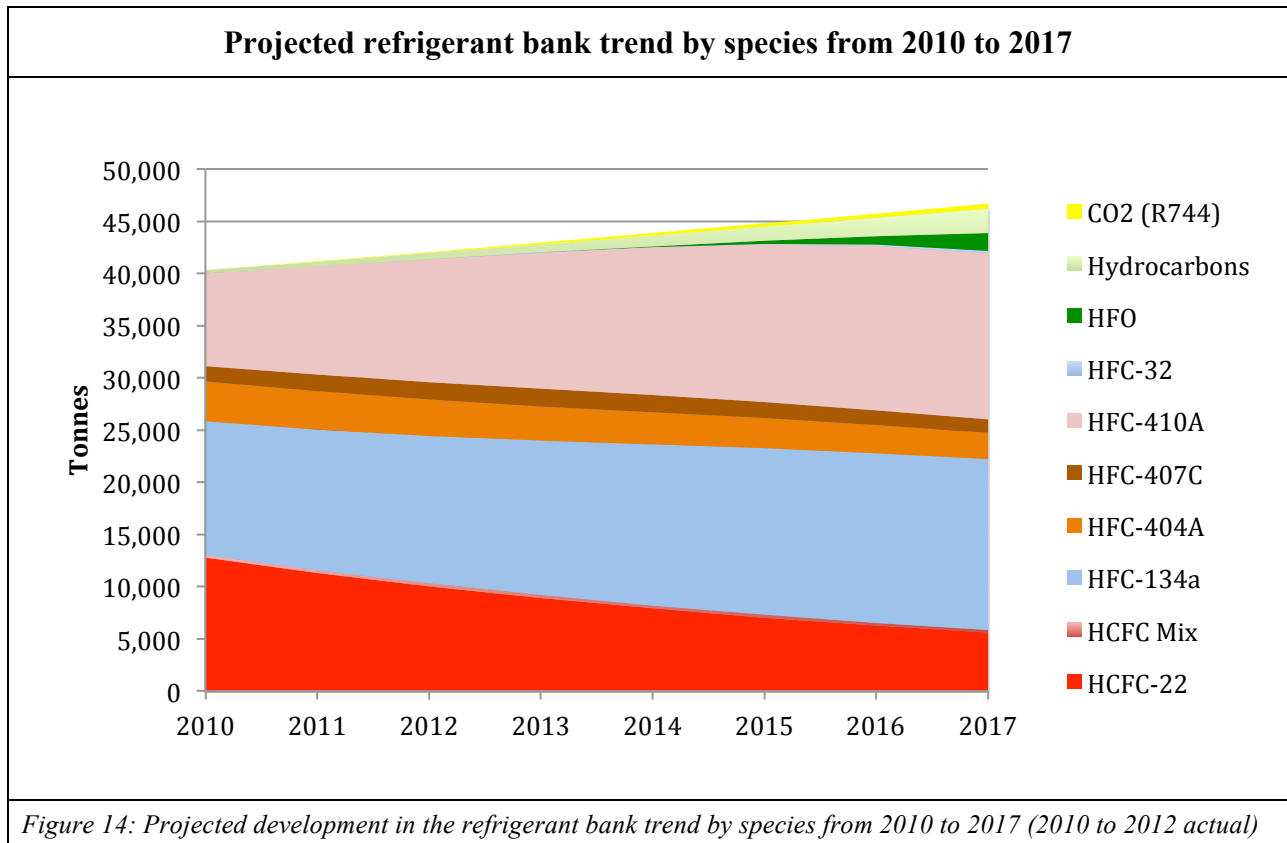
The real question with regard to the rate of transition to low GWP refrigerants is cost, and whether a change will be mandated by regulation or market driven. For the moment none of these gases are actually available in the wholesale supply chain so projections of their uptake are based entirely on the gas manufacturer's projections.

5.2.10 Projections of low GWP refrigerant and impact on high ODS and GWP refrigerants

Retirement and replacement rates for equipment types, coupled with assessments about the rate of change in equipment design and expectations for gas charges moving to lower GWP gases, have been used to predict the transition of the bank in each segment for the five years from 2013 to 2017.

These changes in each segment are used to generate a projection for the entire working bank of gas between 2013 and 2017 as seen in Figure 14 (data from 2010 to 2012 is actual).

²⁴ Sanden Eco Hot water heat pump system achieves coefficients of performance of around 4.5.



(Sources: DSEWPaC 2013b)

There are significant differences in the volumes of working gas required to achieve similar levels of thermal transfer when using some ‘natural’, versus some synthetic refrigerants. Because of this the modelling of the ‘natural’ refrigerants (CO₂, hydrocarbons and ammonia) is done by expressing them in terms of the tonnes of HFCs or HCFCs they are expected to replace, rather than the actual (proportionally smaller volume in the case of hydrocarbons) volumes of natural refrigerants employed. This provides a more accurate picture of the proportion of the working bank that they will comprise in the years ahead.

These projections are notable for the strong decline in the main HCFC presently employed in the bank, HCFC-22, from an estimate of approximately 11,300 tonnes at the commencement of 2012 down to a 2017 estimate of approximately 5,600 tonnes, while the overall bank grows steadily to more than 46,750 tonnes. This quite rapid decline is a result of the accelerating retirement of HCFC charged equipment that was first introduced after the phase out of CFCs was implemented in the late 1980s (with import and manufacture banned from 1996), combined with the effect of Australia’s commitment to the phase out of HCFC’s.

HFC-404A is projected to decline by about 30 per cent in the period to 2017. The industry has been moving away from use of this gas for the past few years ago in preference for ‘natural’ refrigerants (CO₂, hydrocarbons and ammonia), and other HFCs such as HFC-134a on medium temperature commercial refrigeration applications.

HFC-407C is also projected to decline, as it was already being substituted with HFC-410A by equipment manufacturers (local and overseas) prior to the introduction of the equivalent carbon price for HFCs.

HFC-134a and HFC-410A are projected to continue to grow (the latter particularly so) and together are expected to comprise nearly 70 per cent of the working bank by 2017. This projection is likely to be reached in the absence of new affordable drop in replacements and significant changes in industry practice.

Use of HFC-32, which is a component of HFC-410A, is expected to increase as a stand-alone refrigerant. Some equipment manufacturers are well progressed in development of technology using HFC-32 in order

to meet the next stage of the Minimum Energy Performance Standards. HFC-32 also has a comparatively lower GWP of 650 and generally a lower refrigerant charge is required.

As illustrated in *Figure 14*, CO₂ and hydrocarbons are expected to grow to an equivalent tonnage of approximately 2,797 tonnes in 2017, or 6 per cent of the total refrigerant bank. Ammonia is already widely used in most large cold storage facilities, which was not considered part of the working bank of HCFCs and HFCs in previous models, and therefore the full extent of ammonia refrigerant use is not reflected in this illustration. Expected new uses of ammonia in other applications, such as process refrigeration, only represents 0.2 per cent of the bank. This equates to approximately 89 tonnes, and is not visible on the scale of this illustration.

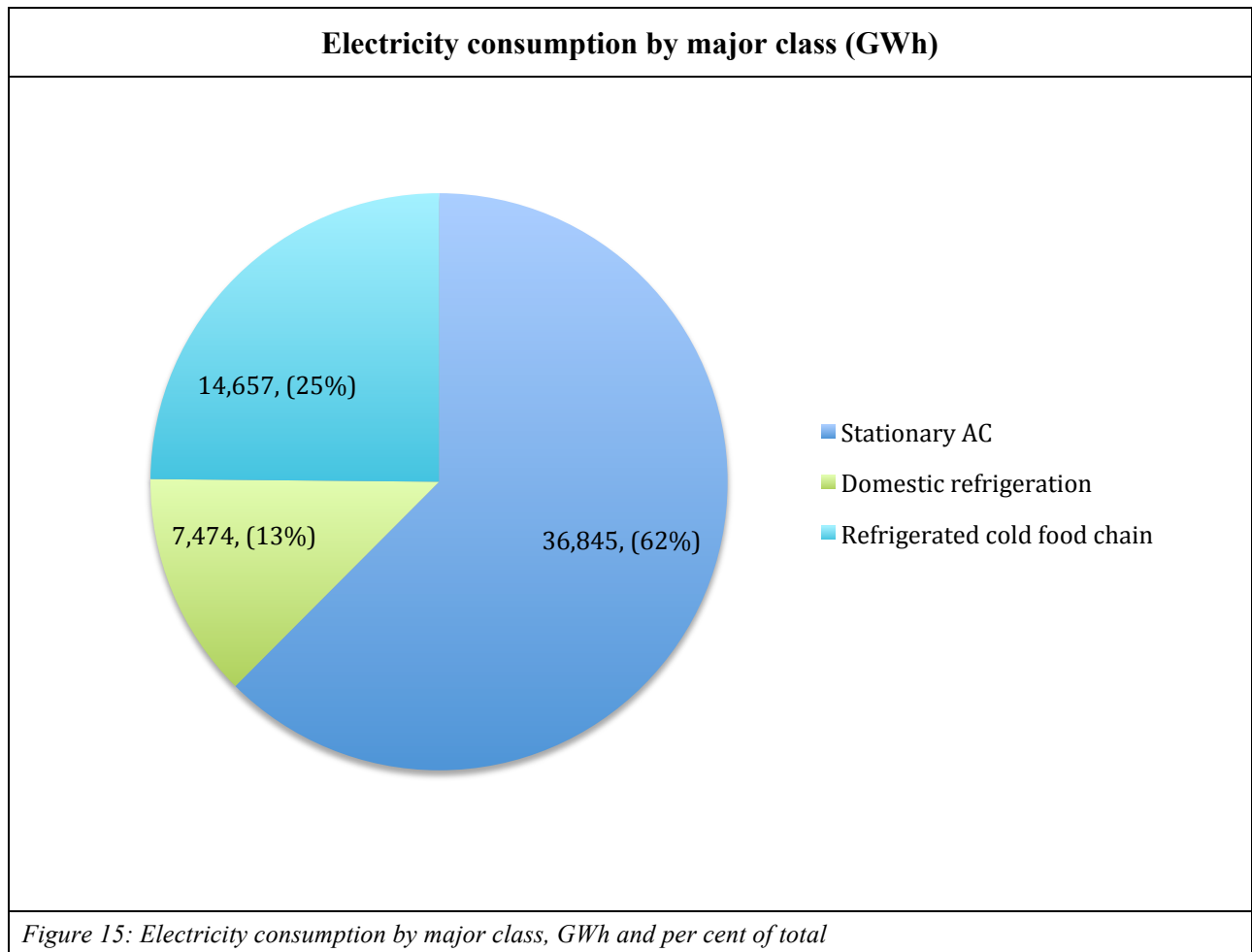
HFOs are predicted to enter the market around 2015 as imported vehicles charged with HFO-1234yf arrive in Australia and some early adopters take up HFOs in some stationary applications. It has been noted that a significant proportion of HFC-134a charged applications could potentially use HFOs if they were at least comparable in price, and if the HFC-134a equipment were 'flame proofed'. This would be possible in some technology segments where the cost of that work could be outweighed by savings on the lower GWP HFOs. Any price advantage that HFO's could enjoy in Australia depends largely on the continuing impact of the ECP on the price of high GWP gases.

It must be noted that the 2012 starting point estimate of the working bank does not include any gas held in stock by suppliers of either bulk gas, or of pre-charged equipment. In previous studies it was assumed that stock of bulk gas (to replace gas that had been lost through leaks) and pre-charged equipment was not much greater than was required to meet market demand, in a timely manner.

6 Energy and emissions

RAC services are a major feature of the Australian energy economy. Based on the extensive ‘bottom up’ analysis made possible with the CHF2 stock model, it is estimated that RAC equipment consumed 59,000 GWh of electricity in 2012, more than 22 per cent of the approximately 265,000 GWh of electricity production in Australia that year.

The share of electricity consumption by major class of electricity driven technology is illustrated in *Figure 15*.



(Sources: CHF2 stock model)

Total electricity consumed is equal to some 212 Petajoules (PJ) of energy. With the addition of the estimated 46.5 PJ consumed in liquid fuels providing mobile air conditioning and transport refrigeration total energy consumed for the provision of RAC services in Australia in 2012 was 258.9 PJ equivalent to 7 per cent of total final energy consumption in Australia in 2010-11 (BREE 2012).

Shares of total energy consumption in the sector are illustrated in *Figure 16*. In this figure, transport refrigeration has been identified separately from the refrigerated cold food chain. The primary fuels used in transport refrigeration services (and in mobile air conditioning) are liquid fuels, whereas the refrigerated cold food chain is otherwise fuelled by electricity.

Electricity consumption by major class (PJ)

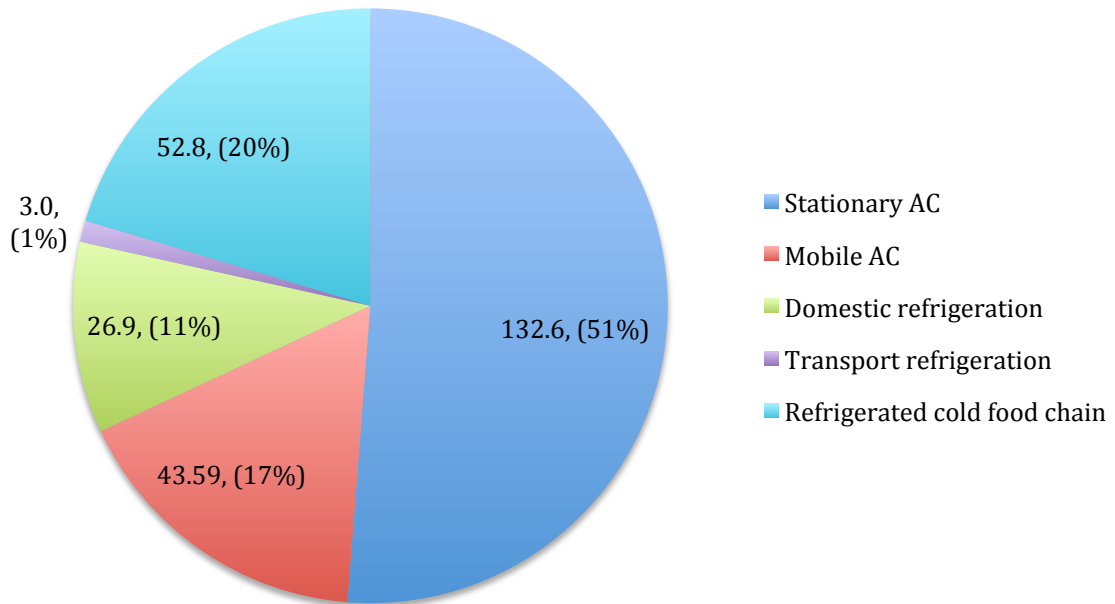


Figure 16: Energy consumption by major class in PJ and per cent of total

(Source: CHF2 stock model)

With emissions from energy consumed in mobile air conditioning services and transport refrigeration included, the indirect emissions from energy consumed to deliver these services is calculated as being more than 57 Mt of CO₂-e in 2012. This is more than 10 per cent of the total national greenhouse gas inventory (NGGI).²⁵

The share of indirect greenhouse gas emissions produced by energy used to deliver refrigeration and air conditioning services are illustrated in *Figure 17*.

²⁵ Total Australian emissions reported by the NGGI for FY2011-12 were 550.8 Mt of CO₂-e. This value is the sum of the September 2011 Quarter, December 2011 Quarter, March 2012 Quarter and June 2012 Quarter (DCCEE 2012a). The models in CHF2 are based on calendar years.

Electricity consumption by major class (Mt CO₂-e)

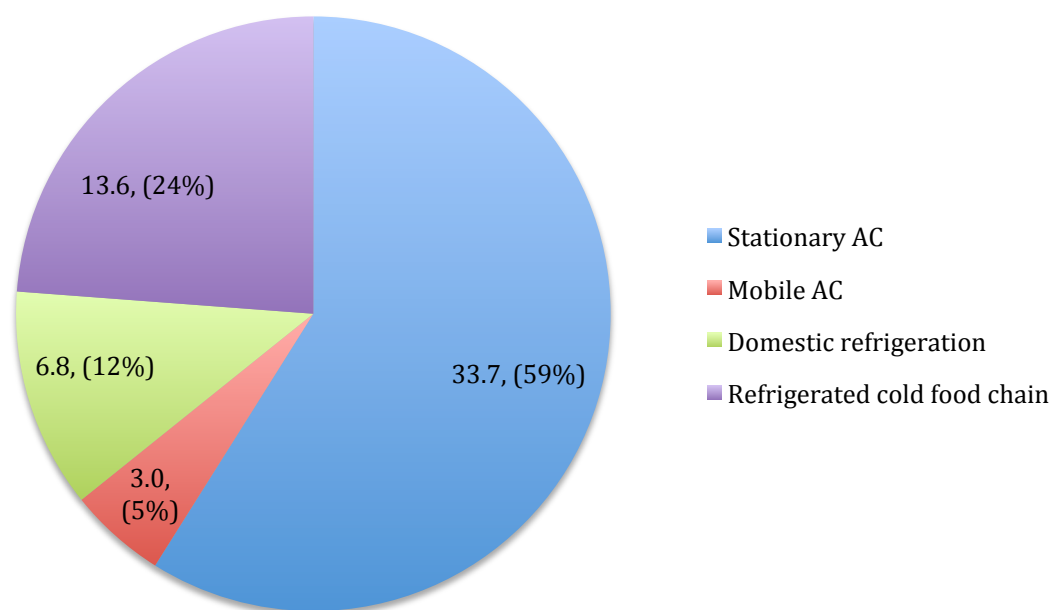


Figure 17: Indirect emissions by major class in Mt CO₂-e and per cent

(Source: CHF2 stock model)

In something of an obvious ‘positive’ feedback loop, though with potentially very negative consequences, the demand for RAC services goes up strongly on hot days, significantly increasing demand for electricity.

Hot days and peak electrical demand combine to decrease the efficiency of the electrical distribution systems. The higher the temperature of the distribution system components, particularly the transmission lines, the greater the resistance to transmission and thus the greater the transmission losses incurred.

These increased losses feedback directly into the average greenhouse gas emissions calculated for every kWh of electricity consumed, and into the total national emissions.

Rapid growth in installed air conditioning, starting in earnest around the turn of the century, has often been noted in the last decade as a major driver of new electricity demand and of peak electricity demand, requiring very large investments in transmission and distribution infrastructure. This investment in electrical infrastructure has been the main reason for electricity price increases in Australia in recent years. As a result, it could be said that everyone who pays an electricity bill is paying for the increased use of residential and commercial air conditioning, whether they own air conditioning devices or not.

One often quoted figure in this regard is that for every new 2 kW (electrical input) of air conditioning capacity added to the electrical distribution networks, some \$7,000 in costs for network augmentation are imposed on the system (DRET 2011). While the source of this statement and its veracity cannot be tested, we are very confident in the overall estimates of energy use to provide cooling services. Of course there are some uncertainties. Although overall we believe that the estimates of total energy use are accurate within ±15 per cent.

For instance the stock model itself is a complex construct in which some errors could well be incorporated due to poor underlying data or flawed assumptions. For instance the retirement rates for equipment are to a

large degree deduced from secondary sources, such as warranty periods and manufacturers public information, not on any extensive quantitative or field research. The methodology for arriving at the equipment stocks in the model are discussed in *Appendix A: Methodology*. However overall we are confident that the stock model is robust and an error in any one equipment category would not exceed ± 10 per cent.

