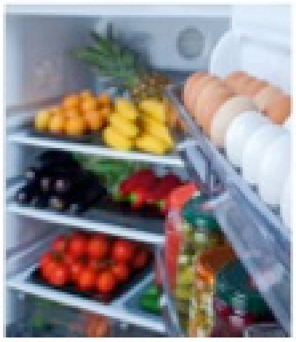
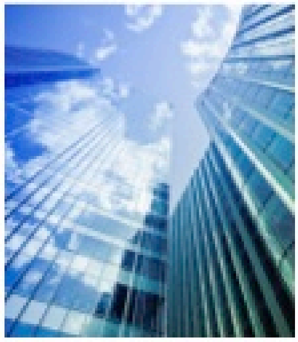
Hydrofluorocarbon Consumption in New Zealand





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Companies

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Arandee Industries

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BOC

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CRL Energy

Daikin

EcoChill

Fonterra

Foodstuffs

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Heatcraft

McAlpine Hussmann

Pan Pacific Auto Electronics Limited

Patton Limited

Polymer Group Limited

Rheem NZ and Solar Hart (division of Rheem)

Skope Industries

Smardt Powerpax

Temperzone

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1 Executive summary

This report investigates consumption of hydrofluorocarbons (HFCs) in New Zealand, and makes projections of demand for HFCs across all the major applications out to 2030.

Conclusions about the volumes of HFCs and hydrochlorofluorocarbons (HCFCs) employed in New Zealand, and the annual consumption of HFCs required to service the bank of working gas, are based on the outputs of a complex stock model of all refrigeration and air conditioning applications in New Zealand that has been constructed for this study.

That model calculates that a working bank of approximately 7,000 metric tonnes of HFCs, HCFCs and chlorofluorocarbons (CFCs) are presently employed delivering air conditioning and refrigeration services in the New Zealand economy.

More than 49% of the bank (3,400 tonnes) is employed in stationary air conditioning, and 29% (2,040 tonnes) in mobile air conditioning. A further 17% of that bank (1,200 tonnes) is used in the extensive cold food chain through which farm produce passes from field to plate, and to distribution points for export by air and sea. Just 5% of the bank is found in domestic refrigeration in New Zealand's home and businesses.

The stock model indicates that more than 640 tonnes of HCFCs are still employed in equipment in New Zealand, primarily HCFC-22 in stationary air conditioning and commercial refrigeration systems, with smaller quantities of HCFC blends also found in commercial refrigeration. It is also estimated the bank of equipment contains as much as 50 tonnes of CFCs in older vehicles, domestic refrigerators and commercial equipment.

In aggregate, the model calculates that the entire stock of equipment loses some 486 tonnes of HFC refrigerants to atmosphere per annum - this includes gas lost from leaks, during equipment servicing, or as a result of catastrophic failures of critical components, such as occurs in car crashes.

Net imports of bulk HFCs average around 530 tonnes per annum. There is an estimated 68 tonnes of bulk gas imported each year on average, that is later re-exported in smaller bulk gas containers to service equipment in Pacific Island nations, or that leaves the country after being used to service systems in visiting international shipping, or to service refrigerated shipping containers, known as reefers. Re-export is predicted to be greater in 2017.

A relatively small quantity of bulk imported HFCs is consumed every year in the manufacture of insulating foams (~15 tonnes), although this consumption does not add to the bank.

A tiny fraction of annual imports is used servicing existing fire suppression systems, or constructing new ones (~4 tonnes).

Approximately 156 tonnes of annual bulk HFC imports are used to charge new equipment that is manufactured in New Zealand, or to charge equipment that is imported without refrigerant gas in place and is charged when it is installed, or is used in equipment that is retro-fitted with a replacement refrigerant.

These well-established uses of HFCs indicate that the average annual volume of gas used to replace gas lost via leaks and equipment failures is in the order of 355 tonnes per annum, despite calculated HFC leaks being 468 tonnes. This indicates underservicing of some of the stock of equipment. Industry advice is that mobile air conditioning systems in cars in New Zealand are often not serviced, are let fail and are not repaired.

This conclusion is supported by the observation that service and repair of car air conditioning systems is relatively expensive in New Zealand. While it is not possible to definitively say that it is only mobile air conditioning that is underserviced, what is known about the mobile air conditioning market suggests that underservicing and not repairing car air conditioning is likely to be the primary reason for the difference between total leaks and bulk gas imports available for servicing.

On the basis that service consumption of HFCs is 355 tonnes per annum, and assuming that other classes of equipment such as stationary air conditioning, and commercial refrigeration are properly serviced, this suggests that a little less than half of the calculated leaks from mobile air conditioning are replaced every year.

The working bank of HFCs grew by approximately 4% (260 tonnes) in 2016. The bank grows via two sources of new HFCs entering the economy. Some 425 tonnes were added to the bank in 2016 contained in new, pre-charged equipment that is imported and added to the total stock of equipment, although this is offset by equipment leaving service, and refrigerant recovered from end of life equipment and destroyed. There is also additional growth in the bank from some part of the 156 tonnes noted above, that is used in new equipment that then stays in New Zealand, as some of the locally manufactured equipment is exported.

The working bank of HFCs in the New Zealand economy is equivalent to 13.6 million tonnes of carbon dioxide (CO_2). Total estimated losses to air of all synthetic greenhouse gases in 2016, including HFCs, HCFCs, and CFCs of 536 metric tonnes is calculated as being equivalent to as much as 1.1 million tonnes of CO_2.

In the year ended on March 31 2017, approximately 35 tonnes of refrigerant gases of all types were reported to be recovered and destroyed by Refrigerant Recovery New Zealand (RRNZ). More than 80% of those gases recovered and destroyed are HFCs. In the 23 years since its inception RRNZ has collected and destroyed about 385 tonnes of refrigerant gases. This has significantly reduced emissions of ozone depleting substances (with an equivalent global warming potential of 455 kt CO_2, based on AR4 GWP-100 calculations), and has also avoided the equivalent of 450 kt CO_2-e of HFCs from being released into the atmosphere.[1]

Sector by sector commentary is provided in the body of the report identifying what are thought to be the most likely outcomes for the main HFC application areas by 2030.

This report on HFC use, and the associated stock model of HFC end use applications in the New Zealand economy, has been prepared using a variety of data including, data compiled by CRL Energy (MfE 2017) [2] referred to as the Kigali MoP estimate; Reclaim Levy data (RT 2017) [3]; data on equipment imports collected by the Energy Efficiency and Conservation Authority (EECA)[4], New Zealand Environmental Protection Authority (EPA) data, and from interviews conducted with industry participants.

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[1] Report of the Corporate Trustee – Year ended 31 March 2017, Recovery Trust for the Destruction of Synthetic Refrigerants, 2017 (RT 2017a). Please note, the GWP equivalent of Ozone Depleting Substances is not covered by in the Kigali Agreement under the Montreal Protocol.

[2] Calculations from the New Zealand Hydrofluorocarbon Inventory in relation to the Kigali Amendment 2016 to the Montreal Protocol, prepared by CRL Energy Ltd for the New Zealand, Ministry for the Environment, 2017 (MfE 2017).

[3] Levies Received: April 2013 to March 2017, Recovery Trust for the Destruction of Synthetic Refrigerants, 2017 (RT 2017b).

[4] Synthetic Greenhouse Gas, Aggregated Bulk Import and Export Data, Environmental Protection Authority, 2013 to 2016 (EPA 2017).

2 Introduction

Hydrofluorocarbons (HFCs) are a group of synthetic greenhouse gases (SGGs). The global warming potential (GWP) of the most widely used HFC gases varies from a GWP 675, in the case of HFC-32, to a GWP of 14,800 in the worst case of HFC-23 used in some types of fire suppression systems and older generation refrigerated shipping containers.

HFCs are used primarily as working gases in refrigeration and air conditioning equipment (RAC). HFCs were widely marketed starting in the mid-1990s as a replacement for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), both of which are very long-lived ozone depleting substances.

HFCs also replaced CFCs and HCFCs in the production of insulating foams, and can be used as fire extinguishing agents, and in aerosols, solvents and medical aerosol applications.

The production and use of CFCs have been phased out entirely, although some older refrigerators and car air conditioning systems may still be found that contains them. HCFCs are now in the last stages of being phased down to a small fraction of the demand that, at its height in the late 1990s to early 2000s, saw HCFCs dominate as the refrigerant gas of choice for nearly 20 years.

Both the CFC and HCFC phase outs have been managed under the international timetables set out in the Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol).

While the international community has been very successful in replacing the ozone depleting CFCs and HCFCs, as a result of growing global demand for air conditioning and refrigeration services it has been calculated by some parties that without action to stem HFC use, HFCs could be the source of as much as 19% of increases in global warming by 2050 due to their high GWPs.

With the settlement of the Kigali Amendment to the Montreal Protocol in October 2016, national governments, international bodies and the suppliers of HFCs, have negotiated the inclusion of HFCs into the Montreal Protocol as the instrument that will be used to manage a global phase down of HFCs.

It is estimated that the Kigali phase down of HFCs under the Montreal Protocol would avoid aggregate emissions of more than 90 Giga tonnes CO_2-e by 2050 – equivalent to two years of total global greenhouse gas emissions (US EPA 2016).

Implementation of the Kigali Amendment in New Zealand would require New Zealand to begin phasing down HFCs in 2019, and reduce HFC consumption by 85 per cent by 2036. At the same time, demand for the services presently provided by HFCs is expected to steadily rise.

For the majority of current uses of the high GWP HFCs, viable low, or zero GWP refrigerants are either available now, or are being readied for commercial release within one to three years.

This is the case for the majority of refrigeration and air conditioning applications in the market, and for smaller applications of the chemicals, such as in fire suppression systems, foam blowing, aerosols and other medical and industrial uses.

A number of international technological trends already underway, such as the EU requirements for all new vehicle air conditioning to employ refrigerant gas with GWP <150 by 2016, mean that some low GWP alternatives to HFCs are already being introduced to the market that should steadily reduce the CO_2 equivalent value of New Zealand's annual HFC consumption over time.

There are a few very demanding applications, such as in small commercial fishing vessels that are typical of the New Zealand fishing fleet, where no obvious options are available for replacement of the high GWP refrigerants used. Engineering work and technical developments are needed to be able to deliver the refrigeration services required on fishing vessels with lower GWP gases.

International chemical manufacturers, who presently supply HFCs, have been working on alternative substances for several years and there are now a range of alternatives commercially available, or expected to be available in the next few years. Many of the new gases, such as the Hydrofluoro-olefins (HFOs), are mildly flammable, presenting potential problems for workplace identification, handling and management practices.

The rate at which economically viable alternative gases can be brought to market for all of the many applications for HFCs has implications for the HVAC&R supply chain, including consumers and the wider economy, of the transition away from HFCs.

An important consideration for the HVAC&R industry in planning for the HFC phase down is the diversification of refrigerant gases that will be employed. This diversification includes, importantly, the introduction of mildly-flammable, low GWP HFOs. Slightly flammable gas charges will inevitably be employed across a wider range of applications. Technicians need to be able to identify and work with potentially many novel blends of low GWP HFCs. More than 50 new blends are reportedly being tested.

This significant investment by the international chemical companies in new refrigerants, and the recent commercial release of low GWP options for a number of applications, is expected to provide many pathways for migration of air conditioning and refrigeration services to lower GWP gases.

The Expert Group stock model of RAC equipment in the New Zealand economy provides a starting point on which to prepare projections of changes in the size and make-up of the bank of refrigerant gases in the New Zealand economy.

2.1 *Notes on Reporting of HCFCs and CFCs*

While the purpose of this report is to calculate total HFC consumption in New Zealand, there are significant tonnages of the previous generation of gases, HCFCs, and a smaller quantity of CFCs, still employed in equipment in New Zealand. Throughout this report where we refer to the 'bank' of working gases, we will often include what is known about these earlier generations of gases, as the services they presently deliver will eventually have to be delivered by some other gas.

However in reference to annual consumption of bulk refrigerant gas this study only reports the annual consumption of HFCs. Where HCFCs are being used to service equipment in New Zealand, the gas has mostly been recovered and reconditioned, or possibly sourced from existing small stocks remaining on shore in the country. As such, the bank of HCFCs in New Zealand is not increasing, and there are no imports of HCFCs, either as bulk gases or in pre-charged equipment.

2.2 *Notes on Global Warming Potential (GWP) of Refrigerant Gases*

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

New Zealand's emission obligations under the Kyoto Protocol, which was originally negotiated in 1997, were calculated based on GWP values published in the Second Assessment Report (AR2) of the International Panel on Climate Change (IPCC) released in 1996. As such, since that time, industry participants will have become very familiar with the AR2 values.

However, after 10 years of further scientific analysis, revised GWP values were published in the Fourth Assessment Report of the IPCC (AR4) in 2007, and many of the GWP values of refrigerant gases changed. For instance, the GWP of HFC-134a changed from 1300 under the AR2 to 1430 under the AR4.