The total energy consumption for RAC systems calculated from the stock model is dependent on the estimated average annual hours of use of equipment in each category. Many of these estimates of hours of use have been informed by manufacturer's data, estimates from previous studies into particular equipment categories, and from first-hand experience of some categories. However, even if adjusting annual hours of use to the lowest likely estimates for the equipment categories (in those categories where there is less certainty), the end result is a less than 10 per cent reduction in the estimates of total energy use.

In reality, given what we know about equipment in the field, it is possible that estimated energy use is low. This is particularly relevant in the smaller equipment sizes where hundreds of thousands, and in some cases millions, of pieces of equipment are likely to be quite poorly serviced. Routine maintenance of air conditioning equipment (or lack of it) can have a profound effect on overall energy use in RAC equipment.

Maintenance of optimal refrigerant charge at the design specification of the compressor and condenser employed in a piece of equipment ensure the most efficient transfer of heat possible. However cleaning of air filters and removing grime from heat exchange surfaces are very simple measures that have a direct impact on energy efficiency in RAC equipment as well. Unfortunately even such simple cleaning of RAC equipment is often not done. The HVAC HESS estimated in 2007 that just routine cleaning of heat exchange surfaces and changing of air filters in commercial HVAC systems in Australia could reduce energy related greenhouse gas emissions significantly.

6.1 HVAC energy use in buildings

There are few alternative sources of data available against which to check any of the outputs of the CHF2 model. However one recent study of energy use in commercial buildings does provide a very useful reference point against which to compare the CHF2 bottom up calculations.

Prepared by 'pitt&sherry', on behalf of the Department of Climate Change and Energy Efficiency, 'Baseline Energy Consumption and Greenhouse Emissions in Commercial Buildings in Australia' (CBBS), has been published as a reference work under the Creative Commons licence²⁶ so that researchers can use it as a common starting point for more detailed studies, and hopefully add to the body of knowledge in this field (DCCEE 2012b).

The CBBS estimated total energy consumption in all commercial buildings in Australia to have been some 142.7 PJ in 2012, a figure that is predicted to rise to just under 170 PJ by 2020.

Analysis of commercial building energy use in the 1990s, using data from a small selection of commercial and educational building energy audits, concluded at the time that as much as 30 per cent of energy in commercial buildings was being used in HVAC systems.

The extensive CBBS analysis revises this estimate upwards, calculating that HVAC energy use in commercial buildings ranges from 40 per cent to 52 per cent depending of the building use.

The study which involved reviewing the energy consumption records and energy audits of more than 5,600 buildings, estimated that total non-residential non-industrial floor space in Australia in 2009 stood at approximately 143.3 million square metres.

In terms of overall energy consumption, retail buildings accounted for the largest share of energy consumption in commercial buildings, consuming approximately 47 PJ or 35 per cent of the total (see *Figure 18*). 'Stand alone' office buildings represented the second largest share with nearly 34 PJ or 25 per cent of the total energy consumption.

²⁶ Creative Commons Attribution 3.0 Australia Licence.

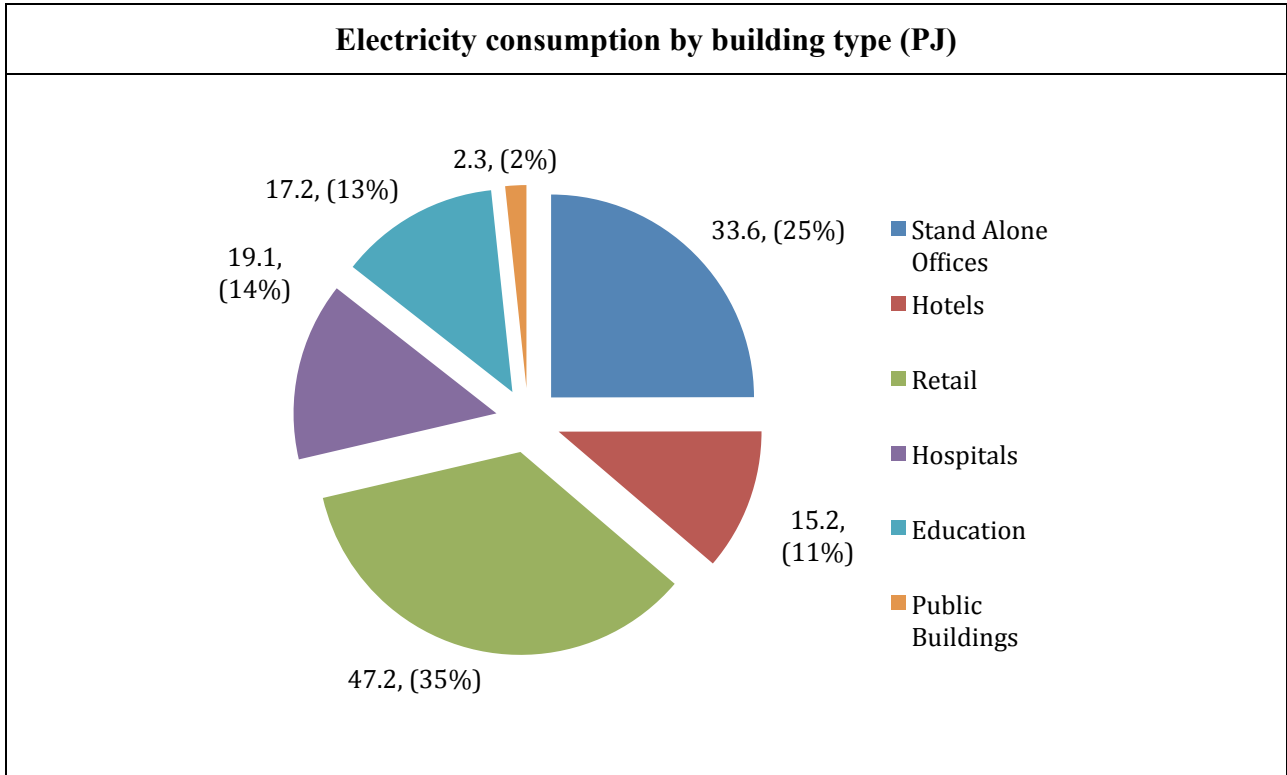


Figure 18: Total energy consumption by building type in PJ and per cent

(Source: DCCEE 2012b, CBBS Volume 1, page 5)

However, if ‘non-stand-alone’ offices are also considered, that is office space situated in mixed use buildings, total energy consumption in offices in Australia could be significantly higher by approximately 26 PJ. This would mean total energy use in all office building types in Australia is nearly 60 PJ, much greater than that in retail buildings.

The study uncovered sufficient detailed energy use data in office buildings to determine that around 83 per cent of all energy used in office buildings is electrical with the balance provided by gas. More than half of the gas consumed is used for space heating as illustrated in *Figure 19*.

Natural gas consumption end-use shares 1999 to 2012

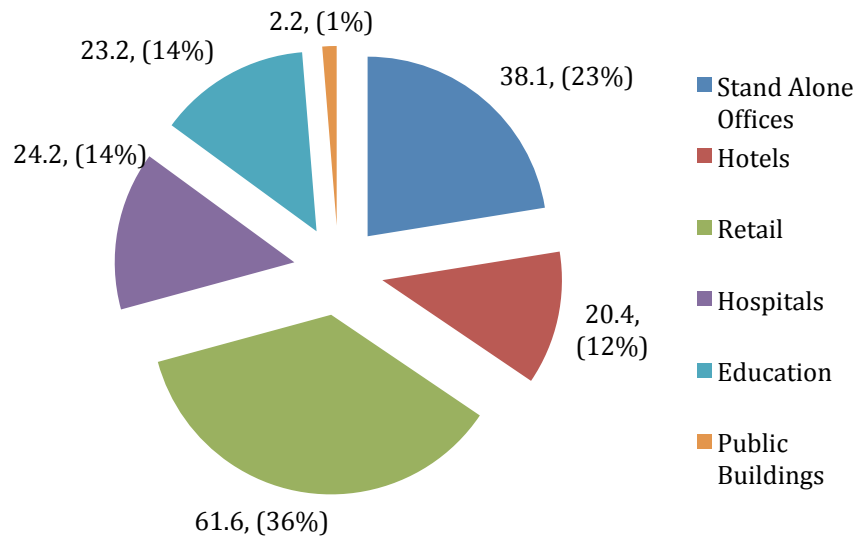


Figure 19: Offices (All), natural gas consumption end-use shares, 1999 - 2012

(Source: DCCEE 2012b, CBBS Volume 1, page 45)

CBBS also calculates the end-uses of electricity in offices, and concluded that 43 per cent of electricity used in office buildings is consumed for HVAC services as illustrated in Figure 20.

Electricity consumption end-use shares 1999 to 2012

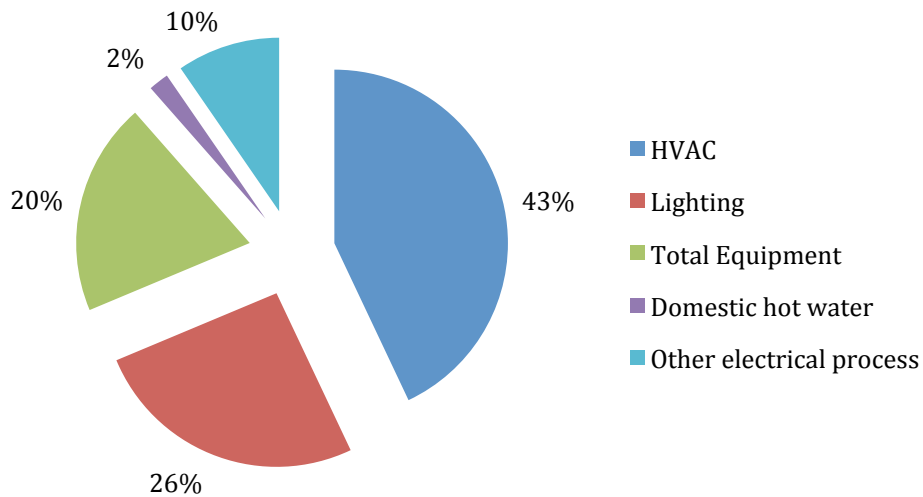


Figure 20: Offices (All), electricity consumption end-use shares, 1999 - 2012

(Source: DCCEE 2012b, CBBS Volume 1, page 45)

While it is not possible to determine exactly how much of the fan power used in ventilation is used to distribute heated air (as opposed to being used in distributing cool air), based on anecdotal evidence and first hand experience, the vast majority of fan power throughout the year, even in buildings in cooler climates, is used in either removing heat (cooling), or distributing cool air.

For the purposes of this exercise we have attributed 15 to 20 per cent of all electricity consumed in HVAC to fans for distribution of warm air for space heating.²⁷ This is equivalent to around 8 per cent of all electricity use in commercial buildings. Subtracting this amount from total electrical use for HVAC in commercial buildings as calculated in the CBBS, we can say that 35 per cent of all energy used in commercial buildings is used for air conditioning and cooling ventilation (ACCV), all of which is electrical.

Across all building types for which sufficient data was available to allow calculation of end-use energy shares, the building type that had the highest proportion of HVAC energy use was hotels, with 52 per cent, followed by universities at 50 per cent, hospitals at 47 per cent, public buildings at 47 per cent and schools at 27 per cent.

If we make a similar adjustment to these values to allow for fan energy used in distribution of warm air, the figures for ACCV are adjusted to: hotels, 44 per cent, Universities 42 per cent, hospitals 39 per cent and public buildings 39 per cent. This adjustment is not required for schools as they are rarely conditioned using chillers and boilers (typically split systems, gas space heaters, evaporative coolers and other unitary air conditioning equipment or systems).

Only average fuel mix observations were available for shopping centres rather than time series. Taking all shopping centres as a whole, the average fuel mix was found to be completely dominated by electricity at around 97.5 per cent, with the balance accounted for by natural gas. Within shopping centre tenancies, electricity's share on average is even higher, at over 99 per cent (natural gas is the balance).

No statistically significant end-use information was available in this data set, however it is likely that the modest amounts of gas consumed in shopping centres are associated with space heating, cooking and domestic hot water applications.

Similar to shopping centres, supermarket energy consumption was found to be completely dominated by electricity, with an average for all supermarkets of over 99 per cent, with the balance being natural gas.

Given the near absence of gas use, and insufficient data to arrive at energy end-use shares, for the purposes of this exercise we will allocate the average of the other three building types ACCV energy use of 41.5 per cent to the ACCV energy use in shopping centres and supermarkets. By using these energy end-use shares we can calculate total ACCV energy use in the categories of buildings (non-residential, non-industrial) that the CBBS studied as set out in *Table 19*.

Table 19: Total air conditioning and cooling ventilation energy use in CBBS building stock

Building Type	2012 Energy use (PJ)	ACCV Energy use (%)	ACCV energy use (PJ)
Stand Alone Offices	34.8	39%	13.6
Hotels	16.1	44%	7.1
Retail	50.4	42%	21.2
Hospitals	20.2	39%	7.9
Schools	7.7	19%	1.5

²⁷ Fan energy of unitary air conditioning equipment is part of the input power of the system and is included in the CHF2 model, whereas chillers used for space cooling, and boilers for heating require separate fans and neither are included in the CHF2 model.

Universities and VET	11.2	42%	4.7
Public Buildings	2.3	39%	0.9
Total	142.7		56.8

(Source: DCCEE 2012b, CBBS Volume 1, page 3)

Thus, using the results of the CBBS top down study, we can calculate that some 56.8 PJ is used in non-residential and non-industrial ACCV. This is all electrical energy used and is equivalent to 15,782 GWh.

The CHF2 stock model calculates at total of 36,845 GWh of electricity consumed in all stationary air conditioning systems (including heat pumps used for hot water). This value is arrived at using the bottom up approach of multiplying equipment counts by their average electrical consumption, and by average annual hours of use.

Of that total, approximately 32 per cent, or 11,771 GWh is calculated as being consumed in residential applications, leaving some 25,074 GWh as the estimate of electrical consumption in all non-residential uses of stationary air conditioning.

There are several equipment categories that can be removed from that total to provide a comparison with the CBBS figure. The approximately 181 GWh of electricity calculated as being used in hot water heat pumps can be safely removed, as this end-use would not have been included in any of the CBBS calculations of HVAC electricity use. More significantly the 1,478 GWh of electricity calculated as being used in close control air conditioners can probably be safely excluded. These specialised systems are more likely to be found in specialised computer bunkers and server farms. When they are housed in part of a larger office building, the inclusion of uninterruptible power supplies will generally mean they have their own power circuits and are metered separately to a normal commercial office building.

These two exclusions reduce the CHF2 estimation of electricity used in commercial stationary air conditioning applications to 23,382 GWh.

Further, the CHF2 stock model allocates portions of the stocks of smaller air conditioning devices to non-residential applications. Large numbers of small split systems for instance have been installed during the last decade in small businesses in industrial areas ranging from the offices found in warehouses, storage and transport businesses, in workshops, and in large appliance, furniture and hardware stores that previously may not have been air conditioned. Air conditioning is also commonly found in small retail outlets in suburban shopping centres and along commercial ‘strips’, and in open malls all over the country. The proportion of the stock in different equipment categories allocated to non-residential uses are based on interviews with equipment importers, resellers and installers and are allocated as per *Table 41 in Appendix B: Technical resources and assumptions*.

The authors of the CBBS study noted the limitations of their study, in terms of the building types analysed, that excluded ‘non-stand alone’ offices, retail stores of all types outside of shopping centres and all industrial building types. These exclusions cover a significant proportion of building use in Australia. Because CHF2 has allocated proportions of the energy used in categories of smaller types of equipment to exactly these sorts of end-uses, the energy calculated as consumed in these equipment types must be excluded from the comparison.

Table 20 lists the smaller equipment categories in question, and the percentage of the energy calculated by CHF2 as being used in non-residential applications. This percentage has been further deducted from the calculated total stationary air conditioning energy.

The essential assumption here is that all chillers are used in the type of buildings that are captured in the CBBS study, as are the majority of 3 phase ducted systems and the majority of VRF multi-splits. All of the smaller, non-ducted systems, all unitary systems and some of the larger 3 phase ducted systems and VRF systems are used in the classes of buildings that fell outside of the scope of the CBBS analysis.

Table 20: Estimated share of air conditioning category allocation to commercial or residential use

Category code	Product category	Calculated commercial use (PJ)	Deducted from commercial use (%)	Deducted from commercial energy use (PJ)
AC1-1	1Ph Non ducted split 0-4kW	195.2	100%	195.2
AC1-1	1Ph Non ducted split 4-6kW	441.9	100%	441.9
AC1-1	1Ph Non ducted split 6-10kW	1,336.9	100%	1,336.9
AC1-1	1Ph Non ducted split >10kW	192.7	100%	192.7
AC1-2	3Ph Non ducted Split 0-20kW	578.3	100%	578.3
AC2-1	1Ph Ducted	1,129.9	100%	1,129.9
AC2-2	3Ph Ducted 0-20kW	808.7	75%	606.6
AC2-2	3Ph Ducted 20-40kW	2,241.8	40%	896.7
AC2-2	3Ph Ducted >40kW	275.2	10%	27.5
AC3	1Ph Non ducted unitary 0-10kW	1,019.4	100%	1,019.4
AC4	Portable AC 0-10kW	31.7	100%	31.7
AC6-1	Multi Splits - Com	1,739.0	40%	695.6
Total				7,152.4

When deducting the electricity used in these non-residential applications from 23,382 GWh arrived at above (after deduction of heat pumps and close control applications) the CHF2 estimate of electricity in the larger non-residential categories of equipment comes in at 16,230 GWh.

This compares very well to the CBBS electricity consumption estimated, adjusted down as it was to discount for fan energy used in heating, of 15,782 GWh. The 448 GWh difference is less than 3 per cent and certainly within the margin for error of either study.

While the process of deriving these comparative figures has not been that rigorous, even as a superficial comparison of the results of the top down CBBS data, and the bottom up approach of CHF2, this confirms the broad agreement of both approaches to understanding electricity use in larger classes of non-residential air conditioning systems.

6.2 Direct emissions

While it is clear that in the scheme of things RAC equipment is a very significant feature in the Australian energy economy, they are also the main source of direct emissions of synthetic greenhouse gases. HFC refrigerant gases are listed in the Kyoto Protocol as an industrial gas and gases in common use have AR2 GWPs ranging from 1,300 to as more than 3,260. However the HCFCs that are regulated internationally under the Montreal Protocol are also a powerful greenhouse gases. The widely used HCFC-22 that presently makes up 26 per cent of the entire bank has a GWP of 1,500.

Irrespective of the regulatory regime under which the different gases are controlled and reported, the stock of equipment leaks both major species, HFCs and HCFCs, at various rates depending on the equipment category. Estimated total direct emissions of HFCs and HCFCs totalling more than 3,300 tonnes in 2012 were equivalent to more than 5.4 Mt of CO₂-e, or about 0.9 per cent of total Australian emissions.

The relative share of direct emissions from each class of equipment for SGGs is illustrated in *Figure 21*, and ODSs in *Figure 22* (Source: CHF2 stock model).

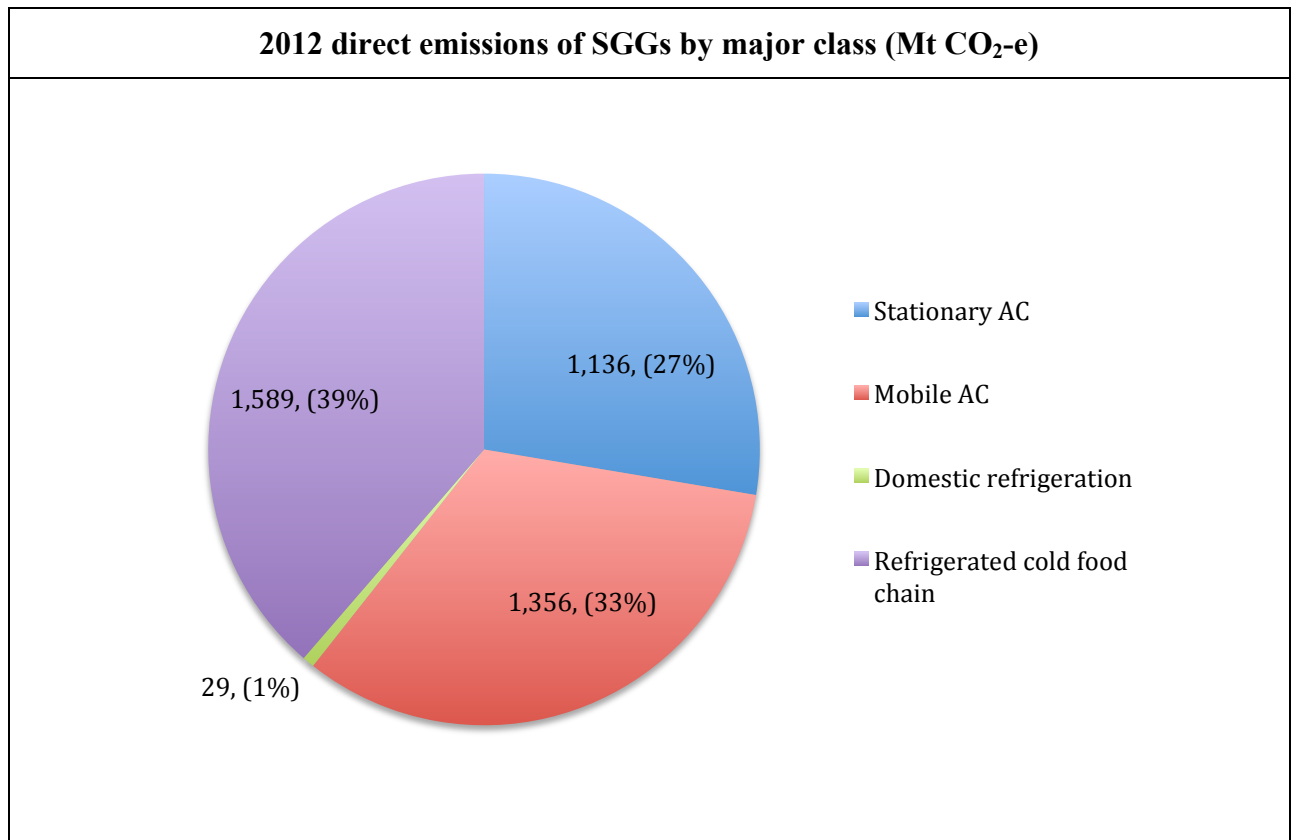


Figure 21: 2012 estimated direct emissions of SGGs by major class in Mt CO₂-e

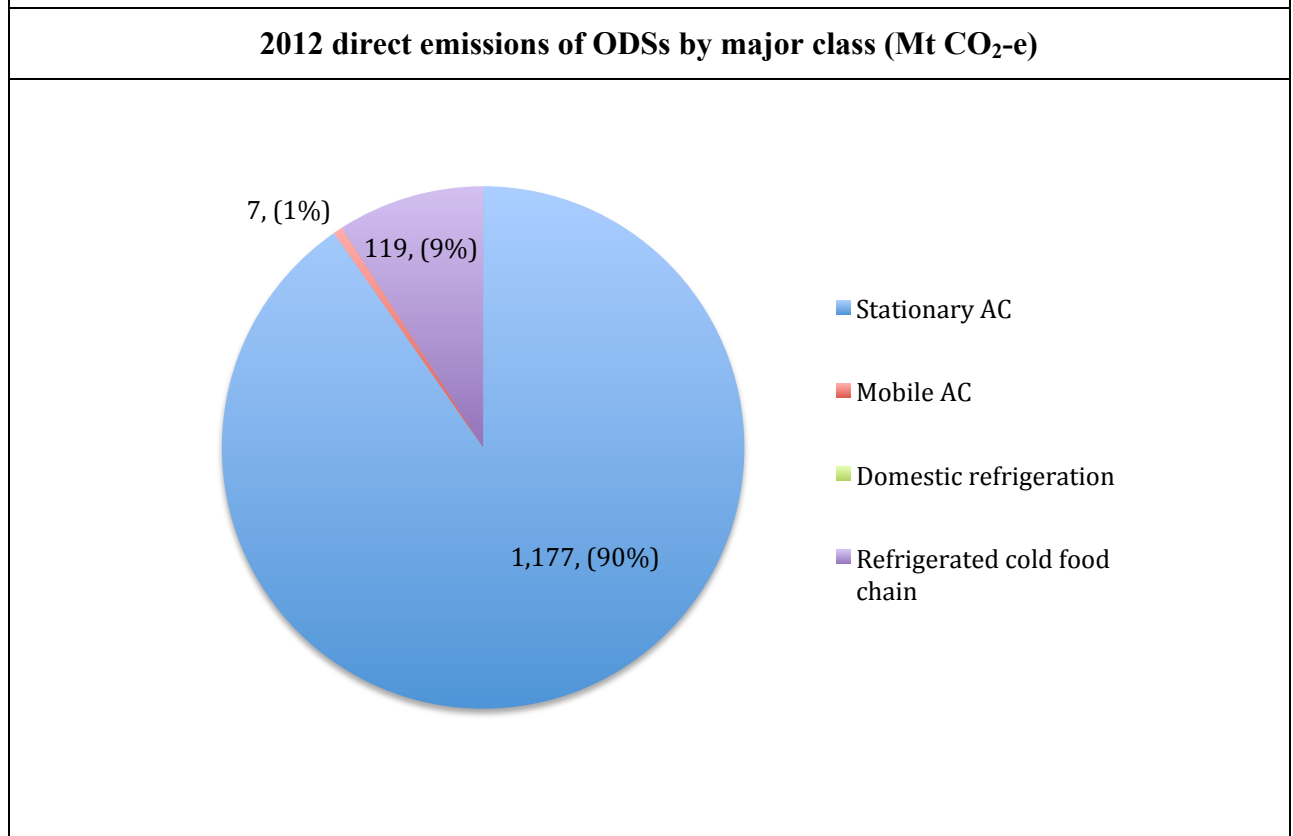


Figure 22: 2012 estimated direct emissions of ODS by major class in Mt CO₂-e

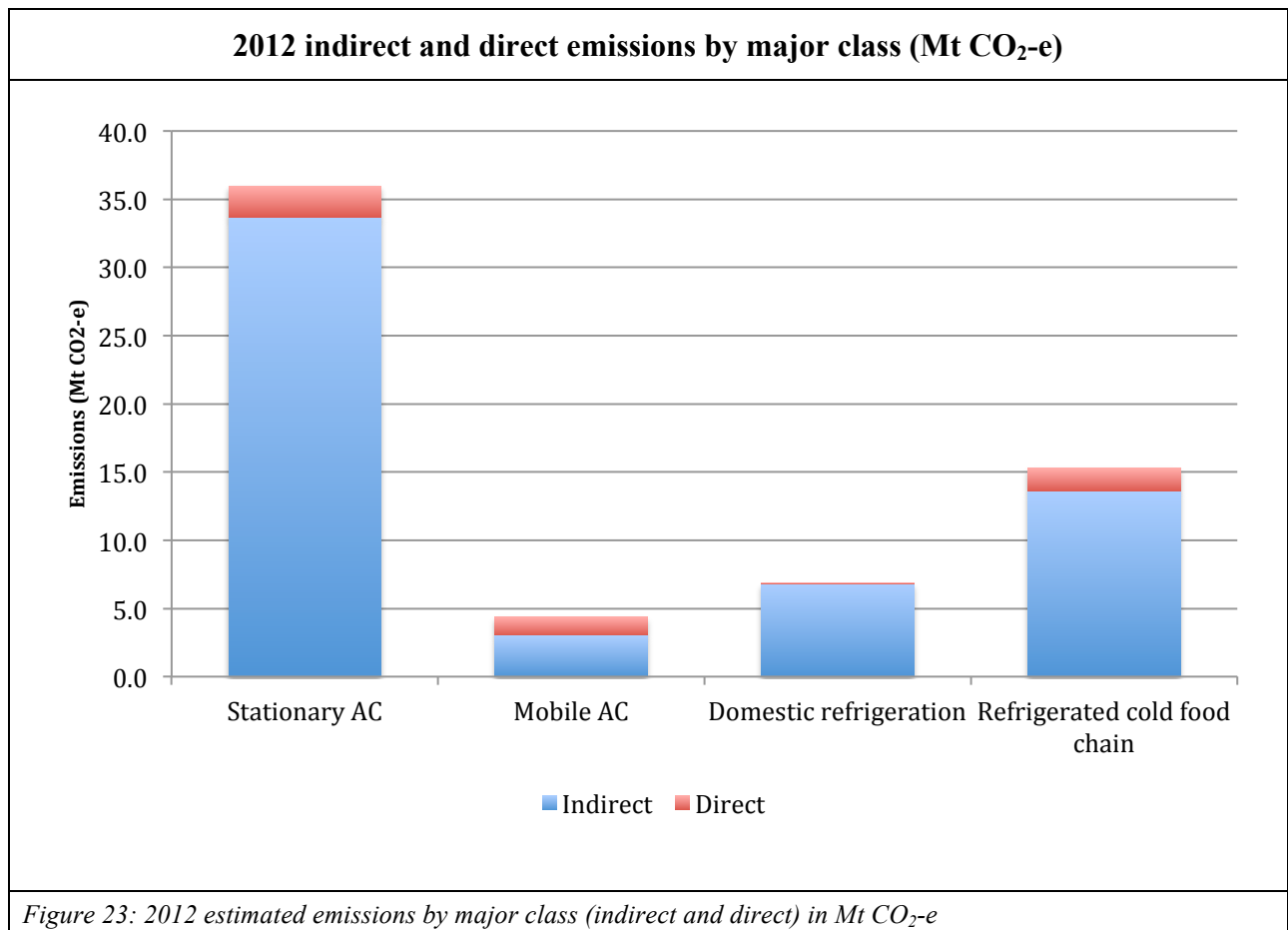
Combined, the total of energy related indirect emissions from the sector, plus direct SGG emissions from leaks, are calculated as having been equivalent to 57.1 Mt CO₂-e in 2012, or approximately 11.1 per cent of total Australian emissions as published in the NGGI for FY 2011-12.

This total does not include approximately 1.3 Mt CO₂-e of direct emissions of earlier generations of refrigerant gas that are also strong ozone depleting substances (ODS) that are being phased out of use under the Montreal Protocol on Substances that Deplete the Ozone Layer.

The emissions profiles of the major equipment classes, including both indirect energy related emissions, and direct emissions of refrigerant lost to air, demonstrate some of the characteristics of the equipment classes as illustrated in *Figure 23*.

While stationary air conditioning produces the largest volume of direct emissions from across the stock of more than 11.5 million devices, the relative proportion of direct to indirect emissions in mobile air conditioning demonstrates the higher leak rates of mobile air conditioning systems. This is partly a result of the high vibration environment in which these systems operate, and partly as a result of the number of ‘catastrophic’ system failures that result from collision or impacts on system components of some sort. Mobile air conditioning systems are expected to be the class that migrates most rapidly to low GWP gases and already have the highest use of hydrocarbons of any class.

The refrigerated cold food chain, characterised by often very hard working systems, also has a higher proportion of direct to indirect emissions than stationary air conditioning. With slightly more than a million pieces of equipment in the class, many of them large installations, this class of equipment has significant potential for a reduction in direct emissions through improved refrigerant containment, use of equipment maintenance log books and leak detection devices.



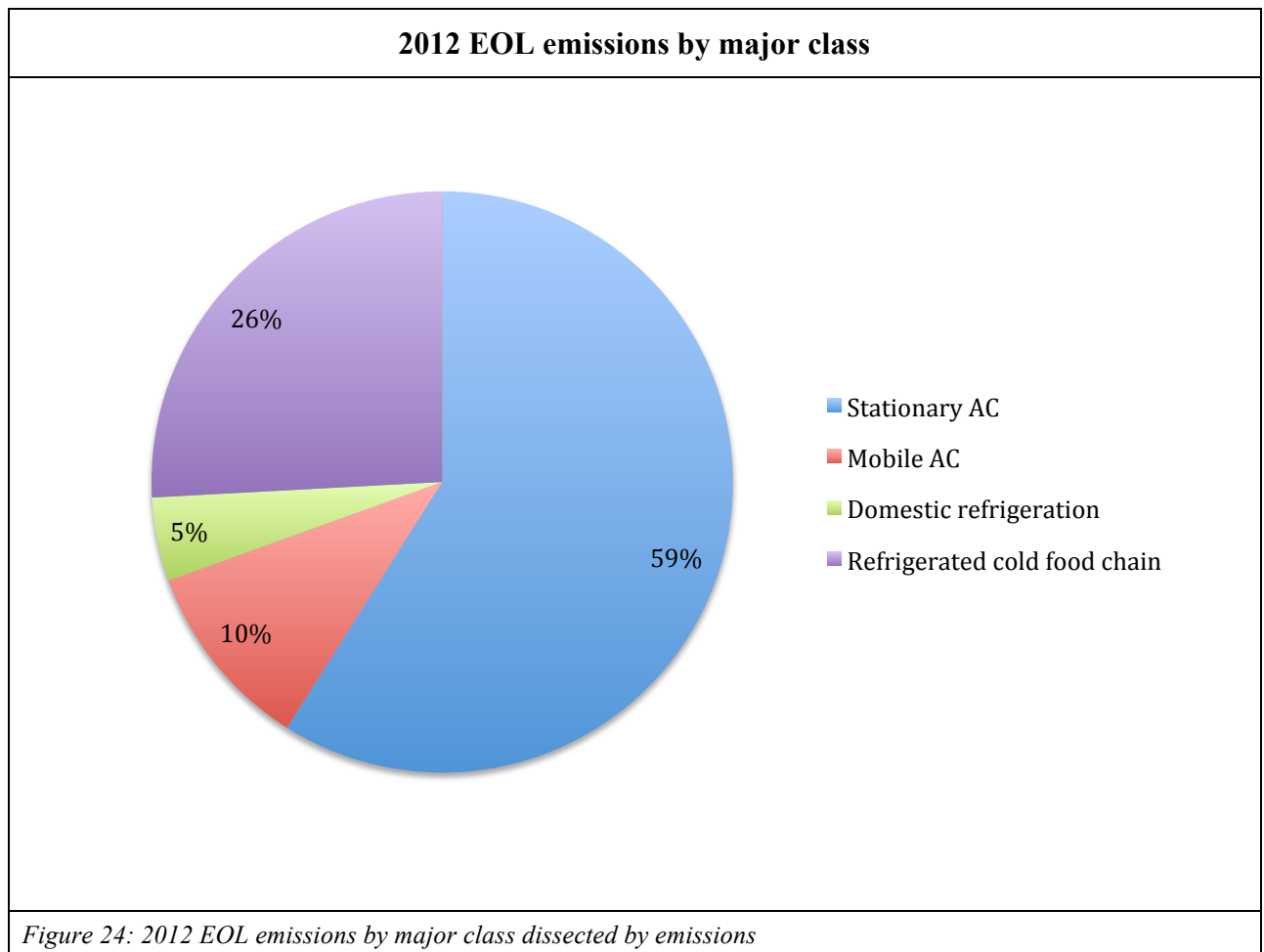
(Source: CHF2 stock model)

Finally, a relatively small pool of potential direct emissions from end-of-life equipment has not been added into the total emissions calculated above. End-of-life (EOL) emissions are calculated based on the equipment survival and retirement rates applied to the stock model, and assumptions about leak rates that result in various estimates of EOL gas charges in various categories of equipment.

In 2012, the total tonnage of all refrigerant gases in EOL equipment was estimated to be 1,700 tonnes equivalent to approximately 2.7 Mt CO₂-e. The sources of EOL refrigerant gas are illustrated in *Figure 24*.

The estimate of volume of refrigerant retiring can vary significantly depending on modelling assumptions, as it is a relatively small magnitude output from a model of a large bank of equipment with many variables. A recent paper by the authors, *Clearing the Air, The Options for a Rebate for Destruction of ODS and SGGs in Australia, 2013* made predictions of average EOL emissions of around 2,400 tonnes per annum over the next five years (DSEWPaC 2013b). The two models used were essentially based on the same components, however one change to the underlying assumptions in CHF2 has inflated the 2012 number of air conditioning units by 782,000 units that resulted in a significantly reduction in the number of retirements and EOL emissions. In calculating retirement rates the average life of equipment in product categories AC1 and AC2, the average lifespan was increased from 10 years to 12 years. This change reflects industry reports, experience with these product categories, and reconciled consumption and inventory levels of HCFC-22.

Further field investigation is certainly required to validate the volumes of equipment retiring, however this difference in EOL predictions demonstrates the potential risk of a bubble of air conditioning equipment installed just over a decade ago nearing end of life.



While the NGGI assumes that this volume of gas is emitted and includes the SGGs in the annual total of Australian emissions, there is a question over how much of this gas might be recovered and reused by technicians.

The refrigerant gas importers industry stewardship scheme, Refrigerant Reclaim Australia (RRA) (www.refrigerantreclaim.org.au), runs a rebate scheme for the recovery and destruction of used refrigerant gases. For the last few years gas recoveries have averaged just under 500 tonnes per annum. While the gas is generally mixed up, and contaminated with oil, moisture and some hydrocarbons, the recovered gas is roughly equivalent to 0.75 Mt CO₂-e. It is safe to assume that a large proportion of this recovered gas has come from equipment being decommissioned at end-of-life. If all of the RRA recovered gas could be netted off the EOL gas, it leaves potentially around 1,200 tonnes of EOL gas unaccounted for every year, equivalent to roughly 1.9 Mt CO₂-e per annum, or something like 0.3 per cent of total national emissions.²⁸

At the same time, an unknown quantity of EOL gas is certainly recovered and recycled. In recent years, as the cap on imports of bulk HCFCs has become tighter, and the price of this common gas has increased, recycling of HCFCs from EOL equipment has become a much more common practice, although the quantity of gas recovered and reused can only be estimated. Similarly the recent introduction of the equivalent carbon price has almost certainly increased reclamation and reuse of HFCs as, the ECP combined with other inflationary factors has resulted in the retail price of some HFCs tripling.

Because of the uncertainty as to the rate of recycling of refrigerant gas from EOL equipment, the refrigerant gas left in EOL equipment has not automatically been added to the total of direct emissions. However this is not to say that EOL refrigerant gas is not being emitted to atmosphere and that opportunities to minimise these emissions should not be pursued.

Table 21 provides a further comparison of the role of the various classes of equipment in the total energy use and emissions production of the sector.

Table 21: Share of HVAC&R sector energy consumption and emissions by major class

Major class	Share of sector energy based on PJ	Share of sector indirect emissions	Share of sector direct emissions	Share of sector total emissions	Share of NGGI	Share of EOL Tonnes
AC	51%	59%	44%	58%	6.3%	59%
MAC	17%	5%	26%	7%	0.8%	11%
RCFC	22%	24%	30%	24%	2.8%	26%
DR	10%	12%	0.5%	11%	1.2%	5%
Total					11.1%	

1. The shares have been rounded to whole numbers so some columns may not total to 100%.

²⁸ A significant portion of the EOL emissions are HCFCs that are not included in the NGGI and the comparison to total national emissions provides context of the scale of EOL emissions relative to other known sources.