Because of the duration of the first commitment period of the Kyoto Protocol under the United Nations Framework Convention on Climate Change (UNFCCC), the AR4 values were not widely used until after 2013. In the post-2013 negotiations among the parties to the Montreal Protocol, which led to the Kigali Amendment, AR4 values were used, and the Kigali Amendment incorporates AR4 values in calculating the GWP of various refrigerant gases.

The IPCC's Fifth Assessment Report (AR5) was published at the end of 2015, and included a further review of the GWP of substances already listed in the Fourth Assessment Report. AR5 also lists GWP values of various substances that had not previously been listed at all. For instance, HFC-161 (GWP 4), HFC 152 (GWP 16), HFC-236cb (GWP 1210) and HFC-236ea (GWP 1330), all appear for the first time in AR5.

As the Montreal Protocol, and the Kigali Amendment uses AR4 values, this report also uses AR4, other than where a substance is discussed for which no GWP was published in AR4, in which case AR5 values will be used, and referenced in the following manner: *HFC-161 (GWP 4: AR5)*.

The GWPs used by the EPA to calculate emissions for the Emissions Trading Scheme (ETS) are AR4 values slightly rounded. For example, the AR4 GWP for HFC-404A is 3922 whereas the ETS uses 3920. There are slight differences with the ETS GWPs used for HFC-407C, HFC-407F and HFC-410A, refer to *Appendix C* for further details.

2.3 *Model limits and policy*

The modelling completed for this report have not attempted to incorporate impacts of possible future policy changes. The modelling reports against an existing stock of equipment, bulk gas imports (that are already impacted by the current ETS settings), gas and equipment exports, and a range of well tested assumptions about the rate of change of the underlying technology and changes to gas types. However no changes to the ETS, including unit prices, are included in the model, nor are any possible impacts of any policy that may be put in place to give effect to NZ’s commitment to the HFC phase down.

3 Refrigerant bank and consumption

3.1 Dissection by major sector

In 2016 New Zealand employed an installed bank[5] of synthetic refrigerant gas, including HFCs, HCFCs and CFCs in all applications of approximately 7,000 tonnes.

Import data and market intelligence indicates around 530 tonnes of bulk HFCs were consumed in 2016, of which it is estimated that around two thirds are required to maintain the bank in the existing stock of equipment, equivalent to about 5.5% of the total bank of working gas. There are a further 68 tonnes that were imported into New Zealand and were then exported, and re-exports are predicted to be greater in 2017.

The bank of working gas in New Zealand is comprised of commonly used synthetic refrigerants with GWP values that range from 1430 for HFC-134a, up to 3922 for HFC-404A, and a relatively small quantity of refrigerants with GWP <10, such as ammonia, CO_2 and small amounts of hydrocarbon.

Excluding only gases with a GWP <10, in aggregate the GWP of the bank is calculated to be equivalent to approximately 13,600 kilo tonnes of CO_2-e (13.6 Mt CO_2-e) and the 2016 consumption of bulk imports was equivalent to 1,270 kilo tonnes of CO_2-e, (1.27 Mt CO_2-e) excluding 68 tonnes of re-exports.

The refrigerated cold food chain accounts for around 17% of the total refrigerant bank, with domestic refrigerators and freezers containing a further 5%. Thus, all refrigeration equipment, essential in the maintenance of food supplies and food quality, employs around 22% of the total bank.

Air conditioning for human comfort in homes and workplaces accounted for 49% of the bank and consumed approximately 29% (~152 tonnes including local manufacture) of the annual bulk imports. Stationary air conditioning applications dominate imports of pre-charged equipment.[6]

On average more than 100,000 new air conditioning units have been installed each year in New Zealand for the last 10 years, a level of demand which is fed by the expectations of householders, the workforce and consumers for air conditioning services to be ubiquitous in urban and city buildings in areas that enjoy a warm summer climate.

Mobile air conditioning comprised approximately 29% of the total bank in 2016. This gas is predominantly contained in a rolling stock of more than 3.55 million registered vehicles containing HFC-134a. An estimated 21% (~110 tonnes) of bulk imports were consumed in mobile air conditioning applications, which have an estimated effective service rate of 5% per annum including gas lost as a result of collision or compressor failure. The estimated service rate, is thought to be about 50% of the actual losses to air per annum from MAC however vehicle air conditioning in New Zealand is understood to be chronically underserviced.

Around 4% of bulk imports are consumed in applications that do not form part of the working bank such as foam blowing, fire protection and miscellaneous applications. Additionally, it is estimated around 68 tonnes is re-exported for servicing shipping vessels and reefers, and supplying wholesalers located in the Pacific Islands. Re-export is predicted to be greater in 2017.

Figure 1 below illustrates the dissection of the refrigerant bank for 2016 by major application in tonnes, and *Table 1* provides summary data of both the bank and calculated consumption by major application in tonnes and Mt CO_2-e.

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[5] *The 'bank' of refrigerant gases is the aggregate of all HFC, HCFC and CFC refrigerants, and natural refrigerants (excluding large capacity cold storage and process applications where ammonia is widely used as the transition away from HCFCs and HFCs is considered virtually complete) employed as working fluids in the estimated 8 million mechanical devices using the vapour compression cycle in New Zealand.*

[6] *'Pre-charged equipment' is defined as refrigeration or air conditioning equipment that contains a HFC or HCFC refrigerant when it leaves the factory gate.*

2016 bank by major sector (% of tonnes)

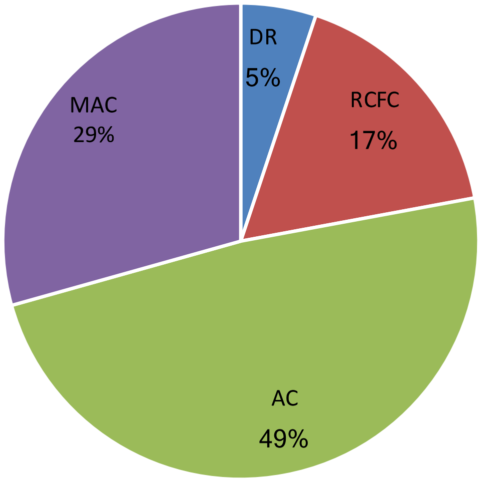

Figure 1: 2016 bank by major sector based on bottom-up analysis of equipment, % share of tonnes.

2016 bank by major sector (% of CO_2-e)

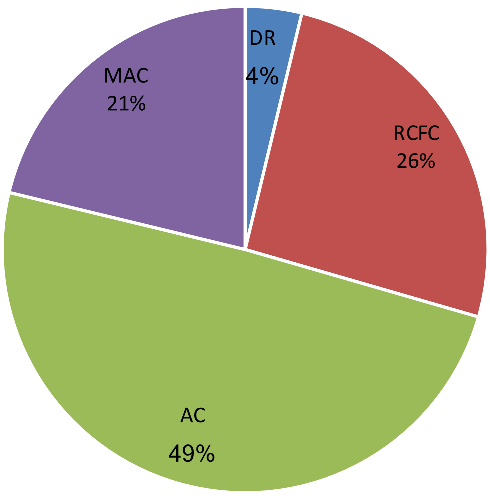

Figure 2: 2016 bank by major sector based on bottom-up analysis of equipment, % share of Mt CO_2-e.

Table 1: Estimates of 2016 gas consumption and refrigerant bank by major sector in tonnes and Mt CO_2-e.

Sector/applications	2016 HFC Consumption (tonnes/Mt CO_2-e)		2016 HFC/HCFC Bank (tonnes/Mt CO_2-e)	
Domestic refrigeration	4	0.01	360	0.5
Refrigerated Cold Food Chain	245	0.7	1,200	3.5
Stationary air conditioning	152	0.4	3,400	6.7
Mobile air conditioning	110	0.2	2,040	2.9
Foams	15	0.05	-	-
Fire protection	4	0.01	-	-
Aerosols	-	-	-	-
Total	530	1.3	7,000	13.6

Notes:

1. HCFCs are included in the refrigerant bank and excluded from the HFC consumption estimate.
2. Total use includes a further 68 tonnes exported that is predicted to be greater in 2017.
3. The numbers in the table above are rounded.

3.2 Dissection by common gas types

The bank of working gas is dominated by four main gases: HFC-134a (~2,900 tonnes or 41%), HFC-410A (~2,600 tonnes or), HFC-404A (~700 tonnes or 10%) and HCFCs (~640 tonnes or 11%) which is mostly HCFC-22.

HFC-134a is the predominant gas used in mobile air conditioning. An estimated 107 tonnes of bulk gas were consumed servicing existing mobile air conditioning systems plus replacing gas lost from vehicles that had some form of collision or compressor failure. HFC-134a has become more widely used in other applications in recent years including in large space chillers for air conditioning, and medium temperature non-domestic refrigeration.

The Montreal Protocol sets out a mandatory timetable for the phase out of ozone depleting substances (ODS). However, HCFCs, with a GWP of around 1810, still make up a significant portion of the bank of working gas in stationary air conditioning equipment, much of which can routinely achieve an effective working life of more than 15 years.

This bank of working HCFC will decrease quite quickly as newer equipment charged with alternative gases replaces older air conditioning equipment. With estimated stock of some 1,250,000 small and medium air conditioning units (<20 kWr[7]) in the economy, and slightly more than 150,000 of those being older machines still charged with HCFCs, and with average annual imports in the last few years of more than 100,000 units, some of which will be sold to replace older equipment that is retired from service, the majority of equipment containing HCFCs is expected to be replaced within the next five to ten years.

[7] *kWr refers to kilowatts of refrigeration capacity where as kW relates to kilowatts of electrical power.*

HFC-410A (a blend containing 50% HFC-32 and 50% HFC-125 with a GWP of 2088) was first introduced to New Zealand in commercial quantities in the early to mid-2000s, primarily for use in split air conditioning systems in medium size and light commercial applications.

Because of HFC-410A's previous dominance of this technology segment up until 2016, HFC-410A was the fastest growing refrigerant in the bank with more than 232 tonnes of gas imported in pre-charged equipment in 2016 (totalling more than 50% of all refrigerant imported in equipment and motor vehicles that year).

The main class of equipment containing HFC-410A is split air conditioning systems connected to one indoor evaporator unit. These units have an estimated leak rate of 3% per annum, which is a significant improvement on older equipment, mostly containing HCFC-22, which has leak rates typically 8% or more per annum. The improved leak rate is mostly attributed to the dominance of mass produced split air conditioning systems with more reliable components, and improved designs delivering better containment. Bulk gas consumption of HFC-410A in 2016 is estimated to be around 134 tonnes.

HFC-407C (a blend containing 23% HFC-32, 25% HFC-125 and 52% HFC-134a with a GWP of 1774) was introduced in New Zealand around the same time as HFC-410A for similar applications. HFC-407C was viewed by some local and overseas equipment manufacturers as an opportunity for a simple transition from HCFC-22, as it has similar operating pressures that can use the same components with minimal re-design.

The existing bank of HFC-407C is estimated to be around 170 tonnes with consumption in 2016 estimated to be 15 tonnes. Many stationary air conditioning equipment designs have migrated to HFC-410A or HFC-134a for larger chillers.

HFC-404A (a blend containing 44% HFC-125, 4% HFC-134a and 52% HFC-143a with a GWP of 3922) and HFC-507A, a similar blend in terms of composition, characteristics and applications are both referred to as HFC-404A in this report.

HFC-404A was commonly used in refrigeration applications from 1995 onward, when using CFCs in new equipment was banned. In 2016 the HFC-404A bank comprises around 700 tonnes or around 10% of the volume of the working bank, but closer to 20% in GWP terms because of its high GWP.

The consumption of HFC-404A is very high relative to the size of the bank (10% of the bank and 24% of consumption). This occurs firstly because new equipment containing HFC-404A is mostly charged on site. HFC-404A pre-charged equipment represented only 2% of pre-charged imports on average over the last three years, and secondly its common applications exhibit considerably higher leak rates than most other applications. Notably supermarket refrigeration systems, walk in cool rooms, beer cooling systems, and mobile refrigeration systems with typical leak rates ranging from 10% to 25%. In particularly hard working applications in hostile environments in the fishing fleet, leak rates as high as 35% are known to be reasonably common.

Figures 3 and *4* illustrate the dissection of the refrigerant bank for 2016 by common gas types based on tonnes and CO_2-e, and *Figures 5* and *6* provide a projection to 2030 in tonnes and Mt CO_2-e.

2016 Bank by gas type (% based on tonnes)

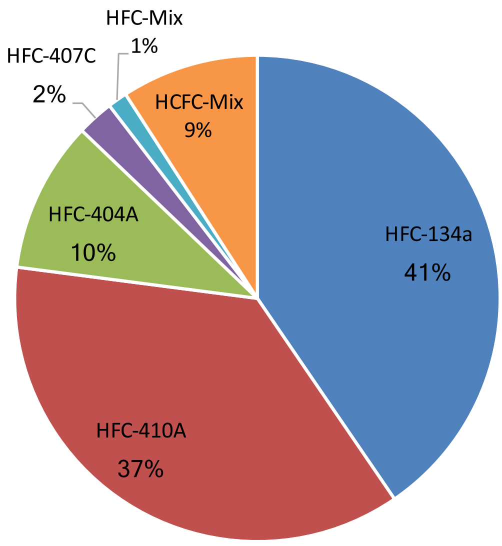

Figure 3: 2016 bank by substance based on bottom-up analysis of applications, % based on tonnes.