7 Economics and employment

7.1 Structure of the industry

The vast majority of the equipment and appliances, and all of the working gases described in the previous sections are imported.

The industry is made up of five main commercial groups that can be characterised as follows:

- Equipment and refrigerant gas importers.
- Equipment and gas resellers, wholesalers and retailers.²⁹
- Equipment manufacturers.
- Contractors, designers, engineers and professional services.
- Refrigerated transport operators.

These commercial groups could also be viewed through the lens of the various industry associations that have developed to represent the interests of these groups in the wider industry, and to government and the community. A list of the leading industry associations is included at the front of the document in *Acknowledgements*.

7.2 Supply lines

The supply chain of HFCs can be dissected into three major supply chains:

- Bulk gas decanted into trading quantities for supply to manufacturers, installers and service companies;
- Imported pre-charged consumer appliances and equipment, and;
- Locally manufactured products.

These three product chains involve seven distinct commercial players prior to the end user:

- Importers;
- RAC manufacturers;
- RAC distributors/suppliers;
- Gas wholesalers;
- Specialist dealers of heating and cooling equipment (typically with their own showroom);
- White goods and household appliances retailers; and,
- Contracting businesses installing, repairing and servicing equipment, and sub-contractors.

Importers take delivery of ship borne ISO containers each carrying between 10 and 18 tonnes of gas. These refrigerants are pumped into large vertical or horizontal storage tanks at the importer's yards. The larger tanks will generally be capable of holding between 20 and 70 tonnes of gas, depending on the volumetric capacity and pressures of the refrigerant. Importers decant gas into tradeable quantities depending on purpose and market. There are three significant bulk import decanting facilities currently operating in Melbourne, and another one scaling up in Sydney.

Gas is decanted at these sites into thousands of cylinders ranging in size from 10 kg, to 18 kg, and 60 kg, and then 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 kilograms and 700 kilograms of product depending on

²⁹ Some wholesalers of equipment and gas are also importers, and some retailers of appliances are also importers.

the gas involved. Some suppliers are expected to release smaller size cylinders in the near future as a source of competitive advantage as it will lower the trading price of the cylinder and reduce the amount of refrigerant stock carried by contractors.

More than 200 gas wholesalers around the country provide the channel for the tens of thousands of small cylinders to be distributed, the majority going to contractors and service companies.

RAC equipment manufacturers decant from transportable tanks into some smaller cylinders for use around their facility and for use when commissioning or servicing their own machinery. However they will also decant directly from the larger storage into supply lines in their factories to charge machinery that they have manufactured prior to dispatch from the factory floor.

Air conditioning distributors/suppliers import and distribute pre-charged equipment and do not themselves require large volumes of bottled gas supplies from importers. They mostly purchase refrigerant from wholesalers for charging larger systems (i.e. variable refrigerant volume split systems) and small volumes when directly undertaking service work.

Specialist dealers are unlikely to carry bottled gas supplies. Some dealers will be operating as contractors installing or servicing equipment for their customers, in which case they will have bottled gas demands as part of providing that service. Specialist dealers will likely get a range of product from different air conditioning distributors/suppliers and may also stock and sell equipment from local air conditioning manufacturers. If the specialist dealer does not operate as a contractor installing or servicing equipment they are likely to have close relationships with contractors whom they rely on to install and service equipment they have sold.

Retailers have no requirement for any bottled gas. Retailers sell pre-charged equipment supplied to them by air conditioning distributors/suppliers, or in some instances import directly. Retailers may also have relationships with contractors whom they recommend for installation and service of equipment they have sold.

Contracting businesses install, repair and service equipment, and often engage numerous individual sub-contractors. There are tens of thousands of individuals licensed to handle refrigerant gases and these contractors hold the majority of those licences. Contractors consume the majority of the small cylinders of gases decanted by importers and distributed through gas wholesalers.

7.3 Indicators of value

There is no simple measure of total economic activity in this sector. However there are a number of indicators that can be used to point to the overall size of the RAC industry and its economic activity.

The total stock of equipment, of almost 45 million devices, is quite well understood. A breakdown of the stock of equipment across all product categories is included in *Appendix D: The stock of equipment*. Australian manufacturers output is well known.

Using models of hours of operation of the various equipment categories that the authors have tested with manufacturers and service technicians, and compared with other models constructed to underpin regulatory impact statements, a calculation of the quantity of electricity that must be purchased to provide RAC services every year can be made.

The approximately 59,000 GWh of electricity purchased was more than one fifth of all the electricity produced in Australia in 2012. Combined with liquid fuels consumed in the refrigerated transport sector, and for mobile air conditioning, the energy consumed produced total energy related greenhouse gas emissions of more than 57 Mt CO₂-e, or more than 11 per cent of Australia's total annual emissions. The value of all energy consumed in the sector is estimated to have been worth more than \$14 billion dollars and is listed by class of equipment in *Table 22*.

Table 22: Estimated cost of energy in air conditioning and refrigeration services in 2012

Expenditure by major sector (\$ Million)	Energy spend (end-user)
Stationary air conditioning	\$7,456
Domestic refrigeration	\$2,058
Refrigerated cold food chain: stationary	\$2,811
Refrigerated cold food chain: mobile	\$99
Mobile air conditioning	\$1,637
Total estimated energy spending	\$14,061

At the present (FY 2012-13) a fixed carbon price is being employed in Australia of \$23 per tonne, the emissions from this energy consumption could be costed at more than \$1.3 billion dollars per annum.

Based on the detailed import records of refrigerant gas, and using market data on wholesale and retail gas prices, total expenditure on refrigerant gas can be estimated to be approximately \$533 million in the present financial year, and the replacement value of the refrigerant bank is estimated to be about \$5.8 billion. This has been calculated on market prices after the introduction of the equivalent carbon price.

Another useful measure of activity is the estimate of expenditure on new installed equipment in 2012 based on well documented imports, accurate national sales data, and conservative average installation costs. The estimated value of new equipment installed in 2012 by major equipment class is provided in *Table 23*.

Table 23: Estimated value of new installed equipment in 2012

Expenditure by major sector (\$ Million)	Equipment spend (installed)
Stationary air conditioning	\$3,350
Domestic refrigeration	\$1,201
Refrigerated cold food chain: stationary	\$728
Refrigerated cold food chain: mobile	\$54
Mobile air conditioning	\$562
Total estimated cost of new installed equipment	\$5,896

This equipment is imported, or designed and manufactured, sold installed and serviced by more than 20,000 businesses, comprising around 18,700 contracting businesses, 2,200 suppliers and the balance consisting of manufacturers and other service providers. One useful measure of the number of enterprises or contracting businesses operating in this industry is the 17,048 Australian Refrigerant Council (ARC) business authorisations to handle refrigerant. The main business types recorded in the licensing database are 47 per cent automotive air conditioning, 46 per cent stationary air conditioning and 4 per cent domestic refrigeration.

We know some things about where this stock of equipment is and the work it does. For instance the approximate area of commercial, retail, educational, public and other non-residential buildings serviced by air conditioning is known to be at least 165 million square metres.

Additionally there are much smaller areas of buildings serviced by energy intensive RAC systems delivering critical tasks keeping telecommunications and server centres under close temperature controls.

The estimate of expenditure on stationary air conditioning systems is conservative and does not include the wide range of ancillary devices and mechanical services such as building management systems, pumps, etc. essential to the operation of large space cooling chiller systems.

Alongside the investment in air conditioning in buildings that we all rely on and enjoy, the more critical infrastructure of the refrigerated cold food chain can be identified and reasonably well quantified.

We know for instance that there are more than 10,000 supermarkets large and small, and convenience stores. There are another 6,400 butchers, grocery stores, fishmongers and specialised poultry and game stores. There are more than 20,000 restaurants, more than 5,000 hotels and clubs, and more than 16,000 delicatessens, sandwich bars, takeaways, bakeries and other retail food outlets (DAFF 2007).

There are more than 20 million tonnes of dairy, fruit, poultry, meat and fish produced every year that are refrigerated, from the point of harvest on more than 80,000 farms and from 420 registered and active large commercial fishing vessels, all the way to the kitchen (or restaurant) table, or to export in refrigerated containers (DAFF 2012).

Worth more than \$28 billion at the farm gate, some of these refrigeration dependent perishable foods are significantly value added through processing and production techniques that require refrigeration and freezing to form a significant part of the total \$130 billion in retail food sales in 2012 (DAFF 2012).

It is no surprise that to move this vast quantity of food employs more than 28,900 registered commercial refrigerated transport vehicles.

There are generally quite large investments in commercial refrigeration in many health facilities and hospitals. For instance large hospitals have major centralised process kitchens in operation to feed patients and staff, bigger than most hotels and restaurants, with some hospitals operating equipment equivalent in refrigeration capacity to a medium sized supermarket.

All of this visible evidence points to a very large investment in the ownership, operation and maintenance of RAC equipment. It also points to the fundamental interdependence of much of our modern world on the art and science of refrigeration and air conditioning.

What is not well known are the number people employed in this industry, developing and maintaining this substantial investment.

A review of the data available from the last census, and other collections of the Australian Bureau of Statistics (ABS), produced results that seemed to generally align with other data that the RAC industry itself could provide regarding the number of licences issued by the Australian Refrigeration Council for handling refrigerant gas.

The total number of refrigerant handling licences that are on issue are known, including the classes of licences held as set out in *Table 24*.

Table 24: Number of refrigerant handling licences by type

Licence type	Number issued
Automotive air conditioning	24,315
Aviation	122

Domestic RAC	387
Marine	241
Commercial refrigeration	5,244
Light commercial (incl. large residential) and chillers	15,731
Split systems (up to 18kW _r)	7,443
Refrigerant handler	267
Refrigerant recoverer	231
Transport refrigeration	121
Total licences	54,102

(Source: ARClick, March 2013)

Searching the ABS database using the ANZSCO employment code for “air conditioning” produces a range of occupations, including:

- 233512 Mechanical Engineer, which includes the specialisations of Air conditioning Engineer and Heating and Ventilation Engineer
- 312511 Mechanical Engineering Draftsperson, which includes the specialisations of, Air conditioning Drafting Officer, Heating and Ventilating Technical Officer, Tool Design Draftsperson, Tool Designer
- 321211 Motor Mechanic (General) which includes the specialisation of “Automotive Air conditioning Mechanic”
- 334112 Air conditioning and Mechanical Services Plumber
- 342111 Air conditioning and Refrigeration Mechanic

The numbers of persons reporting their occupation against these classifications is listed in *Table 25*.

Table 25: Employee numbers in occupations that include air conditioning

ANZSCO 6 digit level	Occupation	Number employed
233512	Mechanical Engineer	10,189 ⁽¹⁾
312511	Mechanical Engineering Draftsperson	3,688 ⁽¹⁾
321211	Motor Mechanic (General)	71,026 ⁽¹⁾
334112	Air conditioning and Mechanical Services Plumber	2,672
342111	Air conditioning and Refrigeration Mechanic	17,471
Total		105,046

(Source: Census 2011)

1. Occupation contains specialisations in air conditioning and heating occupations but it is not possible to quantify this with Australian and New Zealand Standard Classification of Occupations (ANZSCO).

In a simplistic comparison these two sets of numbers align well. By replacing the number of motor mechanics listed in *Table 25*, with the smaller number holding automotive air conditioning licenses from *Table 24* of 24,315, both collections arrive at similar values. The total of 54,526 licensees from *Table 24* is not that dissimilar to a total of 58,335 employed in *Table 25* where only the automotive air conditioning licence holders are included in the ‘Motor Mechanic’ category.

When making further allowances for some of the specialisations in these ANZSCO occupation codes that do not require refrigerant handling licenses, such as the Tool Design Draftsperson and Tool Designers, possibly some people employed as air conditioning engineers, and some of the heating and ventilating technical officers, it is possible to get close to the same number of skilled technicians in both data sets.

However this close alignment between the ABS data and the number of skilled technical personnel who handle refrigerant gases, and who renew their licence every year, does not tell us total employment in the sector.

Another piece of the puzzle is the data presented in *Table 26* that, in part confirms what we already know, and that is that RAC technology is employed across most of the economy. This is demonstrated by the range of industries reported as employing the air conditioning and refrigeration mechanics, identified by ANZSCO Code 342111 in *Table 26*.

Table 26: Industries employing air conditioning and refrigeration mechanics

ANZSCO 1 Digit level (industry)	Number employed
Agriculture, Forestry and Fishing	9
Mining	130
Manufacturing	1,407
Electricity, Gas, Water and Waste Services	15
Construction	6,477
Wholesale Trade	217
Retail Trade	575
Accommodation and Food Services	113
Transport, Postal and Warehousing	178
Information Media and Telecommunications	3
Financial and Insurance Services	8
Rental, Hiring and Real Estate Services	71
Professional, Scientific and Technical Services	116
Administrative and Support Services	211
Public Administration and Safety	56
Education and Training	80
Health Care and Social Assistance	95
Arts and Recreation Services	12
Other Services	7,192
Inadequately described	447
Not stated	81
Total	17,493

(Source: Census 2011)

These numbers cannot really tell the whole story. The large ‘other services’ category no doubt captures a large number of the smaller contracting companies that are known to operate in the sector. These contracting companies would supply a majority of the services required for instance to maintain the cold food chain and RAC services in health and education, being sectors that do not look well represented in their own right in *Table 26*.

Another piece of ABS data from the 2011 Census however provides a very good indicator of a reasonable employment multiplier that could be used. As the enquiry to the ABS database returned more than 130 rows of job classifications it is reproduced in full as *Table 43* in *Appendix E: Business and employment*

types. The table lists all occupations reported as being employed in the air conditioning and heating services industry. The two critical elements of that table are reproduced in *Table 27* and include the total number of employees recorded for businesses involved in the air conditioning and heating services industry, and the total number that are refrigeration and air conditioning mechanics or plumbers in those business.

Table 27: Occupations employed in the air conditioning and heating services industry class

ANZSCO 4 Digit level (class)	Number employed
Air conditioning and Refrigeration Mechanics and Plumbers	6,836
Total Employed	14,623
Ratio	2.13

(Source: Census 2011)

If we assume that all of the ‘Air conditioning and Refrigeration Mechanics and Plumbers catalogued here have refrigerant handling licences, this ratio of general employment to licensed RAC technicians could be applied to all licensed technicians working across the economy. Multiplying total refrigerant handling licences by 2.13 indicates total employment of 116,140.

Separately from this body of employment, the refrigerated cold food chain is supplied with perishable foods via a fleet of 28,900 refrigerated vehicles. Assuming that driving and keeping each of these vehicles on the road keeps two people employed full-time, it would equate to another 57,800 jobs. When added to the first value, this assessment indicates total employment in refrigerated transport and RAC services of 173,940, or roughly 1.5 per cent of total employment in Australia as of February 2013.

Applying the ratio from *Table 27* to all licences on issue may appear too simplistic given the wide range of industries that RAC technicians are employed in, however a different approach yielded almost exactly the same result. As shown in *Table 28*, each category of licence issued by ARCTick was treated separately and the reasoning for an employment multiplier developed and applied. Notes below the table set out the rationale for the multipliers used.

Table 28: Share of HVAC&R sector energy consumption and emissions by major class

Licence type	Number of Licences	Proportion of Licences (%)	Employment Multipliers	Total Employment	Proportion of employment (%)
Automotive A/C	24,315	44.6%	1.00	24,315	21.1%
Aviation	122	0.2%	2.50	305	0.3%
Awaiting Assessment	424	0.8%	0.00	0	0.0%
Domestic RAC	387	0.7%	2.00	774	0.7%
Marine	241	0.4%	2.65	639	0.6%
Commercial refrigeration	5,244	9.6%	4.00	20,975	18.2%
Large residential, light commercial and chillers	15,731	28.9%	3.00	47,194	40.9%
Split systems (up to 18kW _r)	7,443	13.7%	2.65	19,724	17.1%
Refrigerant handler	267	0.5%	2.00	534	0.5%
Refrigerant recoverer	231	0.4%	2.00	462	0.4%
Transport refrigeration	121	0.2%	3.00	363	0.3%
Total licences	54,526	100.0%		115,284	100.0%
Refrigerated Transport Vehicles	28,904		2.00	57,808	
Industry Services	545		1.00	545	
Total employment in RAC industry in Australia				173,638	
Percentage in RAC of total employment				1.50%	
Average Multiplier			2.14		

1. Automotive air conditioning: Employed to inspect and service air conditioning in the Australian fleet of private motor vehicles, buses, trucks, trains and other unregistered mobile systems. A majority of these licence holders would most likely be primarily employed as auto mechanics servicing private motor vehicles and would hold the automotive air conditioning licence as a necessary 'ticket' for their employment. These 'part time' air conditioning maintenance jobs are however multiplied by administration staff that assist with the supply of parts associated with this large stock of equipment. Costs of importers engaged in delivering new and pre-charged equipment picked up in spending on hardware.
2. Aviation: This small number of licence holders, inspect, maintain and service air conditioning systems in the entire aviation fleet and are supported by skilled engineering, design and sales and administration personnel in this specialised area requiring designing, procuring, delivering, testing, recording and inspecting equipment installed.
3. Domestic RAC: Employed only in either the refurbishment of domestic refrigeration for resale or in the installation of domestic air conditioners, cost of transport, sales people, office administration for sales etc. covered by retail price of product. Installation requires labour from electrical trades for every install.

4. Marine: Specialist: Licence holders dealing with largely customised systems that have been designed by engineers for each individual vessel, ranging from large pleasure craft to deep sea fishing vessels to passenger liners and large ships with refrigerated holds. Each licensee installs, inspects and maintains equipment designed by engineers and supplied by specialised procurement and sales staff all supported by admin.
5. Commercial Refrigeration: Employment multiplier in commercial refrigeration includes a significant number of employees, including system designers and engineers who design and deliver large supermarket and distribution centre systems, construction workers, smaller cool room contractor and manual labourers and other component suppliers. Other employees include electrical trades and plumbing trades involved in these sometimes very large construction and installation projects, and in regular maintenance and repairs, control system makers, programmers, administration and services, including data monitoring insurances, financial reporting etc. Additionally the large commercial refrigeration units themselves, from the huge distribution stores at ports and rail heads, and other transport links have full time employment on site dealing with daily maintenance, operation and use of these infrastructure scale facilities.
6. Large Residential, Light Commercial and Chillers: Employment multiplier in light commercial HVAC includes a significant number system designers and engineers who design and deliver large commercial building systems, ducting manufacturers and installers, fan manufacturers, and fabricators of other air handling components, construction workers, parts suppliers for extensive and routine repairs and maintenance work, electrical trades and plumbing trades involved in installations, control system makers, programmers and other services, including insurances, financial reporting etc.
7. Small Split Systems <18kW: Employment multipliers in smaller split systems for residential and small commercial include electrical trades and other building trades, suppliers of consumables, sometimes required for installations and some ducting for a smaller proportion of these systems. All of these employment categories are involved in delivering and installing the more than 1 million of these units sold every year. The costs of importers, sales and administration support for sales all covered in cost of hardware.
8. Refrigerant Handler: Multiplier for refrigerant handling licence primarily in administration and sales in wholesale suppliers of gas.
9. Refrigerant Recoverer: Refrigerant recovery may not be full time employment for some holders of these licences, however the process of recovery creates jobs in a 'reverse supply chain' for the return of gas for destruction or reuse via various chemical processes and testing to bring gas back to specification.
10. Transport Refrigeration: The small number of licence holders in this class deal with an enormous fleet of refrigerated vehicles and shipping containers that are very hard working and consume relatively high volumes of parts and consumables. Some of the refrigerated transport fleet is certainly being serviced by licence holders in the commercial refrigeration category. However it is also highly likely that a significant proportion of the transport refrigeration fleet is also being serviced by skilled tradesmen who are not licensed.
11. Refrigerated Transport Vehicles: Employment multiplier for each registered refrigerated freight truck includes an average of 1.25 truck drivers for each vehicle with the balance being store men and packers, logistics and freight forwarders and administrative and sales personnel associated with consigning freight and physically getting product on and off this significant fleet of refrigerated vehicles.
12. Industry Services: Including curriculum development, training and education, industry associations, professional development, testing services, public administration, consulting and regulatory development, publishing, marketing, advertising, exhibition services and compliance services at 1 per cent of total licences.

While this analysis could not be said to be exhaustive, the results are not unreasonable. In the research for CHF1, a survey of industry leaders and associations at that time arrived at a number of approximately 160,000 people employed across the industry, although that figure was essentially arrived at on the basis of informal survey and anecdotal evidence.

Further, the proportions of employment (calculated in *Table 28*) relating directly to issued licences align quite well with the relative scale of the stock of equipment and bank of working gases in the broad classes of stationary air conditioning (looking at large systems and split systems combined), refrigerated cold food chain and mobile air conditioning.

As such, without the benefit of any better data or method for answering the question of total employment in the industry, we are going to use the total employment number of 173,940.

Using average annual earnings in Australia of \$69,992 indicates a total annual wages spend of approximately \$12.174 billion.

It is too simplistic however to add the dollar values derived from the cost of new hardware, the cost of refrigerant gas, total energy cost and wages costs together to declare total economic activity in the RAC industry of \$32.639 billion. The major uncertainty in these values is about the level of double counting. For instance one can reasonably assume that some of the wages costs are in fact represented by the cost of new hardware installed, and the value of some refrigerant gas sales included in the costs of some maintenance and service.

Obviously there is a lot of skilled services and labour involved in the industry that is paid for separately from the cost of new hardware and refrigerant gas. These services and labour include the design and engineering involved in the construction of commercial buildings and new commercial refrigeration plants, plus the extensive labour involved in maintenance and refurbishment of the large stock of equipment.

However even offsetting 100 per cent of the cost of new installed hardware and sales of refrigerant gas from calculated wages costs, leaves a total discounted wages value of \$5.743 billion not accounted for in the sales of new goods and materials. Using that figure as the value for wages not accounted for elsewhere, a summary of the main economic indicators that point to the size of the RAC industry has been compiled into *Table 29*.

Table 29: Main economic indicators of RAC industry activity 2012

Expenditure categories	Economic spend (\$ Billion)
New hardware costs installed	\$5.896
Annual refrigerant gas cost	\$0.535
Energy cost	\$14.061
Discounted wages cost	\$5.743
Total spend	\$26.235

This calculation is not sufficiently rigorous to use this estimate of direct spending to determine what percentage of the national economy is made up of spending on provision of RAC services. However for the sake of the exercise, the Australian GDP was calculated to be \$1.57 trillion in 2012. The total spending estimated in *Table 29* for is equivalent to 1.67 per cent of that value, a percentage that compares well with our estimate of total employment in the sector being around 1.5% of the Australian workforce.

The further question of the total value of the services that the RAC industry provides to its clients is impossible to determine, although that question is explored in the next section of this report.

8 The dependent economy

There are several sectors of the economy that could be regarded as effectively dependent on RAC systems. The refrigerated cold food chain is an obvious candidate and a critical piece of modern infrastructure which could not exist in the absence of cost effective, efficient and reliable refrigeration. An equally critical role is played by a large proportion of the installed stationary air conditioning in commercial buildings.

Major hospital facilities are another telling example of where a vital community service is highly dependent on the round the clock operation of both refrigeration and air conditioning systems.

These economic sectors that are dependent to varying degrees on the provision of RAC services are included here as further indicators of the overall economic value of the RAC industry.

8.1 Cold food and money – the refrigerated cold food chain

Large scale mechanical refrigeration systems, as they were originally conceived and designed, were entirely for the purpose of maintaining food quality. Australia, as a country with a small population and a capacity for production of large food surpluses, has long been in the lead in the development of refrigeration systems to extend the life of perishable food.

The world's first shipment of refrigerated beef and mutton set sail from Sydney in the sailing ship 'Norfolk' in July 1873.³⁰ Unfortunately inexperience with the management of refrigeration equipment, and refrigerated cargoes meant that the entire shipment of 25 tonnes of beef and mutton were unfit for human consumption by the time it arrived in London. However only a few years later, in the early 1880s, dairy and meat exports from Australia and New Zealand in refrigerated shipping had become a booming industry.

Today the refrigerated cold food chain in Australia handles an estimated 20 million tonnes of perishable food stuffs every year, with an estimated farm gate value of \$28 billion dollars and export earnings of nearly \$11 billion.

The main commodities and some of the economics of their production are listed in *Table 30*.

Table 30: Australian production and export of major perishable refrigeration dependent foods

Product	Production volumes	Farm gate value	Number of farms	Employment	Value of export
Dairy products	9.1 million litres	\$3.9 Bn	8,594	27,500	\$2.4 Bn
Meat Products	3 million tonnes	\$13.6 Bn	55,090	137,726	\$5.6 Bn
Poultry and eggs	866,000 tonnes	\$2.27 Bn	968	8,250	n.a. ⁽¹⁾
Wine grapes	1.53 million tonnes	\$1.1 Bn	4,880	31,309	n.a. ⁽²⁾
Fruit, Berries and Vegetables	3.34 million tonnes	\$7.4 Bn	10,860	31,309	\$1.715 Bn

³⁰ Historical accounts differ as to whether this first shipment occurred in July 1873 or 1876, although either date places it prior to first shipments recorded from the US in late 1876 and then in 1879 from Argentina. However there is a possibly erroneous reference to one even earlier shipment from Australia associated with Thomas Mort's Darling Harbour freezer works in 1868.

Fisheries 2010	241,000 tonnes	\$2.0 Bn		8,500	\$1.2 Bn
Total	20.11 million tonnes	\$25.63 Bn	80,392	244,593	\$10.9 Bn

(Source: DAFF 2012)

1. Exports of poultry products are negligible.
2. More than \$1.9 billion in wine was exported in 2011 however that is post refrigeration and processing and is not included in total estimate of value of perishable exports.

Without around the clock refrigeration there are few other options for the stabilising and transport of most of this domestic and export product.

Fresh and perishable foods for domestic consumption and export are transported from farm to processing and packing facilities, and on to fresh food markets in an estimated fleet of 28,900 refrigerated trucks and exported in refrigerated containers.

Domestically these fresh and perishable foods are either further processed, or sold as fresh food through nearly 60,000 retail food outlets of various sorts, as listed in *Table 31* and *32*, all of which are reliant on refrigeration to maintain the food in good condition until sale for consumption.

Table 31: Estimated supermarket and convenience stores by brand 2012

Brand	Nominal quantity
Coles-Bi Lo	753
Woolworths-Safeway	887
Aldi	300
IGA	1,210
IGA (Friendly Grocer/Eziway)	303
AUR-Foodland branded	435
AUR-Foodland (un-branded)	177
Costco	5
SPAR	135
Convenience stores	5,817
Totals	10,022

(Sources: MC 2012, WF 2013, WOW 2013, Convenience World retailer contributions and estimates, 2012 and company representatives)

Table 32: Non supermarket food retail outlets in Australia 2007

Type of Store	Number of stores
Fruit and Vegetables	2,580
Butchers and Poultry	3,859
Delicatessen	1,900
Bakery	745
Restaurants and Cafes	20,562
Hotels and Clubs	5,417
Sandwich bars	8,959
Quick serve restaurants	5,234
Total	49,256

(Source: Foodmap; Spencer, S. and Kneebone, M. for DAFF 2007)

In addition to these retail outlets, a further 28,000 facilities of various sorts, including hotels and motels, schools, universities, hospitals and aged care facilities, act as end points in the perishable food supply chain, retailing food or providing meals as part of a service.

In total, these approximately 88,000 outlets and facilities are the locations of the more than 1 million devices identified in the equipment categories in the refrigerated cold food chain.

An unknown but certainly large proportion of total perishable food production is further transported from retail outlets to storage in the 17 million domestic refrigerators and freezers prior to consumption.

No estimate of the total value of the perishable food sold for immediate consumption, or for transport to domestic refrigerators and freezers, was identified, however total retail food sales of all sorts was valued at \$130.4 billion in Australia in 2010-11 financial year (DAFF 2012).

The CHF2 stock model estimates that the cold food chain in Australia consumes a total of 52.8 PJ of electricity per annum plus around 3.0 PJ of liquid fuels in the transport links.

Commercial refrigeration places demands on electricity infrastructure, and is a significant contributor to Australia's overall emissions profile. A highly skilled workforce is essential to maintain the refrigerated cold food chain. As such, proposals for Australia to dramatically expand food production and become "the food bowl of Asia," need to consider the implications of this national objective in terms of additional infrastructure and refrigeration services required to make any serious expansion of perishable food productive capacity successful.

8.2 Supermarkets – large energy consumers

An important step in the cold food chain, and one that is obviously completely dependent on efficient refrigeration to fulfil its role, are supermarkets. There are more than 10,000 supermarket and convenience stores ranging in size from huge facilities with more than 3,000 square metres of floor space, to the small 7/11's dotted throughout Australia. A common characteristic of these enterprises, relevant to this report, is the concentration of both refrigeration and air conditioning operating in these businesses. As a result of that concentration of RAC equipment, supermarkets are very energy intensive.

The CBBS report concluded that supermarkets occupy an area of more than 8 million m², including some 22 per cent of all space in shopping centres. The balance of the supermarket stock is assumed to be ‘standalone’ buildings.

Further CBBS found that of all types of buildings surveyed, it was supermarkets that were the most energy intensive, using more than twice the energy per square metre per annum than the nearest other building types, being hospitals, shopping centres (base and tenancy) and hotels, as set out in *Table 33*.

Table 33: Australian average energy intensity trends by building type, 1999 – 2020

	1999 (MJ/m ² /year)	2009 (MJ/m ² /year)	2020 (MJ/m ² /year)
Office - Tenancies	400	385	368
Office - Base Buildings	594	532	465
Office – Whole Buildings	994	917	833
Hotels	1,209	1,420	1,652
Shopping Centres - Base Buildings ⁽¹⁾	403	403	403
Shopping Centres – Tenancy ⁽¹⁾	-	1,202	1,202
Shopping Centres - Base +Tenancy ⁽¹⁾	-	1,605	1,605
Supermarkets (Whole) ⁽¹⁾	-	3,375	3,375
Hospitals	1,420	1,542	1,676
Schools	166	178	191
VET buildings	368	367	366
Universities	780	868	965
Public Buildings ⁽²⁾	1,111	947	768
Total	142.7		56.8

(Source: DCCEE 2012b, CBBS Volume 1, page 8)

1. Only limited time-series data was available for retail buildings, insufficient to describe any intensity trends.
2. Museums, galleries and libraries.

One finding from the CBBS report that also has direct relevance to the higher energy intensity of supermarkets was that supermarkets inside shopping centres were operating for an average of more than 96 hours/week compared to just over 59 hours/week for other retail tenancies.

Other than the longer average hours of running, the primary difference between supermarkets and other retail building uses is the intensive reliance on refrigeration systems. Normalising for hours of running against the energy intensity for shopping centres – (base plus tenancy which includes the energy used in HVAC in the building) supermarkets are still nearly 30 per cent more energy intensive than other types of shopping centre tenants.

Table 34 shows total energy use in shopping centres and supermarkets as estimated in the CBBS report.

Table 34: Energy consumption and GHG emissions of shopping centres and supermarkets 2012

	Shopping centres (total)	Supermarkets in shopping centres	Supermarket (stand alone)	Supermarket (total)
Total energy use (PJ)	31.5	7.8	18.9	26.7
GHG (Mt CO ₂ -e)	8.8	2.2	5.4	7.6

(Source: DCCEE 2012b, CBBS Volume 1, page 67)

The CHF2 model for supermarkets is based on both the bottom up modelling of equipment types, reconciled against a linear algorithm for storewide energy consumption per trading floor based on data provided by more than 500 supermarkets in 2009.

$$\text{Electricity consumption (kWh per year)} = 998 \times \text{trading floor (m}^2\text{)} - 167,500$$

The operating hours of the stores surveyed ranged from 3,152 to 6,552 hours per annum, averaging 87 hours per week across the sample. The study found that operating hours or the inclusion of liquor sales was not statistically significant in terms of differences in energy intensity across the supermarket sample. However ambient temperatures was with supermarkets for example Building Code of Australia (BCA) Climate zone 1 (i.e. tropical northern Australia) reported energy intensities 15% higher than the average, and BCA Climate zones 2, 3 and 4 around 5% higher than average.³¹

The CHF2 methodology arrives at a total nationwide value of 18.4 PJ of energy consumption per annum for all supermarkets (compared to CBBS calculation of 26.7 PJ). The authors estimate that actual energy consumption has possibly declined by around 2.5 per cent per annum or a further 10 per cent since 2009.

The significant difference in these results can to some extent be attributed to the notable differences in the estimates of total area occupied by supermarkets. CHF2 estimates that supermarkets occupy a total trading floor area of 5.5 million m² which does not include an allowance for base building services (i.e. air conditioning) when stores are situated in shopping centres. In comparison the CBBS report concluded supermarkets occupy an area of more than 8 million m². The CHF2 definition for trading floor excludes storage areas (refrigerated and non-refrigerated); plant rooms not accessible to the public; undercover walkways stairwells, atria or lobbies prior to entry or exit; car parking areas (open or undercover); supporting functions such as kitchens and break rooms used by staff, and administration offices and areas.

Interestingly, despite the large difference between the two studies calculations of total area occupied and total energy used, the electricity intensity of supermarkets as calculated by CHF2, of 3,352 MJ/m²/year, very closely aligns with CBBS study of 3,375 MJ/m²/year.

Based on detailed individual energy audits of supermarkets, and data provided by major supermarket chains to other research conducted by the authors, CHF2 estimates that 50% of all energy used in supermarkets is consumed for refrigeration energy. Although a small proportion of stores with more dry goods than average could have a lower proportion of refrigeration energy. Conversely the authors have undertaken audits in independent supermarkets, with little or no air conditioning installed, where refrigeration accounts for as much as 75% of all energy consumed.

Assuming for the moment that the CHF2 value for total energy used in supermarkets is correct, and attributing 50% of all energy to refrigeration suggests that refrigeration in supermarkets in Australia consumes around 9.2 PJ of energy per annum. To put that in perspective, 9.2 PJ is equal to 17 per cent of all the energy estimated to be consumed (for refrigeration and refrigerated transport services) in the entire refrigerated cold food chain, using the bottom up approach of the CHF2 stock model. Given the CBBS estimate of area occupied by supermarkets and total energy use, this value could be conservative.

³¹ For further details on locations of climate zones refer Building Code of Australia, Australian climate zone map.

On this analysis, any national strategy aimed at improving overall energy efficiency in the RAC industry, and in the built environment, should have commercial refrigeration and supermarkets high on the list of priorities.

8.3 Stationary air conditioning embedded in the architecture

Between 1999 and 2012 the number of individual residential size air conditioning systems (AC1, AC2, AC3 and AC4) in Australia grew from an estimated 2.6 million units to just under 11.5 million devices, a number substantially higher than the estimated 8 million private dwellings.

Driven by a massive decline in unit prices (down by 80 per cent), largely as a result of new Chinese and Thai manufacturing capacity, and a long period of strong economic growth in Australia, air conditioning in households went from being something that was relatively rare, to being common, and then an expectation.

A proportion of these smaller refrigerated air conditioning devices have also been installed in small commercial and retail premises, although as evidenced by the late afternoon timing of the summer electricity demand peak they create across Australia's electricity grids, the majority clearly operate in homes.

Stationary air conditioning as a class has become the largest consumer of electricity in the RAC sector, with the explosive growth in residential air conditioning in the last decade often being referenced as the single most important driver of peak electricity demand, and therefore of electricity prices, in Australia.

This has had a range of negative outcomes for the capacity and performance of electricity distribution systems, electricity prices and Australia's greenhouse emissions. However this uptake of residential air conditioning is a relatively recent occurrence.

Over a much longer period, since at least the early 1970s in Australia, the availability of reliable, robust and effective commercial air conditioning has been steadily gaining coverage in non-residential buildings. Today it is nearly ubiquitous in every type of public and private non-residential building in Australia.

Today, there are few places in the non-residential built environment where refrigerated air conditioning and mechanical ventilation systems are not encountered, from airport terminals and exhibition halls, to offices and shops.

As a result of reliable air conditioning and mechanical ventilation becoming a standard feature of the built environment, it has fundamentally changed how non-residential buildings are designed and are operated. From the earliest times up to as recently as the 1960s in Australia, nearly all buildings were designed to not just allow, but in many instances to maximise natural ventilation, for instance with windows that opened in even the tallest buildings of the day.

Changes in materials, particularly in glass manufacture and treatments, advances in construction techniques and in the scale of buildings, combined with rapid advances in refrigerated air conditioning and the controls of the much older technology of mechanical ventilation, have combined to allow completely different approaches to building design.

In the latter decades of the 20th century, the marvellous relief enjoyed on a hot day in almost any modern city when entering a well air conditioned building became an increasingly common experience, and eventually an expectation.

Now, as an example of how fundamental the change is, many modern buildings are designed to effectively eliminate ingress of air, with no opening windows and airlocks at the main doors. 'Outside' air is only introduced through the control of mechanical ventilation and air conditioning systems in order to comply with minimum fresh air requirements for commercial buildings (e.g. *AS 1668.2 The use of ventilation and air conditioning in buildings* prescribes a requirement 7.5 to 15 litres per second per person depending on the types of filters, openings and other factors).

By the last decade of the twentieth century, existing commercial, industrial and public buildings of all shapes and sizes were being retrofitted with chiller systems and advanced building controls and ventilation systems.

While the older buildings were being substantially modified to accommodate HVAC systems, almost all new buildings were being designed and built with a total reliance on the capacity of large HVAC systems, driven by advanced programmable controls, to provide comfort conditions across very complex built environments.

Many of the glass walled towers in Australian city centres (designed and constructed in the last three decades) gain so much solar heat through the expanses of glass, that even on winter days the HVAC systems are operating at high capacity to extract heat from the upper floors of the buildings. On hot summer days most HVAC systems are operating at, or near to capacity, from early in the day until well after sundown. Many of our cities major buildings quickly become uninhabitable if their HVAC systems break down on a hot summers day.

This reliance in our city centres on the operation of HVAC systems, and the costs of failure of these systems, either as a result of power failure, or on an individual basis in important buildings, should not be underestimated. A number of effective measures to improve the overall efficiency, management and maintenance of these systems, and to reduce the risk of individual system failure were identified in the HVAC HESS published in 2007 (E3 2007). Of these measures, a number have not been implemented.

8.4 Cool computers

Alongside the dependency on HVAC that has developed across much of our cityscapes, the rapid development in just the last 20 years, particularly since the beginning of the 21st century, of telecommunications, computing and internet server centres, has embedded reliance on HVAC systems in the core of our modern infrastructure.

All modern computing and telecommunication centres run ‘close control’ air conditioning systems (CCAC) to maintain very tightly controlled temperatures in the machinery rooms.

These ‘server farms’ generate a lot of heat from the operation of the machinery. The computers themselves have quite tight optimal operating conditions and a lot of energy use in computers is actually used in driving internal fans to keep the semiconductors, magnetic and electronic components below maximum allowable operating temperatures.