2016 Bank by gas type (% based on CO_2-e)

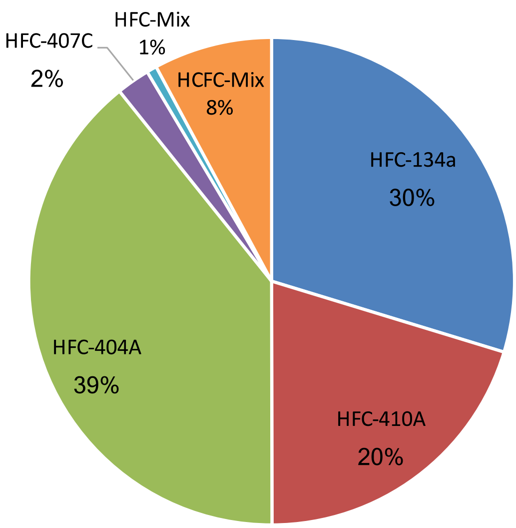

Figure 4: 2016 bank by substance based on bottom-up analysis of applications, % based on CO_2-e.

HCFC Bank and Consumption

There is an estimated 640 tonnes of HCFCs still employed in the New Zealand economy, mostly in large chillers, some air conditioning and commercial refrigeration applications, particularly in the dairy and fishing industries. This bank of HCFCs is largely serviced by recycling and reconditioning of HCFCs, and some remaining stock imported prior to 2015.

Given some equipment pre-charged with HCFCs may have been imported in the last five years, a tail of this activity could easily persist until as late as 2025. However, as HCFCs are inevitably lost to air, or collected and destroyed when it can no longer be reconditioned, all services currently provided by HCFCs, and all HCFC charged equipment will be replaced. Some of those services will be delivered by new equipment, some of which is likely to be HFC charged, adding to both the working bank of HFCs and future demand for HFCs.

For owners of large chillers charged with HCFCs, that are at the end of their useful life, there is a risk that if they purchase HFC charged replacement chillers, the new equipment will still be operational towards the tail end of the HFC phase down, when high GWP HFCs are likely to become increasingly expensive, just as HCFCs have become significantly more expensive in the last 5 years.

3.3 Refrigerant Bank Projections

The refrigerant bank projections illustrated in *Figures 5* and *6* are the aggregate of all banks in tonnes and Mt CO_2-e.

Bank Prediction from 2016 to 2030 (tonnes)

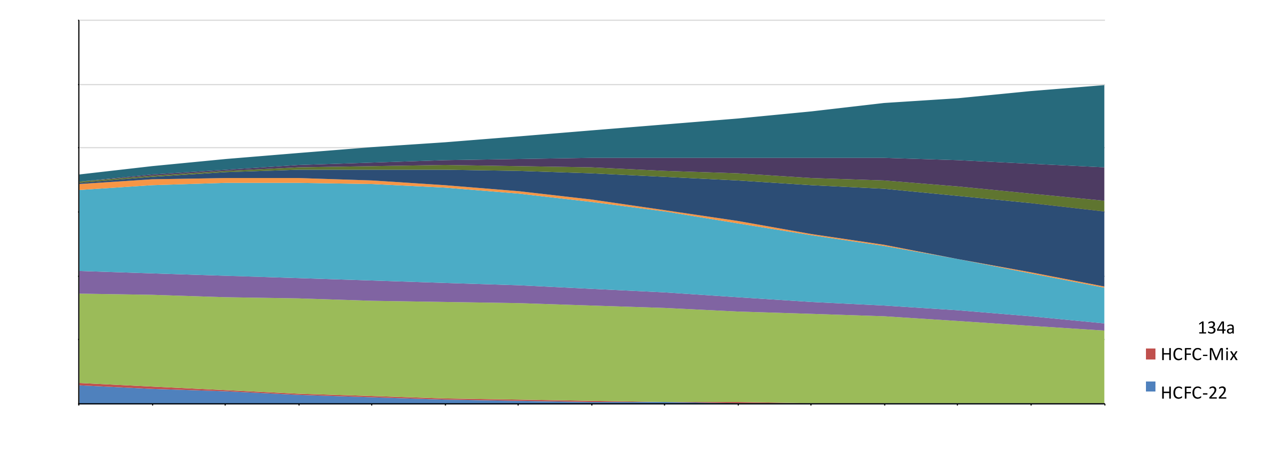

Figure 5: Refrigerant bank in tonnes from 2016 to 2030.

Bank Prediction from 2016 to 2030 (Mt CO_2-e)

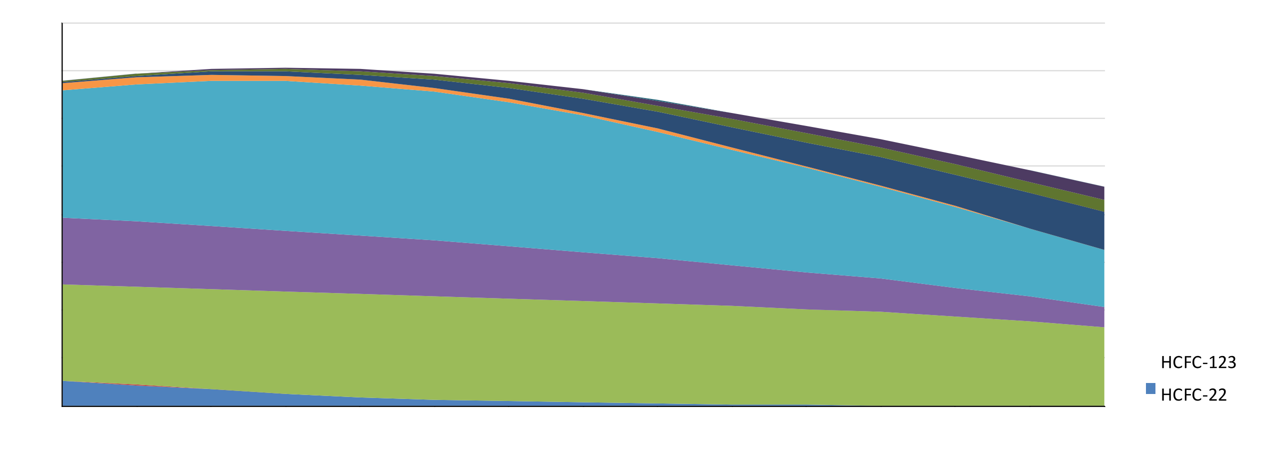

Figure 6: Refrigerant bank in Mt CO_2-e from 2016 to 2030.

Notes:

1. HCFCs are included in the chart of the refrigerant bank.

3.4 HFC Consumption Projections

The HFC consumption projections in *Figures 7* and *8* show the total consumption for the New Zealand economy in tonnes and Mt CO_2-e from 2016 to 2030. These projections include substances with a GWP<10 that are not HFCs for illustrative purposes.[8]

For example, the HFC consumption estimate is 530 tonnes, however the 2016 value of 550 tonnes in *Figure 7* includes 20 tonnes of substances with a GWP<10 that grow over time (illustrated by the dark green wedge). This wedge represents the energy service being substituted by natural refrigerants and HFOs. In *Figure 8* substances with a GWP<10 are no longer visible on the chart due to their very low GWP.

HFC Consumption projection from 2016 to 2030 (tonnes)

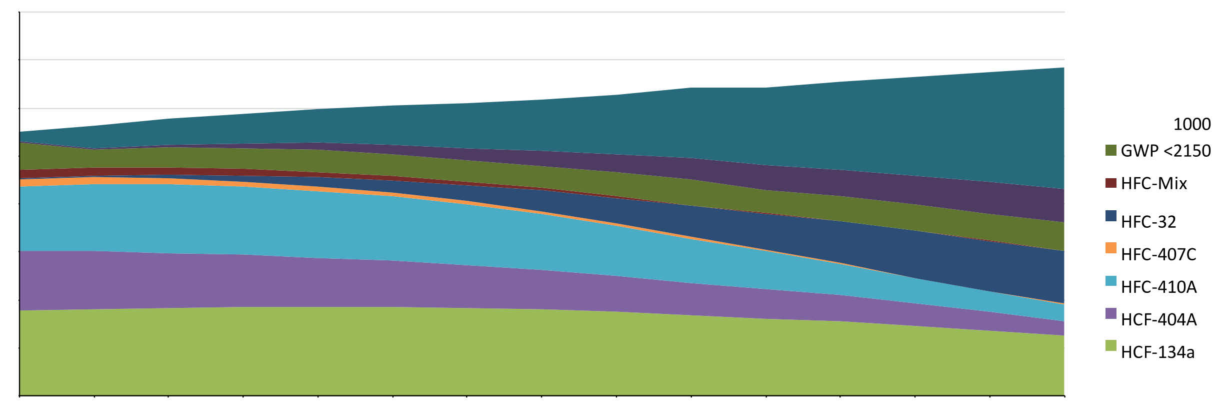

Figure 7: HFC Consumption projection in tonnes from 2016 to 2030.

HFC Consumption projection from 2016 to 2030 (Mt CO_2-e)

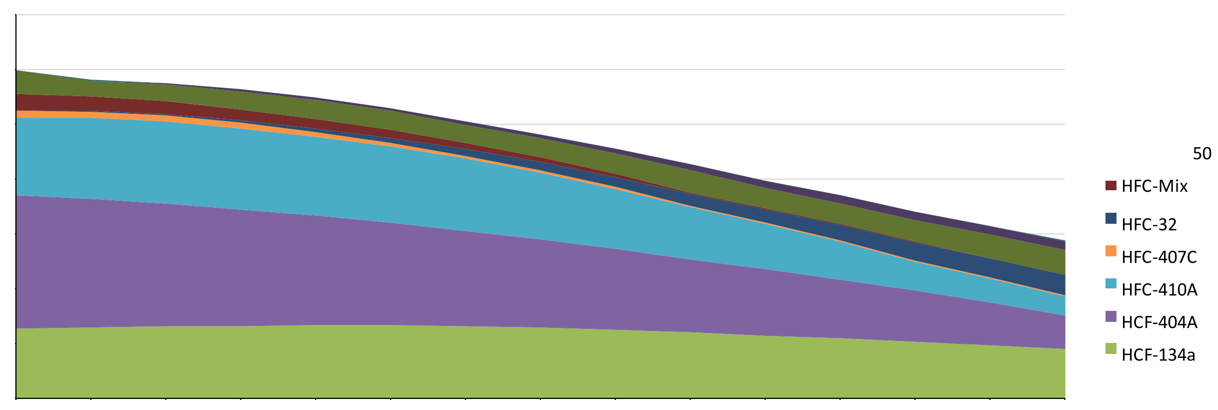

Figure 8: HFC Consumption projection in Mt CO_2-e from 2016 to 2030.

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[8] *Substances with a GWP<10 include natural refrigerants (i.e. CO_2, ammonia and hydrocarbon) and Hydrofluoro-olefins (HFOs), and are not controlled substances under the Montreal Protocol.*

Notes:

1. Refer Appendix B: Technical resources and assumptions for assumptions used in the study.
2. The consumption projection assumes the leak and service rates will remain fixed at the rates nominated in *Table 7: Technical characteristics for product categories (average charge, leak rates, lifespan, end-of-life percentage)* of Appendix B, except Supermarket systems where a compound improvement rate of 2% per annum is assumed. For example, an annual leak rate of 12.5% in 2016 would improve to a leak rate of 9.6% in 2030.
3. New sales mix assumptions are detailed in each section of the report, and the model.

3.5 *Pre-charged imports*

A significant quantity of HFCs enter the New Zealand economy every year in the form of imports of 'pre-charged equipment' (PCE). In 2016 more than 425 tonnes of HFCs were imported into New Zealand in PCE.

Of the almost half a million pieces of pre-charged equipment reported by the EPA in accordance with the Climate Change Response Act 2002, in the period from 1 July 2015 to 30 June 2016, there were more than 288,000 vehicles containing air conditioning (including larger vehicles such as buses) that introduced more than 174 tonnes of HFCs to the New Zealand economy.

While stationary air conditioning systems of all types resulted in the import of more than 232 tonnes of higher GWP HFCs of various types, this value does not include imports containing HFC-32 as the Climate Change Response Act 2002 did not require reporting of this gas. HFC-32 is regarded by the industry as a 'low GWP' gas, even though it has a GWP of 675. In the popular high wall split systems, HFC-32 charged systems could have made up as much as 50% of total imports over the last summer of 2016-17, which suggests the possibility of volumes of more than 60 tonnes of HFC-32 imported in equipment in 2016.[9]

The small balance of PCE imports in 2015-16 introduced a further 17 tonnes of HFCs in a range of equipment, including some 10 tonnes in commercial refrigerator imports, four tonnes in domestic refrigerators and 2.5 tonnes in de-humidifiers (i.e. around 16,000 units based on 150g per unit).

Figure 9 provides a summary of pre-charged imports from 1 July 2013 to 30 June 2016.

HFC Pre-charged imports by equipment type (tonnes)

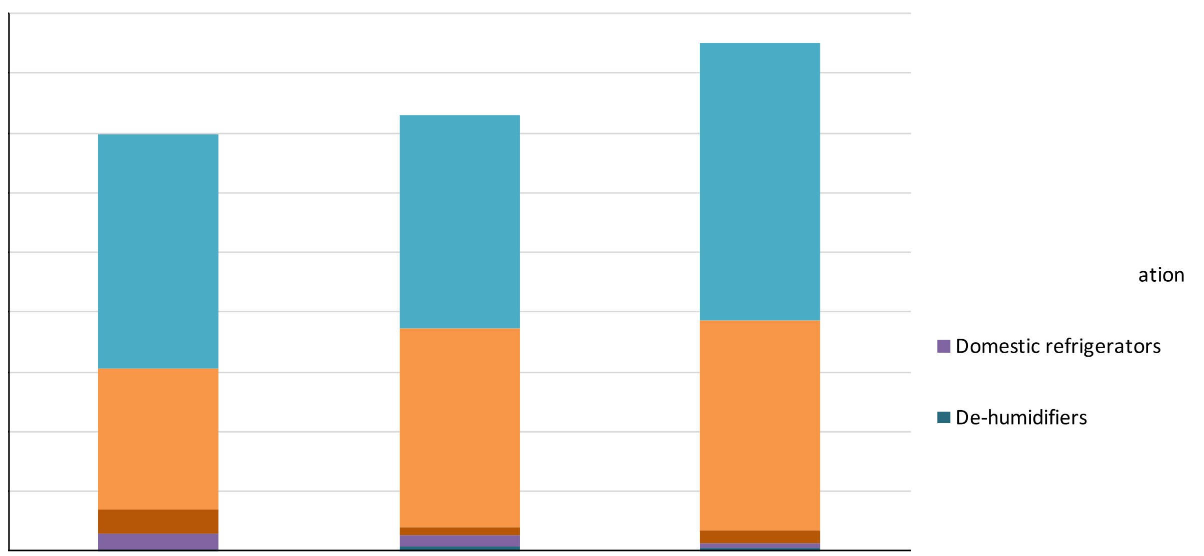


Figure 9: HFC Pre-charge imports by major equipment type in tonnes from July 2013 to 30 June 2016.

Notes:

1. Excludes pre-charged imports of stationary air conditioners containing HFC-32.

[9] *As a comparison, there were 434 tonnes of HFC-32 imported into Australia in split systems over a 12 month period from 1 April 2016 to 31 March 2017.*

4 New Zealand's HFC 2016 Consumption

In 2016 it is estimated that New Zealand's bulk HFC consumption was equivalent to approximately 1.3 Mt CO_2. This is calculated on the basis of an estimated 530 tonnes of virgin bulk gases being consumed in New Zealand in that year, as set out in *Table 2* below, plus around 68 tonnes that was imported and later re-exported.

Table 2: Estimates of HFC consumption in New Zealand in 2016 in tonnes and Mt CO_2-e.

Gas type	2016 Consumption Market estimate (tonnes/Mt CO_2-e)	
HFC-134a	177	0.25
HFC-404A (incl. 507A)	125	0.5
HFC-407F and other blends (3)	50	0.1
HFC-407C	15	0.03
HFC-410A	134	0.3
HFC-Mix (4)	29	0.1
Total	530	1.3

Notes:

1. The above consumption excludes around 68 tonnes of HFC exports.
2. The above consumption includes HFCs consumed by local Original Equipment Manufacturers (OEMs) as HFCs contained in equipment are accounted for in the country of manufacture. Hence the reason pre-charged equipment imports are not counted as New Zealand bulk imports.
3. Includes other blends such as HFC-438A, HFC-427A and HFC-458A.
4. HFC-Mix comprises HFC-227ea, HFC-365mfc, HFC-245fa and other HFCs not widely used.
5. The numbers in the table above are rounded, and the kt CO_2-e are calculated based on the rounded volumes in tonnes and uses a conservative GWP value of 3220 for HFC-Mix.

This estimate of annual consumption has been derived from a comparison of several sets of data including the Kigali Meeting of the Parties (MoP) estimate, Recovery Trust data and EPA data.

A summary of the Kigali MoP estimate of HFC consumption, and 10 year average consumption from 2004 to 2014 is shown in *Figure 10*.

2016 HFC bulk imports by species (Kigali MoP Estimate)

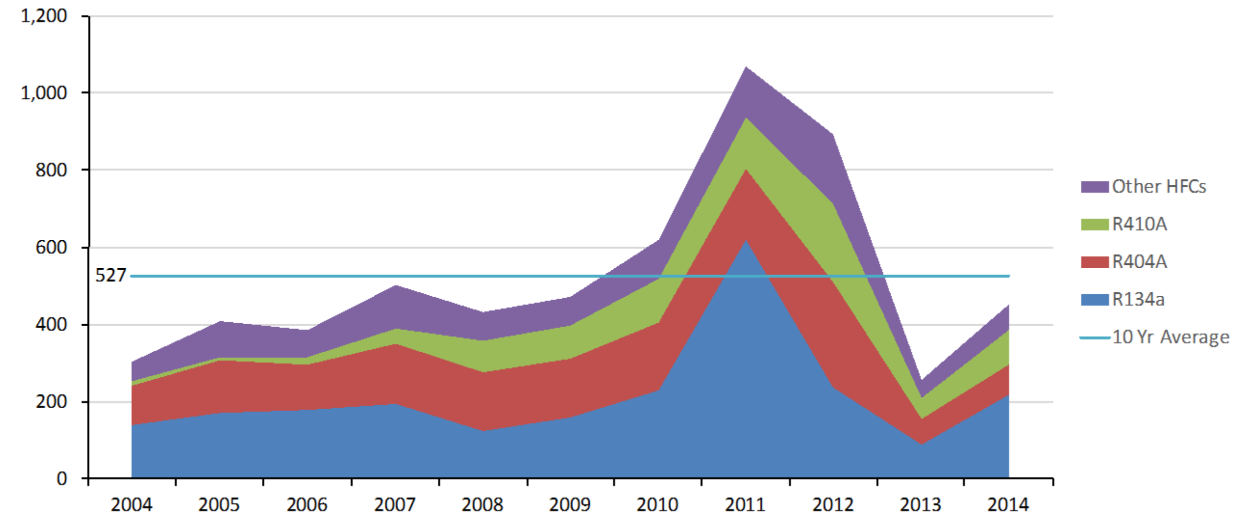


Figure 10: Kigali Montreal Protocol estimate of HFC consumption, and 10 year average in tonnes from 2004 to 2014.

(Source: MfE 2017)

Based on the Kigali MoP estimates, average annual importation of bulk gas over the 10 year period is around 527 tonnes.

Ignoring structural changes in the industry (i.e. factory closures) and subtle differences[10] in assessment this average aligns very well with the author's estimate of 530 tonnes, which can be further validated with data in *Table 3*, derived in part from high quality data provided by the Recovery Trust.

The Recovery Trust was formed in 1993 to promote and facilitate the collection, storage and disposal of all surplus refrigerant gases, largely recovered from equipment reaching the end of its service life. The Recovery Trust programme is funded through a wholesale levy that is placed on every kilogram of bulk refrigerant. The levy is paid by participating companies when the gas is sold.

A summary of the volumes of HFCs, HCFCs and other substances sold by participating companies that paid levies from 2012 to 2016 is provided in *Figure 11*. This chart shows how levies paid on HCFCs have declined to practically zero with the phase down of ozone depleting substances, and that the volumes of HFCs sold by participating companies in 2015 and 2016 were 420 tonnes and 412 tonnes respectively.

[10] *The Expert Group assessment follows the Montreal Protocol method where HFCs contained in equipment are accounted for in the country of manufacture, whereas the assessment by CRL Energy deducted locally manufactured equipment that was exported.*

HFC, HCFC and other substance sales by species

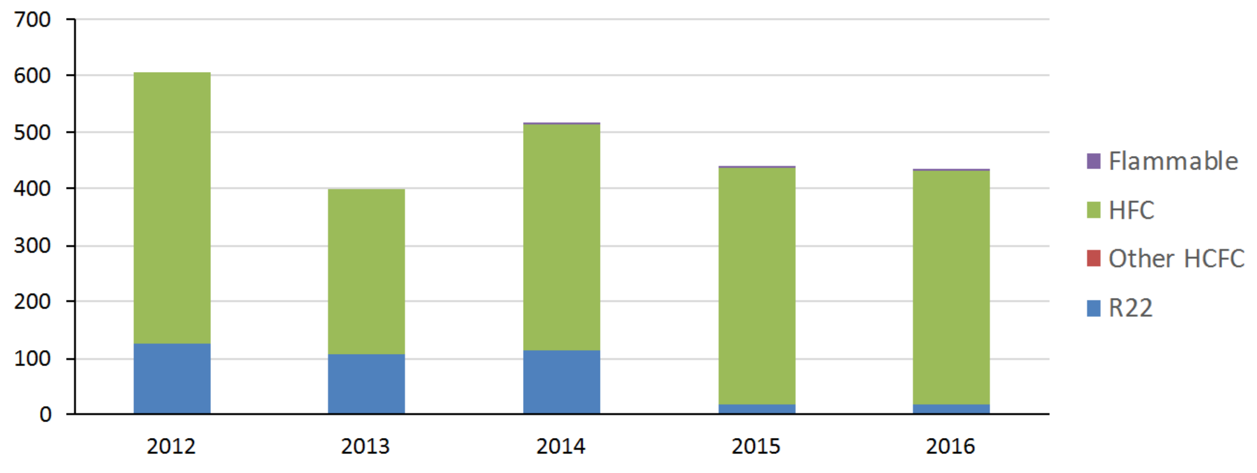


Figure 11: Recovery Trust data of HFCs, HCFCs and other substances sold by participating companies in tonnes from 2012 to 2016.

Table 3 below reports the volume of HFCs sold by participating companies that paid levies in 2016, an estimate of the sales by companies that did not pay levies, and an estimate of consumption in non-RAC applications. Refer to *Appendix A* for a list of companies that do, and do not pay levies. The Kigali MoP estimate of 527 tonnes is within 1% of the total estimate of 530 tonnes from Recovery Trust data.

Table 3: Estimates of HFC consumption in New Zealand in 2016 using Recovery Trust data.

	HFCs in 2016 (Tonnes)
Recovery Trust Participants	412
Companies that do not pay levies: EPA data (2)	79
Companies that do not pay levies: Estimate (3)	20
Foam Blowing	15
Fire Protection	4
Aerosols	0
Total estimate	530

Notes:

1. The above estimate does not include bulk exports.
2. A number of companies released the import-export data submitted to the EPA for the ETS.
3. Estimate of consumption of remaining bulk importers based on industry interviews.

Using data collected by the EPA for the purposes of the Emissions Trading Scheme (ETS), it can also be calculated that, over the four year period from 1 July 2012 to 30 June 2016, there was an average of 1,149 kt CO_2-e of HFCs imported (less exports) per annum.

Assuming a weighted average GWP of 2140, consistent with the mix of bulk imports in 2016, this equates to 537 tonnes of bulk HFCs per annum.

This four year period included the initial reporting obligation for 2012 calendar year activity (reported first quarter 2013) but no surrender obligation, during which period there was an estimated 870 tonnes imported, followed by 213 tonnes in the next year. A second stock piling surge of 753 tonnes was reported in 2014-2015. This second stock piling period is said to have been due to the low carbon price prior to changes in the ETS where only New Zealand Units, and New Zealand originated assigned amount units, were eligible for use in meeting surrender obligations. The year 2015-16 reported an estimated 314 tonnes, which was well below the four year average as many importers were still drawing down on stocks.

This four year average of 537 tonnes from EPA data is within 2% of the Kigali MoP estimate of annual imports (527 tonnes) and the estimate of 530 tonnes average annual imports derived from the Recovery Trust data.

There was limited evidence of reuse of HFCs in 2016, however there is scope for this to occur, particularly with larger enterprises undertaking equipment retrofits using lower GWP substances. If HFC reuse was to become widespread this would further reduce demand for bulk HFC imports.

Reuse of the ODS, HCFC-22, is certainly commonly observed. The practice of retrofitting medium to large refrigeration systems containing HCFC-22, with HFC blends, is also becoming widespread. At the same time, HCFC-22 is a relatively easy substance to reprocess to a virgin refrigerant specification (ARI 700, Specifications for Fluorocarbon Refrigerants). The restriction on importing virgin HCFC-22 under the Montreal Protocol phase out means there is a ready market for recycled HCFC-22 to service equipment that cannot operate on any other gas.