As a result ‘close control’ air conditioning has developed rapidly as a highly specialised and energy intensive industry segment in its own right, hand in hand with the massive investments in computing and telecommunications infrastructure that have been made around the world since the beginning of the 1990s.

CCACs operate under different conditions to those air conditioners providing comfort conditions for people. CCAC are a central air conditioner specifically designed for use in data processing areas, and typically maintaining an internal temperature of 22°C and a relative humidity of 52 per cent. These air conditioners are designed to cool equipment rather than people, hence they are specifically designed to remove more sensible heat rather than latent heat from the controlled environment.

It is estimated that there are about 11,500 CCACs installed in Australia ranging in output from around 10 kW_r to 80 kW_r with an average size of approximately 50 kW_r. Two or more identical units are generally installed at each site to provide redundancy should a unit fail or require maintenance.

CACC units are rotated through an operating cycle, i.e. regularly switched on and off, to ensure a similar operating life for all units installed at a site. No units are kept solely as standby or backup units.

Though the set of CCAC units at any site generally operate 24 hours/day, all year, any given unit operates only 50 per cent to 75 per cent of the time at full capacity. Nonetheless these relatively long operating hours compared to many other stationary air conditioning equipment categories means that while CCACs comprise something in the region of only 1/10th of 1 per cent of the total stock of stationary air conditioning equipment, they consume as much as 4 per cent of all electricity used by all air conditioning equipment.

Minimum energy performance standards were introduced for CCACs in Australia as from 1 July 2009.

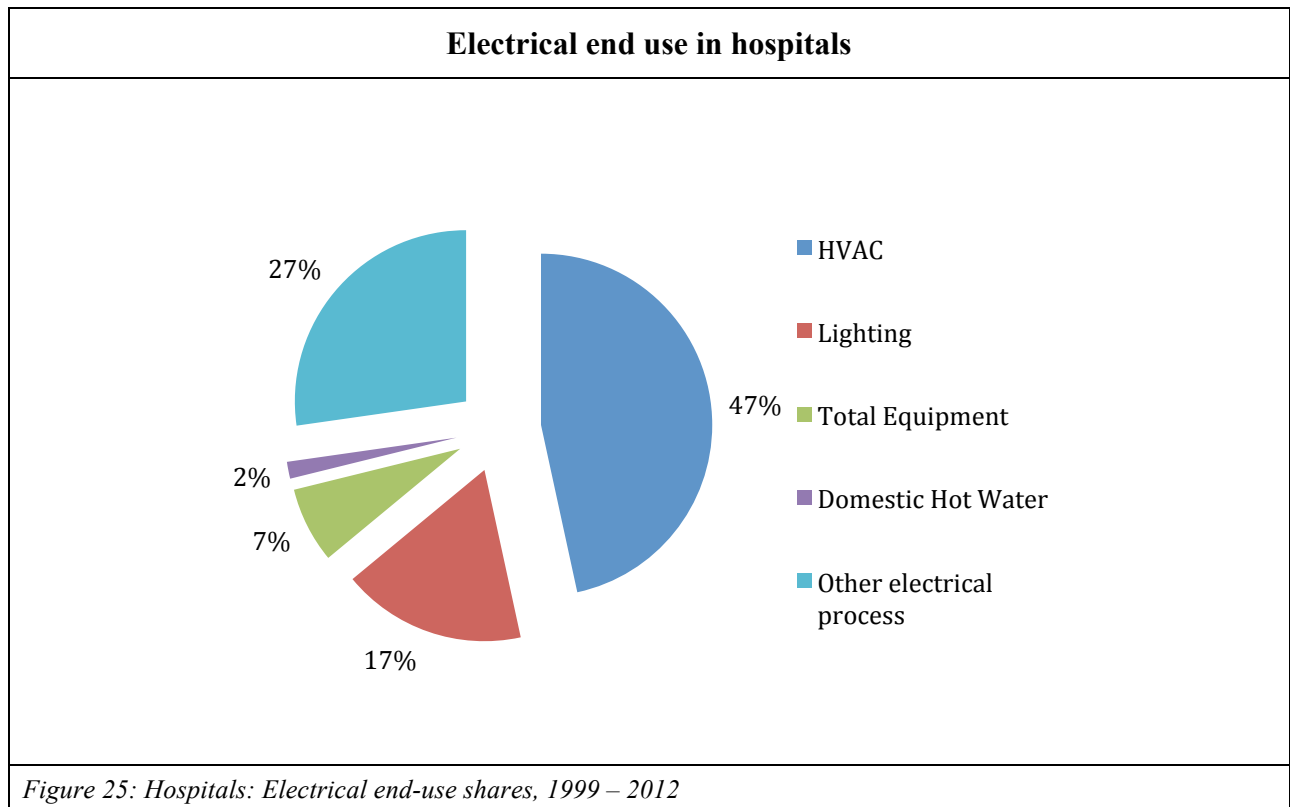
8.5 Cool and clean - hospitals

Australia has approximately 85,000 hospital beds in more than 1,300 hospitals distributed roughly in accordance with the overall population.

In terms of total built environment energy use, hospitals were assessed as the third largest consumer of energy in the CBBS study, using 19.1 PJ in 2009. However based on our assessment below of the end uses and mix of technology employed in hospitals, it is concluded that overall, while obviously of vital importance, refrigeration in hospitals is not a major end-use application relative to the total investment in non-residential refrigeration systems in Australia (*Figure 25*). Air conditioning on the other hand is a significant energy end use in hospitals.

Hospitals are of interest to this study because of the wide range of RAC equipment employed and the very high standards for air conditioning and refrigeration in some hospital applications.

Figure 25 shows the electrical end-use shares for hospitals over the period 1990-2012, noting that end-use shares are based on a sample size of 41. HVAC dominates end-use shares, accounting for 47 per cent of total electrical use.



(Source: DCCEE 2012b, CBBS Volume 1, page 76)

Because of the 24 hour operation of hospitals, and unlike shopping centres for instance (due to the very low levels of traffic), hospitals generally require significant heating during winter months in almost all climate zones in Australia, and obviously more so in the colder population centres such as Canberra, Melbourne and Hobart.

Compounding this situation is the fact that regulation in Australia requires that the indoor temperature of any hospital has to be constantly maintained at 23°C. Unfortunately, although variations of a degree or so are barely noticeable for patients and staff, no flexibility in indoor temperature according to seasons or time of day is allowed. Often these inflexible temperature requirements, combined with widely varying

conditions in different parts of the often large hospitals means that both chilling and heating systems can be running at quite high loads at the same time.

As a result a large amount of energy use in hospitals is invested in maintaining this constant temperature.

Hospital ventilation systems must also provide high levels of indoor air quality for health safety reasons. This creates serious challenges for the ventilation and temperature control systems which means that initiatives, such as natural ventilation are not always possible for hospitals.

Space heating is almost always fuelled by gas in major hospitals. Some hospitals deliver space heating by circulating hot water through radiator systems. But electricity consumption attributed to HVAC includes all fan energy used to drive mechanical ventilation systems that in some cases also circulate warm air for space heating. As a result electricity consumed in HVAC cannot all be attributed to a cooling task.

Figure 26 shows the gas end-use shares for hospitals over the period 1990-2012. Gas end-use shares are based on a relatively small sample size of 9. ‘Other gas use’ (unresolved energy end-uses) accounts for almost half (46 per cent), and space-heating accounts for 32 per cent of total gas use. Of the remaining end-uses, domestic hot water (12 per cent) uses the most gas.

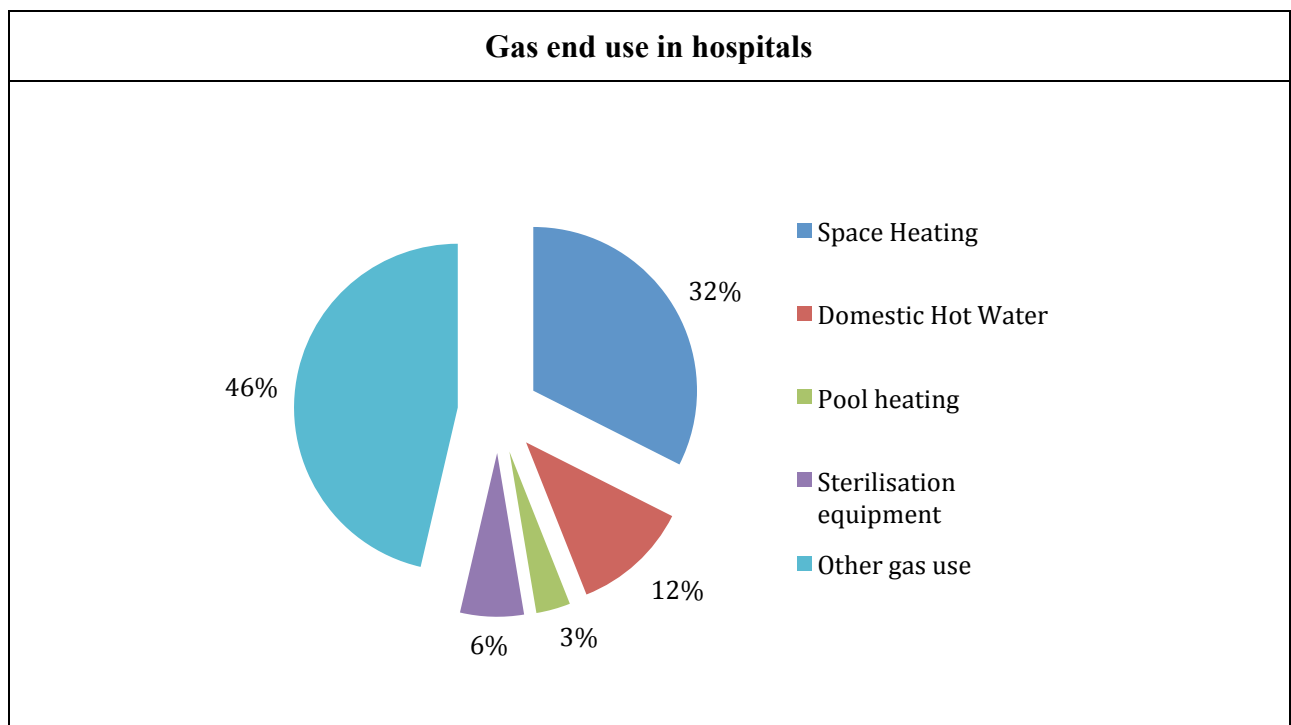


Figure 26: Hospitals: Gas end-use shares, 1999 – 2012

(Source: DCCEE 2012b, CBBS Volume 1, page 76)

A separate study cited by Berger and Newman in a paper on energy efficiency in hospitals reported that energy used by fans in a Melbourne and Brisbane hospital were 36 per cent and 35 per cent of the total energy respectively (CUT 2010). Energy for chillers on the other hand was a very low 7 per cent in Melbourne and 19 per cent in Brisbane.

If one attributes equal portions of the fan energy used in either location to distribution of heating and cooling, then the energy invested in cooling alone in Melbourne would be 25 per cent of total energy used in the facility, and in Brisbane it would be 36 per cent. Given the climate differences between those two sites a fairer allocation of fan power to cooling would probably see those values shift towards 20 per cent in Melbourne and 40 per cent or higher in Brisbane.

There is no Australian data available that allows the calculation of energy use for refrigeration in hospitals. However American studies have concluded that refrigeration consumed between 2 per cent and 3 per cent

of hospital energy in the USA. There is no way of comparing the refrigeration systems employed in US hospitals compared to Australia, and no basis on which to assume they would be either the same, or very different. Although it should be noted that of the US hospitals studied, all had lower energy shares for cooling and ventilation than Australian hospitals, and all had significantly higher shares of energy for heating and hot water than Australian hospitals.

Even so, assuming that a mix of climatic and cultural differences means that refrigeration equipment is employed less frequently in US hospitals, it is unlikely that Australian hospitals would consume much more than about 50 per cent additional energy on refrigeration than their US counterparts, giving an end-use energy share for refrigeration in Australian hospitals of between 3 per cent and 4.5 per cent.

We conclude that, depending on the climate zones, energy in Australian hospitals required for RAC ranges from 23 per cent to 44.5 per cent, a still considerable energy consumption share and important in the energy economy overall given hospitals position as the third largest user of energy in the built environment.

While no studies were found that identified the energy end-use share of refrigeration in hospitals, a detailed survey of one hospital in Melbourne conducted for the purposes of this report did reveal an extraordinary array of refrigeration equipment employed. Uses for refrigeration in hospitals range from domestic refrigerators for snacks and drinks, to fully equipped commercial kitchens to a range of close control medical and laboratory uses including the storage of blood, plasma, other organic material, pharmaceuticals and in morgues.

The total installed refrigerating capacity per hospital bed at this facility was calculated as being 0.146 kW_r per bed. Assuming that the Melbourne facility studies is typical of Australian hospitals, extrapolating that average across the entire national population of hospital beds indicates a total refrigeration capacity in all Australian hospitals of approximately 12.4 MW_r.

This is roughly equivalent to the refrigeration capacity that would be found in around 45 medium sized supermarkets with trading floors of around 2,500 m². Another way of looking at this is that all of the estimated refrigeration capacity in all Australian hospitals is equivalent to adding 5 per cent to the stock of the 985 supermarkets with trading floors of around 2,500 m² in Australia.

While the refrigerating capacity employed in Australian hospitals appears to be a relatively modest proportion of all commercial refrigeration, the total energy consumption of hospital HVAC, as a result of having to deliver the exacting requirements for temperature and air quality control, indicate that stationary air conditioning in hospitals is a significant application of that class of technology in Australia.

Other health related applications that are often thought to be major users of refrigeration were also revealed to be relatively small application areas, such as in morgues, pharmaceutical supply chains and for the blood bank. Refrigeration is essential in these areas however in the scheme of things the total use is small.

Mortuary systems are specialised in a number of ways, particularly in terms of the racking and trolleys. It is estimated that there are around 400 mortuary 'cool rooms' in operation in Australia that manage approximately 128,000 corpses annually. There are both medium temperature and low temperature equipment used, depending on the length of time a corpse has to be retained. The equipment used is captured in the CHF2 database amongst the walk-in cool room equipment.

Pharmacies and the pharmaceutical supply chain are another small medical use of refrigeration. These medical refrigerators have their own technical standard *AS 3864, 1997, Medical refrigeration equipment - for the storage of blood and blood products* as pharmaceutical products that require refrigeration (i.e. vaccines, whole blood, blood derivatives, HIV test kits and ARV drugs) require storage between 2°C and 8°C depending on the product to maintain product quality.

There are approximately 5,200 pharmacies in Australia, each of which is required to have 'medical' refrigerators for any vaccines stored on the premises. There are also some 7,000 general practitioners who are thought to have 100 litre to 150 litre refrigerators for the same purpose. Along with an estimated 3,000 small medical refrigerators at hospitals for storage of vaccines it is estimated that there are some 15,000 of these small devices. The majority of pharmaceuticals do not require refrigeration, however the pharmaceutical supply chain for vaccines and other refrigerated pharmaceuticals involve less than 100

walk-in coolrooms. All of this equipment, which in total would employ less than 5 tonnes of refrigerant gas, is picked up in various small refrigeration equipment categories in the CHF2 database.

Blood collection, processing, packing, storage and distribution is a unique sector of the pharmaceutical industry that is critical in the supply of modern medical services, particularly surgical procedures. There are 8 blood banks in Australia that are operational around the clock, 365 days of the year. The Australian Red Cross administers the collection, inventory and distribution of blood in Australia employing around 4,500 people. A government agency, the National Blood Authority (NBA) provided funds of \$496 million last financial year to purchase and manage blood, and blood products.

The blood collection and handling is spread over 80 static and 37 mobile sites. Blood donations are critical to the process and average 27,000 donations per week nationwide, a total of 956,000 donations per annum. Blood is stored at 2°C to 8°C and Plasma at -30°C.

The NBA coordinates manufacturing and distribution of 1.8 million units of blood products per annum. The product mix is made up of 40 per cent whole blood, 40 per cent plasma and 20 per cent specialized blood products. CSL Ltd (formerly Commonwealth Serum Laboratories) takes plasma ready blood (525,000 kilograms) and infuses it in their manufacturing plant at Broadmeadows in Victoria under contract to the blood bank.

The transport of blood products is mostly done with insulated cardboard boxes operating within tight standards guideline. The blood products supply chain uses around 900 kW_r of refrigeration in collection, packing and distribution using, including more than 150 walk-in coolrooms (WICs) containing around 1.5 tonnes (mostly HFC-404A), these are counted in the stock inventory as WICs. There are at least 250 specialised self-contained laboratory refrigerators in use as well. These highly specialised devices are designed for storing critical materials that demand constant temperature and security with some refrigerators capable of storing products at ultra-low temperatures of -86°C.

Because of the essential nature of the products to the national health and hospital system, the major storage and distribution centres are designed with uninterruptible power supplies. The Melbourne blood bank facility for instance has back up power provided by two separate diesel generators.

9 CHF1 and CHF2 Comparative measures

Since the late 19th century hi-technology pioneers of refrigeration helped establish Australia as a source of quality food exported half way around the world, the refrigeration industry has become a sizeable part of the Australian economy. The core refrigeration technology of vapour compression has also become the basis of an entirely modern industry in air conditioning. How much of the economy was built on that electro-mechanical vapour compression process was one of the central questions that underpinned the creation of CHF1.

When CHF1 was undertaken in 2007, one of the challenges was the paucity of data. The relative difficulty in establishing starting points for data collection, and the characteristics of the various categories of the stock of equipment, to some extent drove the direction of the research. There was also little thought given at that time for any future study being able to draw comparisons against the conclusions drawn, or for the value of those conclusions as initial benchmarks.

Despite this, and while the resources and data available during the preparation of CHF1 were significantly less than those available in the preparation of this report, it is still worth comparing the main findings from the earlier study with results from CHF2, where they can be compared.

All of the main measures are listed in *Table 34*, and explanatory notes accompany most items. To provide a benchmark for future studies, in the cases where equipment categories have been redefined since 2006, the new category is displayed for 2012. These values have also been included in an aggregate value to provide a comparison with 2006.