There were only small volumes of HFC-404A re-use identified, however with predictions of the availability of lower GWP retrofit options in the future (e.g. HFC-448A/449A) there is potential for recovery and reuse that may lead to a reduction in consumption of virgin imported HFC-404A.

Generally, re-use of HFC-404A requires testing to validate the quality of the blend relative to ARI 700, however there is limited evidence of this testing activity. Should this activity become common practice it could reduce imported HFC consumption by 20 to 30 tonnes per annum for a period, as it is estimated there will be around 220 tonnes of HFC-404A removed from the supermarket bank alone between 2017 and 2030. This also presents a contamination risk and energy penalty leading to greater indirect emissions should refrigerants be re-used that do not meet ARI 700 specifications.

Further reductions of demand for bulk imports could be secured if enterprises along the cold food chain, particularly larger enterprises, focussed on leak prevention, detection and repair.

Of the 530 tonnes of HFCs consumed in 2016, it is estimated that around 67% (~355 tonnes) was used to maintain the existing stock of equipment. In other words, around 355 tonnes 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 33%) is used to charge new equipment manufactured in New Zealand; to charge equipment imported without a charge of working gas (i.e. imported holding a maintenance charge nitrogen); to retro-fit equipment; or consumed in other applications such as foam blowing and fire protection. An additional 68 tonnes are re-exported for servicing shipping vessels and reefers, and supplying wholesalers located in the Pacific Islands, a volume that is predicted to be greater in 2017.

5 Domestic refrigeration

A typical domestic refrigerator or freezer contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system with refrigerant charges ranging from less than 50 grams to more than 250 grams. Storage volumes can range from 20 litre portable refrigerators to large 850 litre units with ice and beverage dispensing features. The average size of domestic fridge-freezer is increasing, however machines with beverage dispensing capability represent a relatively small fraction of existing stock.

The main refrigerants used in domestic refrigeration are HFC-134a (GWP of 1430), and hydrocarbon HC-600a (Isobutene, GWP of 3). The large majority of the existing stock of appliances contain HFC-134a (>80%). Some very old products, manufactured prior to the early 1990s and still in operation, will contain CFC-12.

New Zealand has detailed sales data on domestic refrigerators that has been collected for the last 14 years. As part of the Energy Efficiency (Energy Using Products) Regulations 2002, any New Zealand importer or manufacturer of products covered by Minimum Energy Performance Standards (MEPS) regulations is required to report to the Energy Efficiency and Conservation Authority (EECA) for statistical purposes. The data collected includes the numbers of each model that are imported, exported and sold in New Zealand (EECA 2016).

Some data on the type of refrigerant charge in domestic refrigeration and freezers was also sourced from the EPA's 2013, 2014 and 2015 Synthetic Greenhouse Gas Levy Report, (EPA 2015) which reported any imports of domestic refrigerators containing HFC-134a.

As a result of the data collected from these two data sets, domestic refrigeration in New Zealand is estimated to contain approximately 360 tonnes of high GWP HFCs, approximately 5% of all high GWP HFCs in the stock of RAC equipment in New Zealand. Domestic refrigeration is estimated to consume less than 0.7% (~4 tonnes) of annual bulk imports of synthetic refrigerant consumption.

The stock of equipment, annual sales, industry trends

In 2016 there were an estimated 3.07 million domestic refrigerators and freezers in New Zealand, a figure that is growing at an estimated 1.5% per annum. This estimate is consistent with the *Residential Energy Baseline Study: New Zealand*, by the Equipment Energy Efficiency programme (E3 2015), that estimated there were 2.9 million domestic refrigerators and freezers in 1.6 million residential dwellings in New Zealand in 2016, allowing for 200,000 appliances in businesses. More than 2.5 million of these devices are presently estimated to be charged with high GWP HFCs, containing in aggregate more than 360 tonnes of HFCs.

New sales are estimated at around 223,000 units in 2016, outstripping annual retirements of old and broken-down equipment in that year by around 48,000 units. The life of domestic refrigerators-freezers ranges from 10 to 25 years and the stock is modelled based on an average of 15 years for refrigerators and 20 years for freezers, which based on the mix of technology in the market, gives an average life across this technology segment of 16.5 years.

More than 65% of new refrigerators sold in New Zealand in 2016 employed hydrocarbons (HCs) as a working gas, compared to only 10% in 2010. This rapid growth of HC charges in domestic equipment is set to accelerate with the HFC phase down, influencing manufacturers to turn over their remaining assembly lines that still use HFCs, to use HCs within the next few years. In the financial years FY 2013/14, FY 2014/15 and FY 2015/16 the EPA reported declining volumes of HFC-134a contained in domestic refrigerators imported into New Zealand of 12.4, 10.0 and 4.2 tonnes (EPA 2016) respectively, providing further evidence of the rapid substitution with domestic refrigerators charged with HCs.

Therefore, it is thought likely that by as soon as 2020, 99% of all new domestic refrigerators and freezers sold in New Zealand will be charged with HCs, and the remaining 1% are likely to be charged with new generation, low GWP, HFOs.

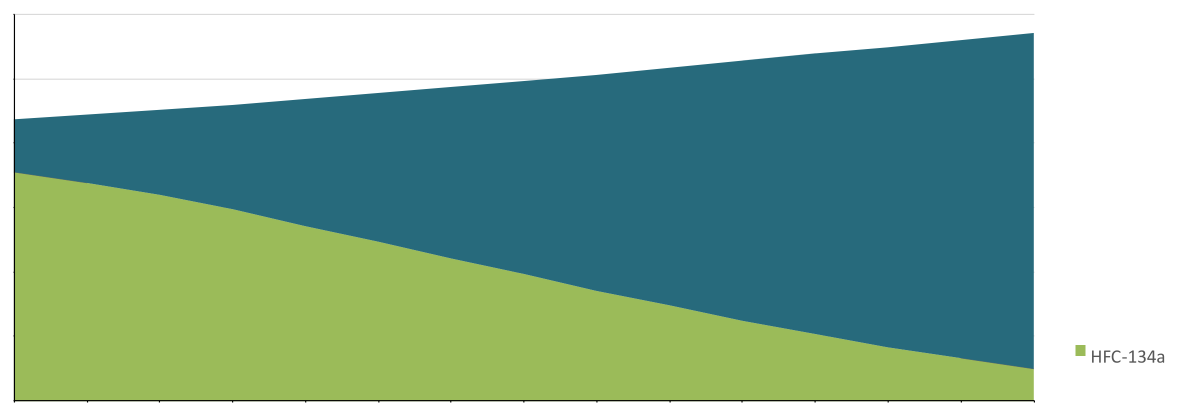
Manufacturing of refrigerators in New Zealand ceased during 2016 with the closure of the last Fisher & Paykel white goods manufacturing facility. While there is an unknown level of refurbishment of second hand refrigerators and freezers, New Zealand will be entirely dependent on imports for all new domestic refrigeration systems from now on.

However, with the rapid development of HC charged equipment forming nearly 100% of new equipment entering the stock, it is predicted that the total stock of HFC charged equipment will fall to less than 10% of the total stock of domestic equipment by 2030.

Consumption of bulk imported HFCs for manufacturing of domestic refrigeration was historically around 30 tonnes per annum. However, prior to the closure of the last Fisher and Paykel facility that consumption had declined to near zero, as Fisher & Paykel transitioned production lines to HC charged refrigerators.

The figures below show the projected bank of working gas and projected consumption to 2030 in tonnes.

Bank and consumption (tonnes): 2016 to 2030



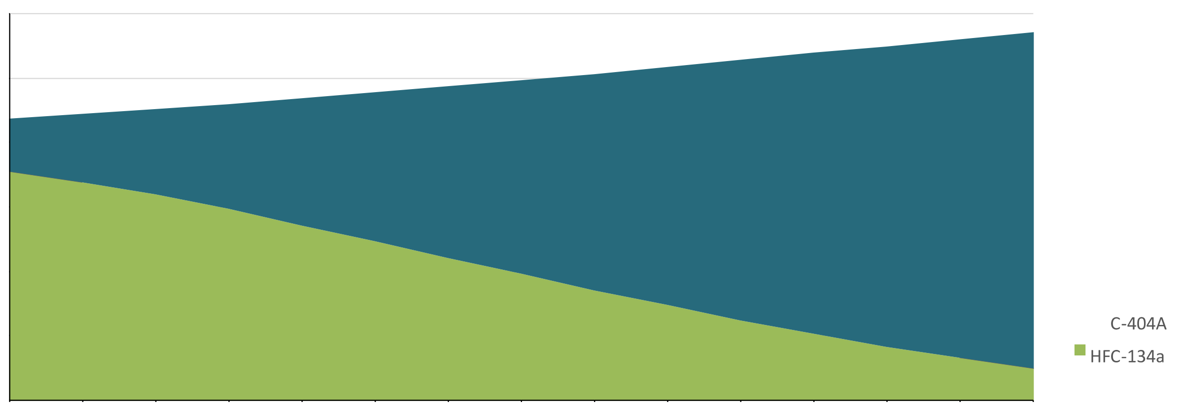


Figure 12: Domestic refrigeration refrigerant bank (above) and consumption (below) in tonnes from 2016 to 2030.

Assumptions:

1. Average charge is 140 grams; Leak rate is 1.0% per annum; and, New Sales Mix projection in 2020: 99% HC and 1% HFO 1234yf.

6 Refrigerated cold food chain

Introduction

This diverse sector, incorporating hundreds of thousands of individual pieces of equipment, comprises what is often referred to as the refrigerated cold food chain, the backbone of the fresh and processed foods distribution network.

Non-domestic refrigeration devices have to store and display food and beverages at different temperatures for chilled and frozen food. The refrigerating capacities of equipment vary from hundreds of Watts (fractional horsepower rated units) up to 1.5 MW.

There are three main categories of equipment found in the refrigerated cold food chain:

- Stand-alone equipment, referred to as 'self-contained' equipment;
- Remote condensing units; and,
- Supermarket systems, sometimes referred to as centralised systems, as they are found in plant rooms.

This sector also includes mobile refrigeration systems that provide the temperature controlled transport links between producers, suppliers, wholesalers and retailers. A further important sub-sector is the specialised area of industrial refrigeration commonly found in large cold storage and distribution centres, and food manufacturing processes.

Refrigerant choices with non-domestic refrigeration are often determined by the two main bands of temperature necessary for the conservation of fresh food and beverages (referred to in industry as medium temperature, or chillers, where produce is refrigerated to temperatures above zero degrees Celsius), and frozen food (low temperature, or freezers, refrigerated to zero degrees and below).

The bank and annual consumption

The refrigerated cold food chain is estimated to contain a bank of some 1,200 tonnes of refrigerants (approximately 17% of the total bank), of which around 700 tonnes is HFC-404A with a GWP of 3922, or about 10% of all high GWP HFCs employed in New Zealand. While this bank presently contains refrigerants with the higher GWPs, it is expected to largely transition to refrigerants with lower GWPs including some refrigerant with GWPs less than 10 by 2030. The primary drivers for reducing GWPs in this sector in New Zealand are the price on carbon from the Emissions Trading Scheme, the temperate climate that allows CO_2 trans-critical systems to be effectively used, and the growing technical expertise in the sector.

This sector consumes approximately 245 tonnes of bulk HFCs per annum, or around 46% of all annual bulk gas consumption in New Zealand, despite making up only 17% of the working bank.

Consumption of bulk HFCs, as compared to the share of the working bank, across the three main categories of non-domestic refrigeration varies considerably as a result of the differing characteristics of the technology.

The numerous self-contained systems with small refrigerant charges, which are typically hermetically sealed, contain a bank of approximately 190 tonnes (around 3% of the total bank), and have an annual leak rate of between 3% and 6%, requiring around 10 tonnes of bulk imported HFCs to replace lost gas in 2016. A further 8 tonnes of bulk imported HFCs were estimated to be consumed in 2016 charging new self-contained equipment manufactured in New Zealand.

On the other hand, refrigeration systems with remote condensing units, which are generally hard working systems with often long, exposed refrigeration lines, operating in areas such as loading bays, distribution centres and the packing areas of farms, with a bank of about 660 tonnes of high GWP HFCs (around 9% of the bank), have an annual leak rate of about 15%, requiring more than 100 tonnes of bulk imported HFCs in 2016 (more than 19% of total consumption of bulk imported HFCs in 2016).

A further 55 tonnes of bulk high GWP HFCs are estimated to have been imported in 2016 to charge new equipment with remote condensing units and retrofit existing equipment with blends such as HFC-407F, HFC-407A and HFC-438A.

While larger supermarkets will employ a relatively small number of these self-contained pieces of equipment, and small farms will have some of the walk in cool rooms that employ remote condensing units, the majority of self-contained refrigeration equipment and remote condensing units are used in the food retail and hospitality sector in small grocery stores, butcher shops, liquor shops, corner stores, food takeaways and restaurants.

This diverse sector is often operating on relatively thin margins and is cost sensitive, resulting in relatively low maintenance levels for refrigerating equipment. As an indication of the distribution of this stock of equipment, research indicates that in New Zealand there are:

- More than 900 mini-marts and corners stores;
- A reported 1,019 petrol stations; and,
- More than 1,100 liquor outlets comprising 110 Liquorland; 19 Henry's Beer, Wines and Spirits, 40 Liquor King; 140 Super Liquor; 76 Bottle O NZ; 140 Thirsty Liquor and 580 other liquor outlets.

All of these outlets are likely to employ a mix of self-contained and remote condensing unit refrigeration systems. At this time the total number of restaurants, takeaways and other food outlets that will all employ some refrigeration equipment, is unknown.

The hard working but generally better maintained large supermarket systems are estimated to contain some 330 tonnes of high GWP HFCs (around 5% of the bank) and, with a leak rate of around 12.5%, required some 37 tonnes of bulk imported HFCs to replace losses (or approximately 7% of annual consumption). A further 34 tonnes of bulk high GWP HFCs was imported for retrofitting existing equipment and charging new equipment in the small stores in supermarket sector.

The stock of equipment, annual sales, industry trends

Small RCFC: Self-contained equipment (charge <1.5kg)

Demand from stand-alone commercial refrigeration is estimated to result in the import of approximately 11 tonnes of high GWP HFCs or approximately 2% of total bulk imports in 2016.

Stand-alone commercial refrigeration equipment typically contains a factory-assembled, hermetically sealed, vapour-compression refrigeration system with relatively small refrigerant charges ranging from 40 grams in a bottle water cooler to up to 1.5 kg in a refrigerated display case.

Self-contained refrigeration is used in a diverse range of equipment and applications. It is estimated that there are approximately 167,000 pieces of stand-alone commercial refrigeration equipment operating in New Zealand, of which more than 160,000 are charged with high GWP HFCs in such applications as:

- Refrigerated display cabinets covering plug-in-type food retail and supermarket cabinets; sandwich-pizza preparation and display counters; kitchen and foodservice 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, and various specialised cabinets for food catering and pharmaceutical applications;
- Bottle water coolers and water dispensers for offices, factories, gymnasiums, etc.;
- 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;
- 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;

- 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 pubs, clubs, hotels, large restaurants with bars and entertainment venues;
- Drop-in and slide-in packaged refrigeration units used in small walk-in cool rooms extensively used throughout the food chain to refrigerate fresh, chilled and frozen produce; and,
- Small packaged liquid chillers used in a wide variety of applications in laboratories and industry.

Consumption of bulk import synthetic refrigerant is declining in this technology segment, mostly as more and more equipment is imported as pre-charged equipment or as local manufacturer Skope Industries transitions to lower GWP refrigerants. The model predicts that 65% of new equipment in 2030 will have a GWP<10, primarily hydrocarbon and some CO_2. The balance will be HFOs and HFO blends, with virtually no new equipment manufactured or imported containing high GWPs in 2030.

Medium RCFC: Remote condensing units

Remote condensing units employ a bank of approximately 660 tonnes of high GWP HFCs, or about 9% of the bank. Demand for servicing and retrofitting existing equipment and charging new remote condensing units is estimated to result in the import of approximately 155 tonnes of high GWP HFCs, or approximately 29% of total bulk imports in 2016.

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

Around 65,000 refrigeration systems with remote condensing units are used in a variety of applications including on refrigerated display cabinets, walk-in cool rooms, beverage cooling (beer), milk vat refrigeration on dairy farms and chilling and freezing applications in industry.

These medium sized and very hard-working systems, often situated in high traffic areas of food processing, wholesaling and retailing operations, are estimated to have average leak rates near 15% per annum, making them one of the largest consumers of bulk imports of HFCs. These systems are also an essential element of the cold food chain employed from farm to factory, in retail and hospitality.

The largest stocks of equipment in this diverse class can be found driving refrigeration cabinets, walk-in cool rooms, beverage cooling, and milk vats.

The term walk-in cool room 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 both walk-in-coolers and freezers for more than a decade. Smaller walk-in-coolers typically with self-contained systems are inclined to use HFC-134a.

Beverage cooling applications employ a large gas charge, mostly due to the large cooling load required for beer chilling applications where an average application can have 40 kg of refrigerant. Older systems use HCFC-22, however HFC-404A has been the refrigerant of choice for more than a decade with a small portion of systems operating on HFC-134a

There are around 11,000 dairy farms in New Zealand (DNZ 2016) and 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 chilling technologies used on dairy farms, ‘direct expansion’ cooling and ‘indirect cooling’ systems which are a specialised chiller. Both technology types can use either HCFC-22 or HFCs, and as HCFCs become more expensive, these will all be swapped over to HFCs.

Large RCFC: Supermarkets

Supermarkets can contain a variety of refrigeration equipment including central plant (rack system), remote condensing units servicing display cases and walk-in cool rooms, and self-contained merchandisers located throughout the store.

However, the discussion here relates only to the large centralised systems that are commonly used to deliver refrigeration to the large display cases, and to low temperature glass fronted displays used throughout supermarkets.

A centralised supermarket refrigeration system will typically include 8 to 12 compressors ranging in capacity from 7.5 to 22.5 kWr 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 kg, with medium and small supermarkets generally requiring 600 kg and 160 kg of gas on average respectively.

In New Zealand, there are at least 724 supermarkets (trading floor >400 m^2) which contain around 330 tonnes of high GWP HFCs, or about 5% of the bank. Demand for servicing and retrofitting existing equipment and charging of new supermarket systems is estimated to result in the import of approximately 71 tonnes of high GWP HFCs, or approximately 13% of total bulk imports in 2016.

Table 4 shows the dissection of small, medium and large supermarkets by brand. The supermarket sector in New Zealand is rapidly transitioning to lower or zero GWP refrigerants. The first cascade refrigeration system was installed in 2006 and there are now between 80 to 100 of these highly efficient systems in operation. The first trans-critical CO_2 only system was installed in 2012, and now appears to be the technology platform of choice in the New Zealand supermarket sector, with almost 40 stores expected to be installed by the end of 2017.

There has been significant activity reported retrofitting HFC-407F (GWP of 1825) and HFC-438A (GWP of 2265), and planned activity to retrofit recently certified lower GWP blends HFC-448A (AR5 GWP of 1273) or HFC-449A (AR5 GWP of 1282).

There are no known hydrocarbon charged refrigeration cases used for supermarket freezers and chillers, other than self-contained point of sales merchandisers.

The model predicts that the very large majority of high GWPs will be removed from the supermarket sector by 2030 with around 75% of systems operating on CO_2 by then, and the balance operating on lower GWP blends and HFOs.

Table 4: Supermarket stock by brand and size.

Large Supermarkets		Small Supermarkets	
New World	138	4 Square	260
PAK'nSAVE	55	Write Price	2
Countdown	177	Raeward Fresh	5
Large Supermarkets	**370**	Other small supermarkets	15
Medium Supermarkets		**Small Supermarkets**	**282**
Freshchoice	26		
Supervalue	38		
Shoprite	1		
Gilmore wholesale	7		
Medium Supermarkets	**72**	**Total Supermarkets**	**724**

The suppliers to the supermarket sector are compressor and refrigeration rack system manufacturers Bitzer, and supermarket contractors McAlpine Hussmann (a subsidiary of Panasonic and manufacturers of supermarket refrigeration cases); Ecochill; Engie Services (formerly Cowley Services) and Fonko.

<u>Mobile refrigeration: Road transport</u>

The majority of mobile refrigeration includes road, rail and intermodal containers, commonly referred to as ‘transport refrigeration’.

The transport refrigeration bank is estimated to comprise less than 0.6% (<40 tonnes) of the refrigerant bank and consumes approximately 1.3% (<7 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 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.

Transport refrigeration units are extremely complex systems, powered by dedicated diesel internal combustion engines designed to refrigerate fresh and frozen perishable products. These systems have to operate over a wide range of ambient conditions and insulation specifications.

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 would most likely result in the total loss of refrigerant charge. Compressor replacement would typically involve reclaim and re-use.

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 are predominantly charged with HFC-404A with a typical charge of between 6 and 10 kg. Some smaller systems can use HFC-134a with charges below 4 kg.

The existing stock is prone to high leak rates estimated at around 20% 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.

An estimated 25 to 30 tonnes of bulk imported HFCs in 2016 were consumed servicing refrigerated shipping containers, commonly known as 'Reefers'. Because reefers come and go from New Zealand with every shipment of refrigerated exports they are not considered part of the inventory and the service consumption is considered export and not counted as New Zealand HFC use. Given export food trends it is more likely this sector will see continued growth.

The refrigerant of choice for transport refrigeration systems is HFC-404A which has become a preferred choice for practically all trailers and large trucks. HFC-134a is used in small trucks and vans as well as reefer containers. Testing of low-GWP HFC and non-HFC alternatives are in progress, but not one option seems viable in the short term.

The main issue is that the performance of HFC-404A is difficult to meet. Current and previous tests with trucks using CO_2 suggest that introduction of CO_2 will be possible when more efficient compressors with more than one compression stage, are commercially available. These dual stage compressors are under development.

Marine refrigeration

Marine refrigeration, which is primarily located on fishing vessels, is estimated to comprise less than 40 tonnes, yet has a high annual consumption as a result of the extremely high leak rates that exist in fishing vessels of between 20 and 25 % per annum. The two main fishing operations in New Zealand are Talley's and Sealord. The majority of the fishing vessels are still operating on HCFC-22, with some ammonia and HFCs.

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.

A recent study by Expert Group (EG 2016a) for one of Australia's largest fisheries identified that there were no easy, off-the-shelf, low GWP technology options available for the fleet to move to today that are suitable from both a technical (mission critical) or safety point of view for use on the small fishing vessels that are typical for New Zealand fisheries.

Sealord recently announced the construction of a $70 million factory vessel underway in Norway that will likely replace many smaller vessels in the New Zealand fleet. The system of choice for large European fishing vessels is highly efficient ammonia-CO_2 cascade systems (UNEP 2013, p2).

Some shipping companies also provide support services for ships entering New Zealand ports. An uncertain quantity of refrigerant is consumed in the servicing of marine based refrigeration systems on cruise and cargo shipping while in port. While it is thought to be a relatively small quantity in aggregate, there is simply no reliable data to make an informed judgement at this time.

Industrial and process refrigeration

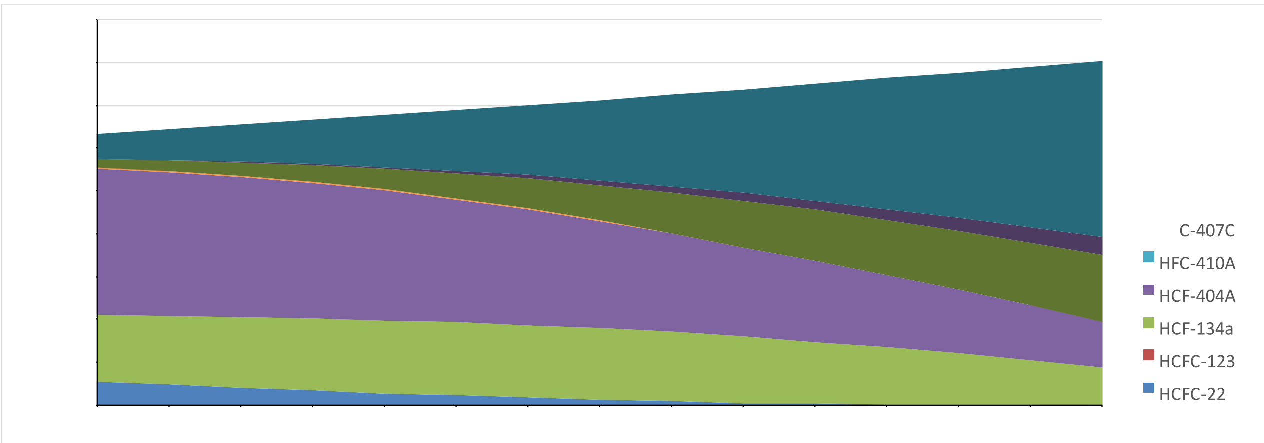
More than 90% of the large industrial refrigeration installations in New Zealand use ammonia (R717). The energy efficiency of ammonia in these large installations is in general 15% better than HFCs systems. As this application segment has already transitioned to low GWP refrigerants it was not modelled in the high GWP bank.

There are food process applications and other industrial refrigeration applications consuming HFC-404A, HFC blends with a GWP<2150 and some HFC-134a that are included in the remote condensing units segment.

Hydrocarbons are rarely used, other than in situations where flammability safety measures are already required or specialised applications to mitigate the risk. For example, EcoChill replaced an old HCFC-22 system at Turners & Growers kiwifruit cold store with an advanced refrigeration system design containing Hydrocarbon as the primary refrigerant and Glycol as the secondary refrigerant.

It is considered likely that all large industrial systems in New Zealand will be ammonia charged where safety concerns can be addressed, and ammonia-CO_2 cascade refrigeration systems are an option where the charge is significantly reduced to mitigate the risk.