Table 35: CHF1 and CHF2 Comparative measures

Main measures	2006	2012
AUSTRALIAN ECONOMY		
Gross Domestic Product (GDP) ⁽¹⁾	\$316.2 Bn	\$371.9 Bn
Electricity consumption ⁽²⁾	194,781 GWh	265,000 GWh
National Greenhouse Gas Inventory (NGGI)	532.5 Mt CO ₂ -e (FY 2005-6)	550.80 Mt CO ₂ -e (FY 2011-12)
HVAC&R INDUSTRY		
Direct spending ⁽⁴⁾	\$15.96 Bn	\$26.235 Bn
Total employment ⁽⁵⁾	163,000	173,940
Electricity consumed ⁽⁶⁾	45,000 GWh	59,100 GWh
Proportion of total electricity generation ⁽²⁾	21.9%	22.3%
Indirect emissions ⁽⁷⁾	40 Mt CO ₂ -e	57.1 Mt CO ₂ -e
Indirect emissions as proportion of NGGI	-	10.4%
Bank of high GWP Gases ⁽⁸⁾	30,200 tonnes	43,500 tonnes
Bank of low GWP Gases	-	4,800 tonnes
Direct emissions (ODS) ⁽⁹⁾	-	1.3 Mt CO ₂ -e

Direct emissions (SGG)	-	4.1 Mt CO ₂ -e
RAC emissions as proportion of NGGI	-	11.1%
STOCK OF EQUIPMENT		
Domestic refrigerators and freezers ⁽¹⁰⁾	13,000,000	17,149,000
Domestic and light commercial air conditioning ⁽¹¹⁾	5,638,669	11,526,500
Chillers ⁽¹²⁾	22,450	28,440
Volume of cold storage ⁽¹³⁾	9,460,000 m ³	13,050,000 m ³
Supermarket chain stores ⁽¹⁴⁾	3,675	3,336
Small independent stores	-	840
Convenience stores	-	5,817
Walk-in coolrooms (also included below for purpose of comparison with 2006)	22,853	98,100
Walk-in coolrooms and self-contained non-domestic refrigeration equipment ⁽¹⁵⁾	821,500	1,055,000
Remote non-domestic refrigeration (also included above for purposes of comparison with 2006) ⁽¹⁵⁾	-	167,000
Refrigerated Vehicles ⁽¹⁶⁾	16,418	28,900
Passenger vehicles with air conditioning ⁽¹⁷⁾	10,293,770	12,079,000

1. GDP can be derived by three broad approaches: the income approach, the expenditure approach and the production approach. The values cited in this table are chain volume GDPs, which is derived by averaging the chain volume estimates obtained from each of the three independent approaches. The chain value GDP grew by \$55.74 Billion or 17.6 per cent over the six years from 2006 to 2012, which equates to an average annual compound growth rate of 2.8% per cent over that period (ABS 5206.0 2012). This growth rate is generally consistent with the growth rates used in this study of mature product categories.
2. The definitions of total electricity generation or sent out have evolved over this period, as has the grid which now includes a higher percentage of devices supplied by renewable electricity sources. CHF1 used the value cited by NEMMCO in their 2005/6 Annual Report, and NEMMCO's roles and responsibilities have since transitioned to the Australian Energy Market Operator. The value used in CHF2 is total electricity and renewable consumption as quoted by Bureau of Resources and Energy Economics (BREE 2012).
3. The NGGI values used in this study are for a slightly different period to other measures, for example CHF2 measures are based on calendar year and the NGGI values are for the previous financial year (DCCEE 2012a).
4. The scope and methodology for calculating direct spending has changed from CHF1 to CHF2, and these two values should not be compared. CHF2 includes an expanded range of equipment types; the cost of liquid fuel consumed in mobile equipment; service costs and the cost of refrigerant gas based on current market prices (i.e. including carbon levy). In addition, the level of confidence of this measure could be improved with further work on the total equipment installed spend by taking larger equipment samples, and undertaking more detailed market research on the cost of installation for each product category. Further details on the methodology can be found in *Chapter 7.3: Indicators of value*.
5. The basis on which the total employment numbers were arrived at is quite different, and is discussed in more detail in *Chapter 7.3: Indicators of value*.

6. The in principal methodology used to calculate electricity consumption was the same in both studies, however the knowledge and available research material (i.e. Australian government regulators and international agencies) has improved the confidence level of this measure and expanded product scope.
7. The indirect emission factors for the two studies were different in that CHF1 used a generous emissions factor of 0.893 kg CO₂-e/kWh, which was the value for NSW whereas CHF2 uses 0.914 kg CO₂-e/kWh which is a population based weighted average of scope 2 emission factors for electricity consumption purchased from the grid. Reported in CHF1 merely as 'Emissions', it was based only on the indirect emissions that would result from the calculated electricity consumption. As a result the CHF2 value used for comparison here is only the indirect emissions as a result of electricity consumption and does not include calculated direct emissions from the working bank, or EOL emissions.
8. While it is interesting to compare the sizes of the refrigerant bank from CHF1 to CHF2, caution should be taken when comparing a percentage change between the two studies as the scope of product categories and stock estimates have been significantly refined over the last six years.
9. Direct emissions were not calculated or quoted as not part of CHF1. Direct emissions were calculated based on CHF1 inventories in a later study by the authors of this study (ES 2007). This study used the same methodology and direct emission factors as used in CHF2.
10. Domestic refrigerators and freezers stock growth equates to an annualised growth rate of around 4.5 per cent, which is higher than GDP growth. The historical data in this product segments is very sound, and variations in total stock value will mostly depend on assumptions about mean and standard deviation lifespans (DSEWPac 2013b, E3 2011, DSEWPac 2011, E3 2010b, E3 2010c and E3 2008d). The growth rate higher than GDP can be explained by several factors; domestic refrigerators often migrate into the garage as a second refrigerator rather than being retired; the emergence of portable refrigerators and the inclusion of these devices in this product category and lower consumer prices.
11. The domestic and light commercial air conditioning product categories for CHF1 and the CHF2 calculation are essentially based on the same components, which includes AC1, AC2, AC3 and AC6. However one change to the underlying assumptions has inflated the 2012 number by 782,000 units. In calculating retirement rates the average life of equipment in product categories AC1 and AC2 has been increased to from 10 years to 12 years. This change reflects industry reports and experience with these product categories. Even with the change to retirements, given the known imports and sales data, the doubling of the installed base of these equipment categories in the past 6 years is primarily due to new equipment and is a very robust figure. Notably the CHF2 stock model includes more than a million devices that use refrigerant gases that were only just emerging onto the market in 2006 and had insignificant volumes at that time. These include portable air conditioning 0-10kW (AC4, 606,000 units in 2012), light commercial 'variable refrigerant volume' multi head systems (AC6-2, 276,000 units in 2012), light commercial hot water heat pump units (AC6-4, 1000 units) light commercial pool heat pumps (AC6-5, 28,000 units) domestic hot water heat pump systems (AC7, 170,000 units), (DSEWPac 2013b, E3 2012, DSEWPac 2011, IEA 2011, E3 2009b and E3 2008a).
12. Chillers used for space air conditioning equates to an annualised growth of around 4%. This is higher than expected in this sector, however the confidence levels in the data in this sector has improved since 2006 as a result of the introduction of MEPs in several capacity categories. CHF2 methodology and stock values are generally consistent with the regulatory impact statements and associated research undertaken in this product category (DSEWPac 2011, IEA 2011, E3 2008b).
13. Increases in the volume of cold storage facilities are attributed to an increase in the allowance for hidden cold storage facilities (e.g. attached to factories) that are not members of the Refrigerated Warehouse and Transport Association. This value 13,050,000 m³ is for all facilities containing both low and high GWP refrigerants, whereas other values cited in this report of 12,400,000 m³ are for low GWP refrigerant facilities.
14. Supermarket and small independent stores equates to an annualised growth rate of around 2.2 per cent. The CHF2 supermarket count has declined as the definition of supermarkets and food retail outlets been refined which now includes 333 large supermarkets (predominantly Coles-Bi Lo and Woolworths-Safeway) with a trading floor ≥ 2,750 m², 985 medium sized stores with a trading floor between 2,750 and 1,500 m², and 2,048 small stores (predominantly Aldi, IGA and AUR-Foodland branded) with a trading floor between 1,500 and 400 m². There are 840 stores (predominantly IGA Friendly Grocer/Eziway, AUR-Foodland branded/un-branded, SPAR) with a trading floor smaller than 400 m² that have been defined as extra small, plus an additional 5,817 convenience stores (i.e. 7 Eleven, AA Holdings, Apco, BP, Caltex, Coles Express, Independents, Matilda, Mobil, New Sunrise, Night Owl, Reliance, UCB, United including distributors and Woolworths Petrol), (SEWPac 2011, E3 2009a, MC 2012, WF 2013, WOW 2013, Convenience World).
15. Non-domestic refrigeration (self-contained and remote condensing units, RCFC1-1 and RCFC1-2) and walk in coolrooms (RCFC1-4, RCFC1-5, and RCFC1-6) have been compared in one line with the original CHF1 number. Since CHF1 was published, many refrigerated cold food chain categories have been redefined. The aggregate

value of 844,353 self-contained units and coolrooms stated in CHF1 equates to a growth rate of 4 per cent per annum when compared with 1,087,281 including units with remote condensers. Although this is possibly consistent or slightly higher than growth rates experienced in commercial refrigeration, this is still considered a robust, and even slightly conservative number and given what is known of compressor sales, it is possible that non-domestic self-contained refrigerator equipment (RCFC1-1 and RCFC1-2) could still be underestimated by as much as 10 per cent (DSEWPaC 2013b, DSEWPaC 2011 and E3 2009a).

16. Refrigerated vehicles have seen solid growth over the period from CHF1 to CHF2, at times reported to be as high as 7 per cent per annum. However, a significant factor is the underestimation of the number of smaller off-engine vehicles (RCFC2-3) that were originally estimated in CHF1 at 10,212 and are now estimated at 17,630 (DSEWPaC 2013b, EG 2011, DSEWPaC 2011 and E3 2009a).
17. Passenger vehicles equates to an annualised growth rate of around 2.7 per cent, which is consistent with growth rates reported in ABS publications, which is based on sound historical data (i.e. registrations) and a generally consistent methodology over the period (ABS 9208.0 2010, ABS 9309.0 2012 and ABS 9314.0 2012).

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Appendix A: Methodology

The data presented in this report has been derived from an extensive Excel workbook that has, at its core, a stock model of RAC employed in Australia.

Data underlying the stock model

This stock model was first 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) 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 was collected from a number of importers, manufacturers and from published market research, constructed into the early years of the model and then exposed 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 manufacturer's 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 Sustainability, Environment, Water, Population and Communities data including bulk and pre-charged equipment import statistics by quantity, mass, species, licence holder, product category from 2006 to 2013 (DSEWPaC 2013);³²
- Reviews of data included in Regulatory Impact Statements and product profiles for air conditioning equipment (i.e. split systems, chillers, close control, portable, etc.), domestic refrigerators and freezers, non-domestic refrigeration (E3 2009a), and other products such as hot water heat pumps (E3 2012);
- 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 gas, parts and tools for the purpose of other RAC industry related studies;

³² *Not all refrigerants need to be reported to Customs at the point of import, however all of the major classes of HCFCs and HFCs, the 'synthetic greenhouse gas' refrigerants must be reported.*

- 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, up-stream processors and end-users of natural refrigerants to establish aggregate industry measures.
- 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 with, the main outputs or the structure of the model.

Product category stock models

More sophisticated 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 models and equipment retirement estimates by refrigerant species or type.

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. So 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:

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

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 or type to predict the refrigerant mix of the bank and retiring equipment.

Gas charges and species

The size of the gas charges in various equipment classes are known from manufacturer's documentation and checks of equipment and appliances in the market and for sale. The size of gas charges can 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.

The gas 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 gas 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 gas.

From 2006 to July 2012 DSEWPac 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 gas charges in various products, and the dissection and transition of refrigerant species in products.

The bank of working gas

Average charges of working gas in each product are used to calculate the total bank of working gas by equipment category and segment, and by gas species.

Leak rates for products operating on HFCs or HCFCs are used to calculate the volume of refrigerant gas applied to servicing equipment segments in any year. This service demand is reconciled against the known volumes imported. Refer *Appendix B Technical resources and assumptions* for details of average charge and leak rate values used in calculations.

DSEWPaC bulk import data provided detailed dissection of HCFC imports by type and blend, whereas HFC bulk import dissection was estimated based on reporting of HFC-134a, secondary refrigerants (HFC-23, HFC-32, HFC-125, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, HFC-365mfc, HFC-43-10mee, which are largely used in common refrigerant blends such as HFC-404A, HFC-410A and others) and ‘exotic’ refrigerants typically used for laboratory research. Mid-way through 2011 full details of HFC bulk imports were provided by type and blend. Bulk gas is primarily imported for servicing and manufacturing RAC equipment, however other uses include charging new commercial refrigeration equipment with remote condensers which are predominantly manufactured or imported with a nitrogen charge and gassed on site. Smaller volumes are used in non-RAC applications including foam blowing, aerosols, fire protection and as cleaning agents (solvents), electricity production.

The volumes of refrigerant gas 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 gases purchased in any year for their production.

Energy consumption

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

The electrical demand and efficiency of every product category is derived from a combination of sources including manufacturer’s data, E3 energy rating data by appliance for relevant technical standard (e.g. split systems *AS/NZ 3823.2*), and energy consumption modeling undertaken by the Department of Climate Change and Energy Efficiency (DCCEE), now referred to as the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, from the most current published regulatory impact statement or product profile.

The average running hours of the products per day and per annum is calculated based on accepted values for average daily use, and those used in DCCEE energy models. Where variable speed drives are employed, an average load factor is applied to arrive at a daily and annual electricity consumption value for a product.

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 arriving at a national average greenhouse intensity factor for electricity, factors from the NGERs Reporting System Measurement Technical Guidelines for estimation of greenhouse gas emissions by facilities in Australia for the 2012-13 reporting year (NGERS 2012), were used. State based indirect (scope 2) emission factors from consumption of purchased electricity from a grid 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 2012).

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

Refer to tables in *Appendix B Technical resources and assumptions*, for actual factors used.

Global Warming Potential (GWP)

This report often has to refer to the GWP value of refrigerant gases. Unless otherwise stated, the GWP of any gas, or blend of gases is calculated using the values published in the Second Assessment Report (AR2) of the United Nations Framework Convention on Climate Change (UNFCCC), released in 1996 by the Intergovernmental Panel on Climate Change.

Revised GWP values were reported in the Fourth Assessment Report (AR4) in 2007, however the revised values have not been accepted by the parties to the UNFCCC to date. Australia's legally binding emission obligations under the Kyoto Protocol are calculated based on AR2 and therefore Australian legislation, including the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 (OPSGMA), cite GWPs from AR2. Where gases that were not included in the AR2 assessment are referred to, the AR4 value is used, if it is available, and that is noted in a superscript after the GWP value (e.g. GWP of HCFC-409A is 1,585^{AR4}).

A new class of substances, very low GWP HFCs or HFOs, was not available at the time of publication of AR4 and the claimed GWPs are based on industry data. The Australian Government has indicated that it will adopt AR4 from July 2017, for the time being the AR2 values are being used as the basis for regulation.

A table has been provided in Appendix B that compares the GWP values published in the Second and the Fourth Assessments, and the chemical mass composition used to calculate the GWP values of common blends.

The GWP values of HFO substances (HFO-1234yf) are those cited by DuPont (DuPont 2010) and Honeywell as based on AR4. The IPCC, Fifth Assessment Report (AR5) is well advanced, however is not publically available at the time of writing this report.

Direct Emissions

Annual emissions of refrigerant gases from each product are calculated using an annual leak rate from each product, and applying that to the bank of working gas that has been calculated as being employed in each product.

There are four main types of direct emissions from RAC equipment:

- Gradual leaks during normal operation;

- Catastrophic losses during normal operation;
- Losses during equipment service and maintenance, and
- Losses at end of equipment life.

The annual leak rate referred to in this report is expressed as a percentage of the initial charge per annum and is calculated as the sum of gradual leaks during normal operation plus; catastrophic losses amortised over the life of the equipment plus; losses during service and maintenance.

In the case of mobile air conditioning equipment, the annual leak rate takes into account losses from vehicle crashes, which are classed as catastrophic losses.

Losses at end-of-life are treated separately as potential emissions.

Refrigerant recovery is compulsory under the OPSGGMA and the associated Regulations, and 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 potential end-of-life emissions are calculated by multiplying the average refrigerant charge by the EOL factor proportion of original charge remaining for each applications sector. 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 equates to the recoverable gas.

Deducting the recycling factor leaves the amount that is available for either reclaim 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.

With some products, such as with roof top mounted and wall hung split air conditioners, calculations of direct emissions include leaks from the equipment during operation, plus losses in handling the equipment and charging or adding refrigerant to the equipment during installation, commissioning and maintenance.

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, portable and mobile air conditioners, and smaller wall hung split systems, is that all of the remaining charge of working gas is lost to air and none is recovered.


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 refrigerant gases that are imported every year is known from DSEWPac bulk import data. The uses to which that gas is put is deduced from the data underlying the calculation of the bank of working gases. The value to the end-users of that gas 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 gas.

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. Two national average rates were used, one for commercial end-users of 18c/kWh, and 25c/kWh for residential. A rate of 13c/kWh was used for large commercial end-users such as cold storage facilities.

The assumptions made about the proportion of different classes of air conditioning equipment found in commercial applications are tabulated in *Appendix B: Technical resources and assumptions*. 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, and devices in the refrigerated cold food chain used the commercial rate.

Appendix B: Technical resources and assumptions

This appendix summarises the main assumptions used in the study, and provides other technical resources used in calculations.

Table 36: GWP factors of main refrigerant gas species

Common substances	AR2 GWP-100 Year	AR4 GWP-100 Year
Substances controlled by the Montreal Protocol		
CFC-11 ⁽¹⁾	3,800	4,750
CFC-12 ⁽¹⁾	8,100	10,900
HCFC-123	90	77
HCFC-22	1,500	1,810
HCFC-141b	-	725
HCFC-142b	1,800	2,310
HCFC-406A	-	1,943
HCFC-408A	-	3,152
HCFC-409A	-	1,585
HCFC-225ca ⁽⁴⁾	-	122
HCFC-225cb ⁽⁴⁾	-	595
Hydrofluorocarbons (HFCs) ⁽²⁾		
HFC-134a	1,300	1,430
HFC-404A	3,260	3,922
HFC-407C	1,526	1,774
HFC-407F	1,824	2,107
HFC-410A	1,725	2,088
HFC-417A	1,955	2,346
HFC-227ea ⁽⁴⁾	2,900	3,220
HFC-245fa ⁽⁴⁾	-	1,030
HFC-365mfc ⁽⁴⁾	-	794
Low GWP alternatives ⁽³⁾		
HC-600a	-	3
HC-290	-	3
CO ₂ (R744)	-	1
Ammonia (R717)	-	0
HFO-1234yf	-	4
HFO-1234ze	-	6
HFO-HFC blend (XP10)	-	600
HFC-152a	140	124
HFC-32	650	675

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. The GWP values of HFO substances are those cited by DuPont (DuPont 2010) and Honeywell as based on AR4. These are new and were not reviewed, included or published in the IPCC, Fourth Assessment Report published in 2007. HC-600a and HC-290 are not published in the AR2 or AR4.
3. All references to HFC-404A 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.
4. Not used as refrigerant in RAC applications, substances used for foam blowing applications, fire protection and as solvents.

The ASHRAE refrigerant mass chemical compositions are used to calculate the GWP values of these blends from the Second Assessment Report (AR2) of the United Nations Framework Convention on Climate Change (UNFCCC), released in 1996 (IPCC 1996). While these values have since been superseded by the Fourth Assessment Report (AR4) in 2007, all of the Australian legislation that refers to the GWP of HFCs use the values listed originally in AR2, based on Australia's obligation under the Kyoto Protocol.

Table 37: ASHRAE Refrigerant designation and refrigerant mass composition of common blends used in Australia

ASHRAE Refrigerant designation	Refrigerant composition (Mass %)
Refrigerant blends: Zeotropes	
404A	R-125/143a/134a (44.0/52.0/4.0)
406A	R-22/600a/142b (55.0/4.0/41.0)
407C	R-32/125/134a (23.0/25.0/52.0)
407F	R-32/125/134a (30.0/30.0/40.0)
408A	R-125/143a/22 (7.0/46.0/47.0)
409A	R-22/124/142b (60.0/25.0/15.0)
409B	R-22/124/142b (65.0/25.0/10.0)
410A	R-32/125 (50.0/50.0)
436A	R-290/600a (56.0/44.0)
436B	R-290/600a (52.0/48.0)
Refrigerant blends: Azeotropes	
507A	R-125/143a (50.0/50.0)

1. The contents of this table is from ANSI/ASHRAE 34-2010, Designation and Safety Classification of Refrigerant, which is published on the ASHRAE website.