Bank and consumption (tonnes): 2016 to 2030



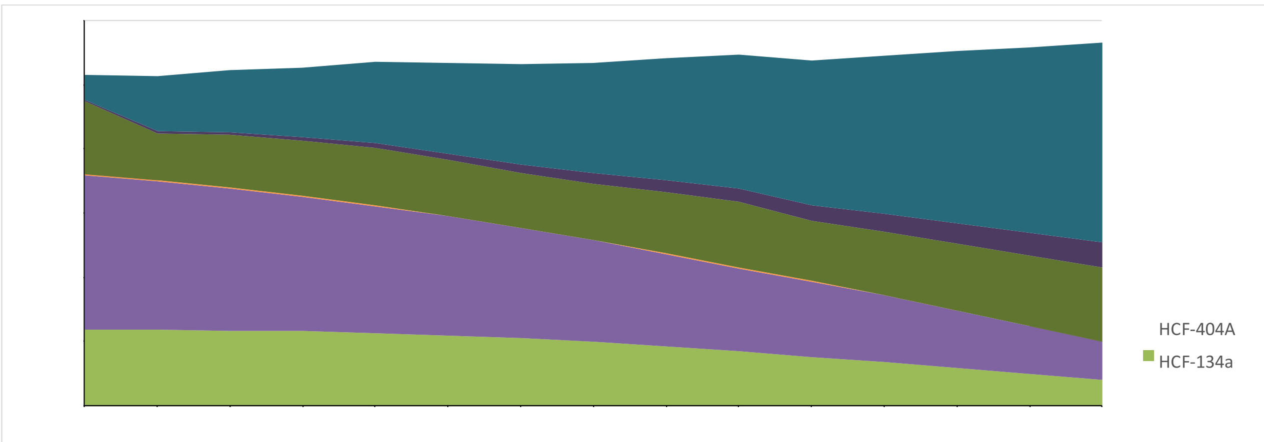


Figure 13: Refrigerated cold food chain refrigerant bank (above) and consumption (below) in tonnes from 2016 to 2030.

Notes:

1. The above chart includes Small: Self-contained equipment; Medium: Remote condensing units; and Large: Supermarket and other systems found in the refrigerated cold food chain.
2. HCFCs are included in the chart of the refrigerant bank and excluded from the HFC consumption chart.
3. Refer to *Appendix C* for assumptions on average charge, lifespan and leak rates by equipment types.
4. New Sales Mix projection for Small: Self-contained equipment: 0% HFC-404A in 2025, and 0% HFC-134a; 80% GWP<10; 15% GWP<2150 and 5% GWP<1000 in 2030.
5. New Sales Mix projection for Medium: Remote condensing units in 2030: 0% HFC-404A; 0% HFC-134a; 55% GWP<10; 30% GWP<2150 and 15% GWP<1000.
6. Supermarket store mix in 2030: 0% HFC-404A; 0% HFC-134a; 82.5% GWP<10 and 17.5% GWP<2150.

7 Stationary air conditioning

Introduction

Stationary air conditioning as a broad class of equipment includes all forms of stationary air conditioning equipment that use the vapour compression cycle to provide human comfort, mainly in homes and commercial properties, and to provide close temperature control in data processing areas.

The equipment types in this sector can be reverse-cycle (heating and cooling) or cooling only, single phase or three phase, and range in size from a small 2.5 kWr split system with a refrigerant charge of less than 600 grams, to large 4,000 kWr commercial chillers containing more than a tonne of refrigerant.

The main product formats include:

(i) Dehumidifiers and some portable air conditioning for domestic use;

(ii) 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, now predominately a replacement market and generally referred to as 'window/wall' units;

(iii) Hot water heat pumps for domestic and commercial applications;

(iv) Portable space coolers for spot cooling in commercial and industrial applications, or to provide temporary relief where normal air conditioning systems are inadequate or have broken down;

(v) 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, all designed for different applications;

(vi) 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;

(vii) Variable refrigerant volume split systems with multiple indoor units, which is emerging as the preferred technology option for medium sized commercial buildings;

(viii) Close control or precision air conditioning systems employed in 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;

(ix) Roof top packaged air conditioning systems that use high static pressure fans which allow long duct runs. In recent times these systems have been rejuvenated with variable speed compressors (i.e. digital scroll), electric commutated plug fans and advanced controls to enhance efficiency levels to compete with other technology platforms sold into commercial buildings; and,

(x) Chillers for space cooling in large commercial buildings.

For the purposes of this study, partly because of the limitations and characteristics of the technology, and the opportunities that it presents for alternative working gases, the stationary air conditioning sector is being dealt with in three broad categories:

- Small self-contained air conditioning – broadly covering products listed in (i) to (iv) above, except swimming pool heat pumps that are covered in Medium AC;
- Medium air conditioning, Split Systems and Light Commercial – including products listed in (v) to (ix) above; and,
- Large air conditioning, primarily chillers.

New Zealand is largely a 'technology taker' of air conditioning equipment, driven by innovation and product development from overseas manufacturers and suppliers. Trends and developments in the international market are therefore reflected in changes in the New Zealand stock of equipment and bank of working gases.

In this sector the changes brought by the Montreal Protocol, combined with rapid development of the smaller and domestic air conditioning products in the last two decades means that New Zealand still has a legacy of HCFC charged equipment, and a large stock of relatively new HFC charged equipment. The main HFCs employed are HFC-410A, HFC-407C and HFC-134a.

Until as recently as 2014 air conditioning units charged with HFC-410A has been the fastest growing segment, with more than 98% of medium and light commercial air conditioning sales in that year being charged with HFC-410A.

HFC-32 pre-charged equipment imports are expected to increase rapidly following on from the rapid adoption of that gas by international manufacturers since 2014 with HFC-410A charged units expecting to comprise 60% of new sales by 2020 and only 5% by 2025.

In 2013/14, 2014/15 and 2015/16 (1 July to 30 June) the EPA reported total HFCs contained in air conditioners imported into New Zealand of 196, 178 and 232 tonnes respectively (EPA 2016). These numbers do not include imports of air conditioners containing HFC-32 (GWP 675) as this substance is not covered by the reporting requirements at this point in time. Market intelligence however suggests that imports of air conditioners containing HFC-32 may, by the end of that period, comprise as many as 30% of all pre-charged air conditioners imported.

The bank and annual consumption

Stationary air conditioning equipment in New Zealand contains 3,400 metric tonnes, operating in an estimated 1.25 million stationary air conditioning devices, with over 152 tonnes of refrigerant required for service, charging new equipment and use by OEMs each year.

Around 480 tonnes or 14% of the working gases found in stationary air conditioning equipment are HCFCs. From the early 1990s until the early years of the 21st century nearly all stationary air conditioning was either imported pre-charged with HCFC-22, or was manufactured in New Zealand and then charged with it. As the restrictions on HCFCs under the Montreal Protocol took effect, the new generation of HFCs began to replace HCFCs. In 2002 the large majority of air conditioning equipment imported in pre-charged equipment and manufactured locally contained HCFC-22 and by 2006 only about 40% of the new equipment was HCFC-22.

More recently, the combined effects of technological advances, minimum energy performance regulations, and bans on HCFC pre-charged air conditioning in 2010 in neighbouring market Australia significantly slowed the importation of HCFCs in air conditioning equipment.

Today, the very large majority of medium sized and light commercial air conditioning equipment installed contains HFC-410A with small amounts of HFC-407C. HFC-134a and to a lesser extent HCFC-123 are the most common refrigerants used in various capacities of centrifugal and screw chillers in the largest commercial devices.

HFC-134a and CO_2 are used in domestic hot water heat pumps, and HFC-410A in commercial hot water heat pumps. There are some local manufacturers including Econergy, Temperzone and Hot Water Heat Pumps Ltd. Commercial applications include potable water, process heating, and swimming pool heat pumps.

The bank of HFC-410A in air conditioning is estimated at more than 2,500 tonnes, 75% of the AC bank, and 37% of the total bank, followed by 156 tonnes of HFC-134a and over 140 tonnes of HFC-407C.

Small Air Conditioning: Self-contained

The stock of small air conditioning equipment in the economy is estimated to only contain 23 tonnes of high GWP refrigerant gases, although more than 9 tonnes of that is HCFCs. This stock of HCFC charged equipment is not being replenished and as such is declining rapidly. It is estimated that by 2025 it will be virtually non-existent.

Total demand for bulk imported gas to service the stock of equipment is estimated at less than 500 kg of HFCs in 2016. Small air conditioning in New Zealand is a minor category compared to Australia on a per capita basis. New Zealand was a later adopter of air conditioning, and largely skipped packaged room air conditioning units and adopted non-ducted wall hung split heat pump technology categorised in Medium air conditioning.

The temperate climate does not create significant demand for portable air conditioning. However, some 16,000 dehumidifiers were imported in the year 2015/6 assuming an average charge of around 150g. These relatively inexpensive devices found in retail stores do not create service demand as they are disposable appliances.

Generally speaking, like refrigerators, when appliances from this class of small air conditioning are disposed of it is because they have stopped working, many of them because of either compressor failure or loss of refrigerant charge. This fact, combined with the very small charges in small air conditioning at any rate, makes end-of-life recovery of HFCs from small air conditioning economically challenging.

As a result, many will contain very little residual charge, so the existing stock of equipment that is charged with HFCs is not likely to provide much material for recovery that might reduce demand for bulk imports for some other equipment type.

Medium Air Conditioning: Split systems including wall hung, ducted and VRF, and roof top packaged systems

With more than 1.2 million pieces of equipment in the field and a total bank of more than 3,000 tonnes of high GWP gases, the Medium air conditioning segment is by far the largest group numerically, containing the largest aggregate bank of working gas.

This stock estimate is consistent with the Decision and Consultation Regulation Impact Statement for Air conditioners, Chillers and Close Control Air Conditioners prepared by Equipment Energy Efficiency (E3) programme (E3 2017) of 2,150 chillers in 2016.

More than one million of these units are charged with HFC-410A, containing a total of more than 2,550 tonnes of this high GWP gas. While imports of HFC-410A pre-charged units are predicted to decline rapidly as HFC-32 (GWP 675) is adopted, with 130,000 to 140,000 new units expected to be sold on average every year for the next decade, it is expected the bank of HFC-410A will grow to at least 2,900 tonnes in 2021 before starting to decline.

This equipment class requires approximately 104 tonnes of all annual HFC bulk imports to service it (~20% of all bulk imports).

The medium air conditioning class of equipment has a number of demonstrated and rapidly emerging options to shift away from high GWP working gases. HFC-32 particularly is likely to rapidly grow to dominate this class of equipment.

More than 150,000 medium air conditioning units, containing more than 385 tonnes of HCFCs are expected to retire from service between 2016 and 2025.

Large Air Conditioning: Space chillers

There are estimated to be about 2,300 chillers operating in New Zealand, containing in total approximately 275 tonnes of refrigerant gases. This stock estimate is consistent with the Decision and Consultation Regulation Impact Statement for Air conditioners, Chillers and Close Control Air Conditioners prepared by Equipment Energy Efficiency (E3) programme (E3 2017) of 2,150 chillers in 2016.

Approximately 28% of this gas is HCFC-22 (~78 tonnes) with a smaller quantity of HCFC-123 (~10 tonnes). The balance of gases employed (around 185 tonnes) are high GWP HFCs, primarily HFC-134a and quantities of HFC-410A and HFC-407C.

The installed base of high GWP HFC charged equipment created demand for approximately 7 tonnes of bulk HFC consumption in 2016 to replace material lost to leaks (about 1.3% of all high GWP HFC consumption in that year). A further approximately 3 tonnes of HCFC-22 was recycled to service older HCFC charged chillers.

New chillers sales are expected grow at around 1% per annum or in line with construction activity in large commercial buildings.