Table 38: Indirect (scope 2) emission factors from consumption of purchased electricity from a grid

Category code	Population by State	% by State	Emission factors (kg CO ₂ -e/kWh)
New South Wales	7,290.3	32%	0.88
Victoria	5,623.5	25%	1.19
Queensland	4,560.1	20%	0.86
South Australia	1,654.8	7%	0.65
Western Australia	2,430.3	11%	0.82
Tasmania	512.0	2%	0.26
Northern Territory	234.8	1%	0.71
Australian Capital Territory	374.7	2%	0.88
National	22,680.5	100%	0.914

1. The indirect emission factors are from NGERs technical guidelines for the estimation of Greenhouse Gas emissions by facilities in Australia, July 2012. The factors used in this report are the indirect (scope 2) emission factors from consumption of purchased electricity from a grid.
2. The State and Territory emission factors were used to calculate a national indirect emission factor weighted based on Australian population, excluding other territories not listed above (ABS 3101.0, 2012).

Table 39: Fuel combustion - liquid fuels for transport energy purposes for post-2004 vehicles

Fuel type	Energy content factor (GJ/kL)	Emission factors (kg CO ₂ -e/GJ)
Gasoline (petrol)	34.2	66.7
Diesel oil	38.6	69.2

(Source: NGERs 2012)

Table 40: Technical characteristics for product categories (average charge, leak rates, lifespan, end-of-life percentage)

Category code	Product category	Average charge (kg)	Leak rates (%)		Av. Lifespan (Yrs)	EOL (%)
			HCFCs	HFCs		
STATIONARY AIR CONDITIONING						
AC1	Single split: non-ducted: 1 & 3 phase	1.7	8.0%	4.0%	12	80%
AC2	Single split: ducted: 1 & 3 phase	4.7	8.0%	4.0%	12	80%
AC3	Non-ducted: unitary 0-10 kW _r	0.75	4.0%	3.0%	10	80%
AC4	Portable AC 0-10 kW _r	0.6	1.0%	1.0%	7	90%
AC5-1	<500 kW _r	60	8.0%	6.0%	15	80%
AC5-2	>500 & <1000 kW _r	210	8.0%	6.0%	20	80%
AC5-2	>500 & <1000 kW _r (HFC-123)	180	1.0%	n.a.	20	80%
AC5-3	>1000 kW _r	620	8.0%	6.0%	25	80%
AC5-3	>1000 kW _r (HFC-123)	670	1.0%	n.a.	25	80%
AC6-1	RT Packaged systems	12.2	8.0%	4.0%	15	80%
AC6-2	Multi split/VRF	8.0	8.0%	4.0%	15	80%
AC6-3	Close control	30.0	8.0%	5.0%	15	80%
AC6-4	HW heat pump: commercial	110.0	8.0%	5.0%	20	80%
AC6-5	Pool heat pump	2.8	8.0%	5.0%	15	80%
AC7	HW heat pump: domestic	0.9	3.0%	3.0%	10	80%
MOBILE AIR CONDITIONING			Crash	HFCs		
MAC1-1	Passenger vehicles	0.61	1.5%	10.0%	-	60%
MAC1-2	Light commercial vehicles	0.61	1.5%	10.0%	-	60%
MAC2-1	Rigid truck and other	1.00	1.0%	10.0%	-	60%
MAC2-2	Truck: articulated	1.00	1.0%	10.0%	-	60%
MAC2-3	Commuter buses	1.00	1.0%	10.0%	-	60%
MAC2-4	Buses (> 7m)	9.00	1.0%	12.0%	-	60%
MAC3-1	Passenger rail	7.00	-	12.0%	10	60%
MAC3-2	Locomotive	4.00	-	12.0%	10	60%
MAC4	Off-road, defence and other (boat, etc.)	2.75	-	12.0%	15	60%

DOMESTIC REFRIGERATION						
DR1	Domestic refrigerators & freezers	0.140	n.a.	1%	-	80%
DR2	Portable and vehicle refrigerators	0.06	n.a.	1%	8	90%
REFRIGERATED COLD FOOD CHAIN						
RCFC1-1	Refrigeration cabinets	2.00	10.0%	7.0%	15	80%
RCFC1-2	Refrigeration beverage vending machines	0.25	5.0%	2.0%	12	80%
RCFC1-3	Ice makers	0.7	4.0%	3.0%	10	80%
RCFC1-4-1	Walk-in coolrooms: mini	1.0	20.0%	17.5%	12	70%
RCFC1-4-2	Walk-in coolrooms: small	5.0	20.0%	17.5%	12	90%
RCFC1-5	Walk-in coolrooms: medium	17.0	20.0%	17.5%	12	70%
RCFC1-6	Walk-in coolrooms: large	23.0	20.0%	17.5%	15	70%
RCFC1-7	Beverage cooling (post mix)	1.60	8.0%	5.0%	8	80%
RCFC1-8	Beverage cooling (beer)	40.0	17.5%	15.0%	15	70%
RCFC1-9	Water dispensers (incl. bottle)	0.05	2.0%	1.0%	8	80%
RCFC1-10	Packaged liquid chillers	60.0	12.5%	10.0%	15	70%
RCFC1-11	Milk vat refrigeration	40.0	25.0%	15.0%	20	70%
RCFC1-12	Portable refrigerators (commercial)	0.355	2.0%	1.0%	14	80%
RCFC2-1	Mobile refrigeration: road: trailer - inter-modal	10.0	25.0%	20.0%	10	70%
RCFC2-2	Mobile refrigeration: road: diesel drive	7.0	25.0%	20.0%	10	70%
RCFC2-3	Mobile refrigeration: road: off engine	4.0	25.0%	20.0%	10	70%
RCFC2-4	Mobile refrigeration: marine	130.0	35.0%	25.0%	25	70%
RCFC3-1	Supermarket refrigeration: small	160.0	20.0%	15.0%	15	70%
RCFC3-2	Supermarket refrigeration: medium	600.0	15.0%	12.0%	12	70%
RCFC3-3	Supermarket refrigeration: large	900.0	15.0%	12.0%	12	70%
RCFC4	Process and large kitchens	160.0	20.0%	15.0%	15	70%
RCFC5-1	Cold storage and distribution	80.0	15.0%	15.0%	15	70%
RCFC5-2	Process chilling	2.00	10.0%	7.0%	15	80%

The technical understanding of the product categories listed in *Table 40* has evolved over a series of research papers in this area. In the course of various projects all available research in this area was reviewed to build a database of findings and observations of leak rates by other researchers.

Further, a great deal of work was undertaken by the authors in the course of several projects to reconcile consumption of bulk refrigerant gas imports for all major refrigerant species, with all possible end uses of the gas to deduce the total volume of gas required to replace lost gas across the Australian economy.

This top down assessment of bulk gas consumed servicing equipment, when applied to what is known about the stock of equipment, produced results that were remarkably similar to leak rates observed in the field on individual classes of equipment.

The annual leak rate referred to in this report is expressed as a percentage of the initial charge per annum, and is calculated as:

- The sum of gradual leaks during normal operation; plus,
- Catastrophic losses amortised over the life of the equipment; plus,
- Losses during service and maintenance.

In the case of mobile air conditioning equipment, the annual leak rate takes into account losses from vehicle crashes, which are classed as catastrophic losses.

The actual leak rates of different equipment categories vary 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.

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

- *A study into the HFC Consumption in Australia* prepared by the Expert Group for DSEWPaC, Ozone and Synthetic Gas Team, 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 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, Ozone and Synthetic Gas Team, 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.

When considering average economy wide leak rates it is important to recognise that they generally reduce over time. As older equipment retires and is replaced with new designs that employ improved containment, leak rates of the new equipment are generally found to be lower. The evolution of wall hung and ducted split air conditioning equipment demonstrates this evolution in improved design and manufacturing capability, and global economies of scale. This is why older generation equipment containing HCFC-22 have higher leak rates, in the order of 8 per cent per annum, versus current generation models with leak rates of around 4 per cent per annum or less. Reconciling the total service consumption for the existing stock of equipment for each refrigerant type, with bulk imports after deducting consumption for local manufacture, confirms the validity of the leak rates used.

In addition as field practices improve, and as the cost of the refrigerant increases, for instance as the supply of HCFC-22 is restricted, leak rates decline and can do so very rapidly. The Australian supermarket industry is a good example where leak rates at the beginning of the century were thought to be above 20 per cent per annum, and hence the use of a leak rate of 23 per cent in the NGERs Act 2007. Whereas current market intelligence and reconciling consumption shows leak rates of HFC-404A less than half this value within the main supermarket chains.

Other research used to inform these 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.

The average charges listed in *Table 40* are derived from a combination of sources including statistical analysis of pre-charged equipment import data (DSEWPaC 2013), and from supplier data sheets (i.e. averages of most common products by capacity by brand), and other industry design rules of thumb (i.e. commercial refrigeration with remote condensers has twice the pump-down capacity of the liquid receiver for commonly sold models).

Average equipment lifespans were mostly used for calculating end-of-life emissions, except when sufficient historical data was available to develop a detailed retirement function.

The end-of-life factors are generally consistent with others cited internationally (e.g. ICF 2010) and in good practice guides by the IPCC.

Table 41: 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 – Residential	0%
Multi Splits - Commercial	100%
Multi Splits	53%
Close control air conditioning	100%
HW heat pump: commercial	100%

1. The proportion of commercial use is used to dissect residential and commercial use to calculate overall energy spend as they have different tariffs.

Appendix C: End-use applications for RAC systems

The following list is a representative list of all of the applications where RAC systems are found across the Australian economy as opposed to the various product and equipment categories captured in this study.

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

Residential/domestic technology:

- High density multiple dwelling
- Semi-detached and Houses
- Domestic refrigeration

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:

- Passenger vehicle air conditioning
- 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)
- Aqua culture & wild caught seafood
- Food transport and distribution centres
- Retail display
- Supermarkets
- Pharmaceuticals

Process chillers & industrial refrigeration:


- Brewing and winemaking
- Dairy industry
- Milk harvesting and storage
- Milk processing
- Cream 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

- 
- Liquifaction and cryogenics

Power generation industry:

- Mobile plant

Other applications:

- Water coolers
- Heat pump pool heaters

Appendix D: The stock of equipment

Category code	Segment	Product category	Total (units)
AC1	Single split: non-ducted	Single split: non-ducted: 1 & 3 phase	7,145,000
AC2	Single split: ducted	Single split: non-ducted: 1 & 3 phase	1,304,000
AC3	Window/wall	Non-Ducted: Unitary 0-10 kW _r	1,915,000
AC4	Portable AC	Portable AC 0-10 kW _r	606,000
AC5-1	Chillers	<500 kW _r	20,200
AC5-2	Chillers	>500 & <1000 kW _r	7,200
AC5-3	Chillers	>1000 kW _r	1,100
AC6-1	Light commercial	RT Packaged systems	70,000
AC6-2	Light commercial	Multi split/VRF	276,000
AC6-3	Light commercial	Close control	11,500
AC6-4	Light commercial	HW heat pump: commercial	1,000
AC6-5	Light commercial	Pool heat pump	28,000
AC7	HW Heatpumps	HW heat pump: domestic	170,000
AC	Total stationary AC		11,555,000
Category code	Segment	Product category	Total (units)
MAC1	Registered vehicles <3.5 GMV	Passenger vehicles	12,079,000
MAC1	Registered vehicles <3.5 GMV	Light commercial vehicles	2,487,000
MAC2	Registered vehicles ≥3.5 GMV	Rigid truck and other	422,000
MAC2	Registered vehicles ≥3.5 GMV	Truck: articulated	88,000
MAC2	Registered vehicles ≥3.5 GMV	Commuter buses	68,600
MAC2	Registered vehicles ≥3.5 GMV	Buses (> 7m)	22,000
MAC3	Rail	Passenger rail	6,800
MAC3	Rail	Locomotive	1,900
MAC4	Vehicles: other	Off-road, defence and other (boat, etc.)	32,800
AC	Total mobile AC		15,208,000

Category code	Segment	Product category	Total (units)
DR1	Refrigerators and freezers	Domestic refrigerators and freezers	16,649,000
DR2	Portable refrigeration	Portable and vehicle refrigeration	500,000
DR	Total domestic refrigeration		17,149,000
Category code	Segment	Product category	Total (units)
RCFC1-1	Unitary equipment	Refrigeration cabinets	447,000
RCFC1-2	Unitary equipment	Refrigeration beverage vending machines	134,000
RCFC1-3	Unitary equipment	Ice makers	66,000
RCFC1-4	Unitary equipment	Walk-in coolrooms: small	65,700
RCFC1-5	Unitary equipment	Walk-in coolrooms: medium	20,200
RCFC1-6	Unitary equipment	Walk-in coolrooms: large	12,200
RCFC1-7	Unitary equipment	Beverage cooling (post mix)	37,000
RCFC1-8	Unitary equipment	Beverage cooling (beer)	12,200
RCFC1-9	Unitary equipment	Water dispensers (incl. bottle)	235,000
RCFC1-10	Unitary equipment	Packaged liquid chillers	10,000
RCFC1-11	Unitary equipment	Milk vat refrigeration	6,800
RCFC1-12	Unitary equipment	Portable refrigerators (commercial)	5,000
RCFC2-1	Transport refrigeration	Mobile refrigeration: road: trailer - inter-modal	6,300
RCFC2-2	Transport refrigeration	Mobile refrigeration: road: diesel drive	5,000
RCFC2-3	Transport refrigeration	Mobile refrigeration: road: off engine	17,600
RCFC2-4	Transport refrigeration	Mobile refrigeration: marine	420
RCFC3-1	Supermarkets	Supermarket refrigeration: small	2,048
RCFC3-2	Supermarkets	Supermarket refrigeration: medium	985
RCFC3-3	Supermarkets	Supermarket refrigeration: large	333
RCFC4	Hospital refrigeration	Process and large kitchens	120
RCFC5-1	Industrial refrigeration	Cold storage and distribution	12.2 Million m ³
RCFC	Total Refrigerated cold food chain		1,083,900

Appendix E: Business and employment types

Table 42: 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.)
Coolroom 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, sheetmetal, 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.)

Table 43: Occupations employed in the air conditioning and heating services industry class

ABS employment category (OCCP – Digit Level)	Number employed
Air conditioning and Refrigeration Mechanics	5,512
Plumbers	1,324
Electricians	815
Engineering Production Workers	790
Office Managers	414
General Clerks	410
Accounting Clerks	326
Construction Managers	311
Bookkeepers	226
Contract, Program and Project Administrators	220
Industrial, Mechanical and Production Engineers	193
Other Miscellaneous Labourers	190
Call or Contact Centre and Customer Service Managers	188
Receptionists	175
Architectural, Building and Surveying Technicians	166
Secretaries	154
Chief Executives and Managing Directors	151
Sales Representatives	146
Mechanical Engineering Draftspersons and Technicians	120
Sheetmetal Trades Workers	114
Inadequately described	108
Managers	98
Accountants	97
Building and Plumbing Labourers	95
Technicians and Trades Workers	94
Advertising, Public Relations and Sales Managers	93
Electrotechnology and Telecommunications Trades Workers	92
Engineering Managers	80
General Managers	76
Insulation and Home Improvement Installers	76
Storepersons	71
Product Assemblers	65
Purchasing and Supply Logistics Clerks	63
Sales Assistants (General)	63
Structural Steel and Welding Trades Workers	62
Finance Managers	59
Specialist Managers	55
Retail Managers	55
Keyboard Operators	55
Labourers	54
Structural Steel Construction Workers	54
Production Managers	47
Engineering Professionals	45
Metal Engineering Process Workers	45
Payroll Clerks	43
Metal Fitters and Machinists	40
Human Resource Managers	36
Manufacturers	35
Other Hospitality, Retail and Service Managers	35
Carpenters and Joiners	35
Technical Sales Representatives	31
Other Specialist Managers	29
Inquiry Clerks	25

Personal Assistants	24
Other Construction and Mining Labourers	24
Advertising and Marketing Professionals	22
Occupational and Environmental Health Professionals	22
Civil Engineering Professionals	21
Filing and Registry Clerks	21
Not stated	21
Electronics Trades Workers	20
Machine Operators	19
Truck Drivers	19
Supply and Distribution Managers	16
Building and Engineering Technicians	16
Electrical Engineering Draftspersons and Technicians	16
Motor Mechanics	16
ICT Managers	15
Forklift Drivers	15
Commercial Cleaners	15
Factory Process Workers	15
Human Resource Clerks	13
Corporate Services Managers	11
Construction, Distribution and Production Managers	11
Importers, Exporters and Wholesalers	11
Machine and Stationary Plant Operators	10
Business Administration Managers	9
Human Resource Professionals	9
Automotive and Engineering Trades Workers	9
Other Clerical and Office Support Workers	9
Transport and Despatch Clerks	9
Construction and Mining Labourers	9
Other Information and Organisation Professionals	8
Other Miscellaneous Technicians and Trades Workers	8
Call or Contact Centre Workers	8
Product Quality Controllers	8
Handypersons	8
ICT Support Technicians	7
Construction Trades Workers	7
Sales Assistants and Salespersons	7
Research and Development Managers	6
Electrical Engineers	6
Software and Applications Programmers	6
Electronics and Telecommunications Trades Workers	5
Debt Collectors	5
Other Miscellaneous Clerical and Administrative Workers	5
Delivery Drivers	5
Auditors, Company Secretaries and Corporate Treasurers	4
Architects, Designers, Planners and Surveyors	4
Other Engineering Professionals	4
ICT Business and Systems Analysts	4
Computer Network Professionals	4
Clerical and Administrative Workers	4
Logistics Clerks	4
Sales Workers	4
Motor Vehicle and Vehicle Parts Salespersons	4
Retail Supervisors	4
Other Sales Assistants and Salespersons	4
Telemarketers	4
Textile and Footwear Production Machine Operators	4

Other Stationary Plant Operators	4
Cleaners and Laundry Workers	4
Miscellaneous Factory Process Workers	4
Livestock Farmers	3
Commissioned Officers (Management)	3
Hospitality, Retail and Service Managers	3
Transport Services Managers	3
Professionals	3
Public Relations Professionals	3
ICT Professionals	3
Database and Systems Administrators, and ICT Security Specialists	3
Engineering, ICT and Science Technicians	3
Science Technicians	3
Other Building and Engineering Technicians	3
Mechanical Engineering Trades Workers	3
Painting Trades Workers	3
Child Carers	3
Real Estate Sales Agents	3
Plastics and Rubber Production Machine Operators	3
Domestic Cleaners	3
Housekeepers	3
Other Cleaners	3
Total	14,623

(Source: Census 2011)

Table 44: Industries employing air conditioning and refrigeration mechanics

ABS employment category (OCCP – Digit Level)	Number employed
Agriculture, Forestry and Fishing	9
Mining	130
Manufacturing	1,407
Electricity, Gas, Water and Waste Services	15
Construction	6,477
Wholesale Trade	217
Retail Trade	575
Accommodation and Food Services	113
Transport, Postal and Warehousing	178
Information Media and Telecommunications	3
Financial and Insurance Services	8
Rental, Hiring and Real Estate Services	71
Professional, Scientific and Technical Services	116
Administrative and Support Services	211
Public Administration and Safety	56
Education and Training	80
Health Care and Social Assistance	95
Arts and Recreation Services	12
Other Services	7,192
Inadequately described	447
Not stated	81
Total	17,493

(Source: Census 2011)

Table 45: Apprentice commencements and completions

Status	2006	2007	2008	2009	2010	2011
Commencements	1,067	1,009	1,010	901	1,159	972
Completions	316	416	517	539	596	576

ABS employment category – 3421 Air conditioning and refrigeration mechanics