Bank and consumption (tonnes): 2016 to 2030

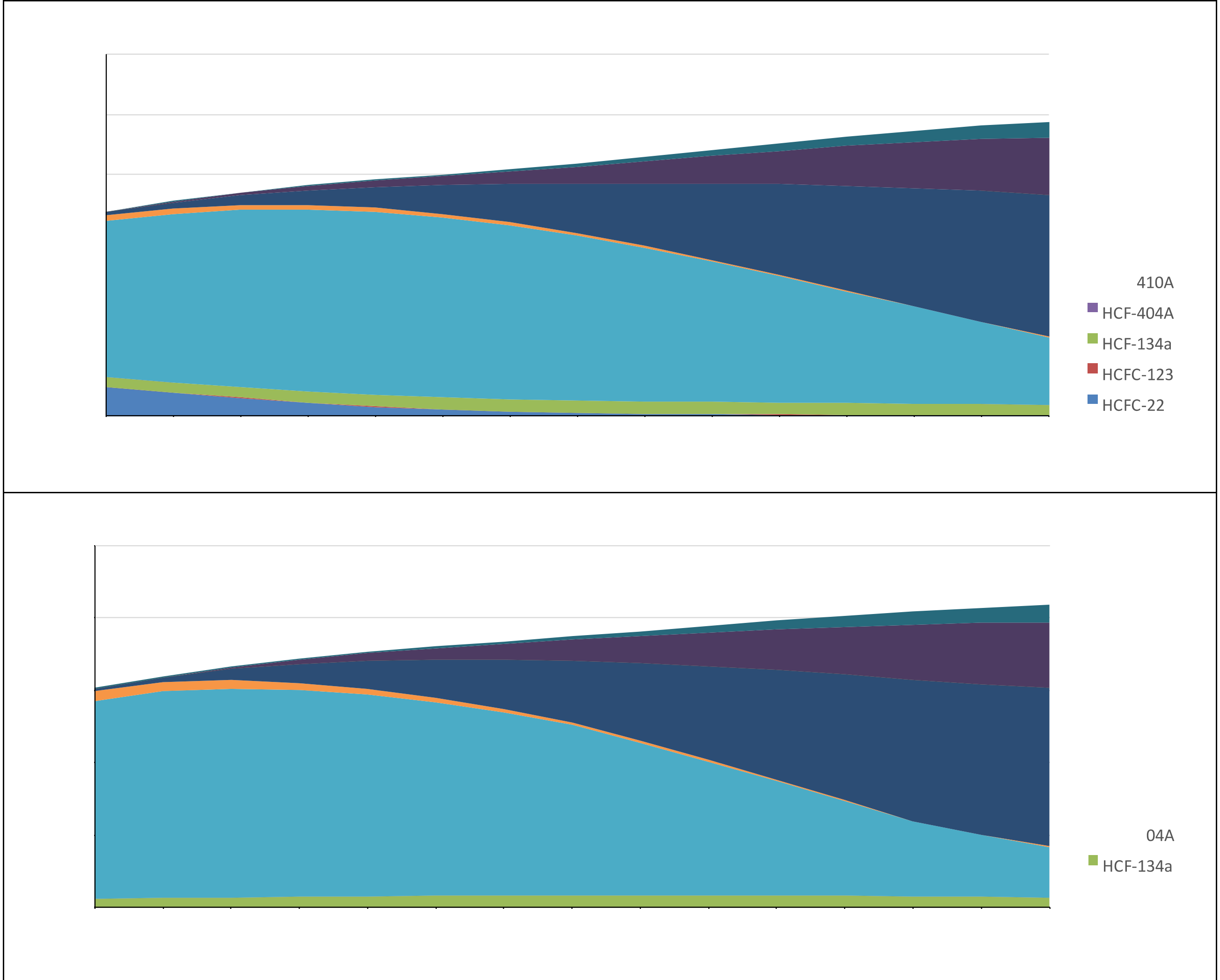


Figure 14: Stationary AC refrigerant bank (above) and consumption (below) in tonnes from 2016 to 2030.

Notes:

1. HCFCs are included in the chart of the refrigerant bank and excluded from the HFC consumption chart.
2. The HFC consumption chart includes locally manufactured product.
3. Refer to *Appendix C* for assumptions on average charge, lifespan and leak rates by equipment types.
4. New Sales Mix projection for Small AC: 5% HFC-410A; 55% HFC-32; 10% GWP<1,000; and 30% GWP<10 in 2025.
5. New Sales Mix projection for Medium AC: 5% HFC-410A; 65% HFC-32; 25% GWP<1,000; and 5% GWP<10 in 2025.
6. New Sales Mix projection for Large AC: 42% HFC-134a; 5% HFC-32; 14% GWP<1,000; and 39% GWP<10 in 2025.

8 Mobile air conditioning

The bank and annual consumption

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

In 2016 the mobile air conditioning bank of high GWP HFCs is estimated to be around 2,040 tonnes, equivalent to around 29% of the total bank of high GWP HFCs in the stock of RAC equipment in New Zealand.

It is estimated that of the 3.55 million registered passenger and light commercial vehicles, around 87% were manufactured with an air conditioner, each containing as little as 620 grams of gas when fully charged. The New Zealand fleet is unique as 46% of vehicles in the fleet are used vehicles primarily from Japan. The used vehicles entering the fleet are typically around 7 to 10 years old when imported, and therefore the transition to refrigerant with a GWP less than 10 will be delayed by a similar timeframe on the used vehicle fleet.

The main industry participants in New Zealand, with a significant proportion of their business focused on supplying gas, components or equipment to the mobile air conditioning market include Ashdown Ingram, Repco, BOC, CoolDrive, Pan Pacific Auto Electronics Limited, and JAS Oceania.

Bank (tonnes): 2016 to 2030

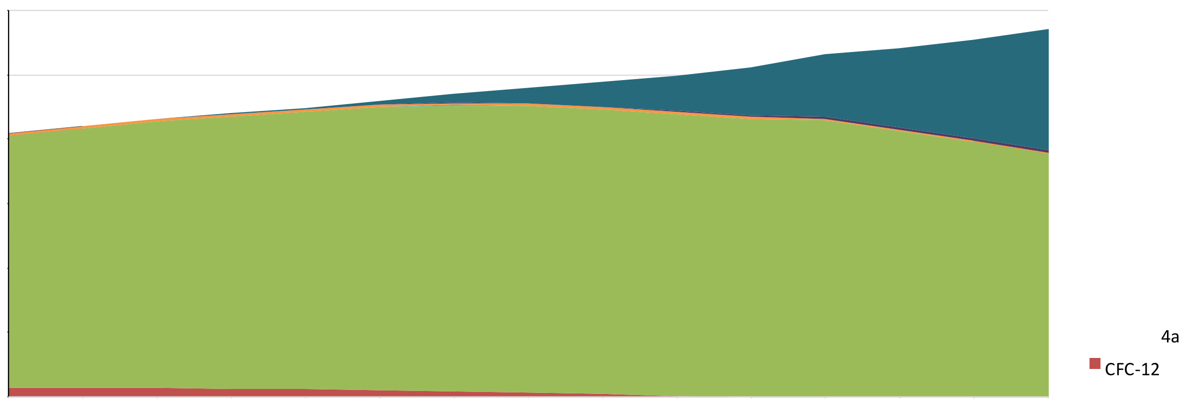


Figure 15: Mobile AC refrigerant bank in tonnes from 2016 to 2030.

Assumptions:

1. The fleet for both new and used vehicles up to 2016 is based on actual registrations, and beyond 2016 is based on the NZ Ministry of Transport's official 'middle' scenario fleet growth curves (MoT 2017).
2. Average charge of passenger and light commercial vehicles is around 620 grams. A polynomial function is applied to the model where the average charge reduces from 1,090 grams for vehicles manufactured in 1991 to 620 grams in 2014, and reduces to 560 grams in 2030.
3. The model assumes the HFC-134a fleet is 90% of the full charge and vehicles that were manufactured with CFC-12 technology are 50% of full charge, some of which have been retrofitted to HFC-134a.
4. The average charge for buses (i.e. Heavy Omini bus and Coaches) is 4.0 kg.
5. New Sales Mix projection for Small MAC: New vehicle fleet: 24% HFC-134a; and 76% GWP<10 in 2025.
6. New Sales Mix projection for Small MAC: Used vehicle fleet: 10% HFC-134a; and 90% GWP<10 in 2023 and will be imported into New Zealand 7 to 10 years later.

7. New Sales Mix projection for Large MAC: 49% GWP<1,000 and 51% GWP<10 in 2025.

Due to the timing of the roll out of mobile air conditioning as a common feature in passenger vehicles, and later in heavy vehicles and public transport, mobile air conditioning skipped the transition from CFCs to HCFC refrigerants in the 1990s, to some extent. The vast majority of mobile air conditioning equipment was manufactured with HFC-134a, while a smaller population of earlier model vehicles that had air conditioning factory installed, or installed after market, were charged with CFCs (refer *Figure 15* CFC-12 red slice at bottom of chart) and, if a changeover from one gas to another has been undertaken, they will most likely have migrated directly from CFCs to HFC-134a.

Other refrigerants employed in large mobile air conditioning applications can include HCFC-22, HFC-407C and HFC-410A in coaches, locomotive, passenger rail and off-road applications. Relatively rarely HFC-124 can be found in extreme ambient applications such as mobile cranes. Small amounts of HFC-410A is used on miscellaneous applications such as luxury vessels and yachts.

Small mobile air conditioning is estimated to have consumed an estimated 104 tonnes or around 20% of all bulk HFCs imported into New Zealand in 2016. The majority of this gas (~90%) was consumed servicing air conditioning systems in existing vehicles, which have a typical leak rate of 10% per annum. However, the climate in New Zealand means that air conditioning is not seen as an essential feature for private vehicle owners, and interviews with industry participants suggest that mobile air conditioning is often not serviced.

The stock model used to calculate the sum of all gas losses includes an allowance for gas lost from passenger and light commercial vehicles that had some form of collision or catastrophic failure (i.e. compressor failure). Systems in commercial vehicles where mobile air conditioning is considered essential for business, and vehicles involved in collisions where insurance is likely to cover the cost of repairs, are more likely to have their gas charge replaced.

As a result, the gas consumed in service every year is estimated to be replacing only about 5% of the bank that has been lost to air, and many mobile air conditioning systems are simply not being topped up as the gas charge falls to the point where the system no longer operates effectively. The Expert Group model assumes a service rate of 6.5% per annum on the new vehicle fleet and 3.75% on the used vehicle fleet, including an allowance for crash.

Consumption (tonnes): 2016 to 2030

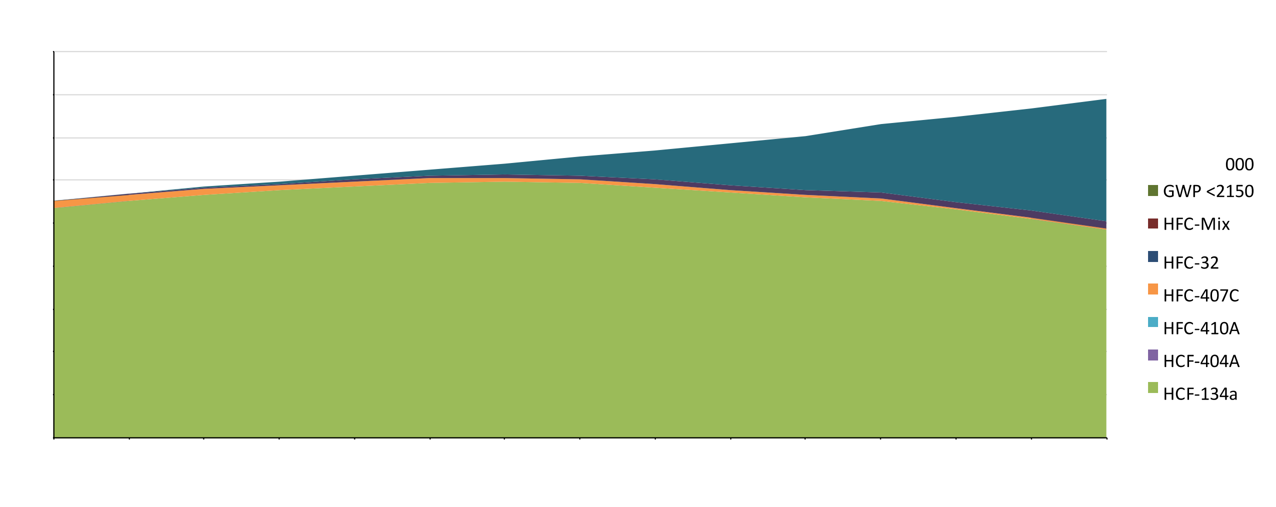


Figure 16: Mobile AC refrigerant consumption in tonnes from 2016 to 2030.

Assumptions:

1. The service rate of the new vehicle fleet is 6.5% per annum, and 3.75% per annum in the used vehicle fleet, which includes an allowance for crash.

In the FY 2013/4, FY 2014/5 and FY 2015/6 (July 1 to June 30) the EPA reported strong growth in volumes of HFC-134a contained in mobile air conditioning imported into New Zealand of 193,272 and 288 tonnes (EPA 2016) respectively.

The stock of equipment, annual sales, industry trends

While the New Zealand climate does not make mobile air conditioning an important feature in vehicles, as all cars are imported to the country, New Zealand has been importing a considerable bank of HFCs, and earlier generations of refrigerant gases, since shortly after air conditioning became a common feature in car manufacturing by the major brands in the early 1990s.[11]

However, despite the cool climate and the tendency for many vehicle owners to not service, repair or replace air conditioning in their vehicle, this is not to say that the industry is completely moribund. Recently, international participant CoolDrive Distribution completed the first phase of its expansion into the New Zealand market with the acquisition of the Auckland Auto Air parts business, on top of earlier acquisitions of Direct Auto Parts and Total Air Conditioning. This is a strong indication that market research suggests some growth for the mobile air conditioning market and services in New Zealand.

It is estimated that in total there are more than 3.55 million registered vehicles of all types (excluding coaches, heavy omini buses and rail) with mobile air conditioning systems. Significant growth in vehicle imports in 2014, 2015 and 2016 saw more than 287,600 passenger and light commercial vehicles imported in 2016 (EPA 2017), a greater number of imports than in any previous year.

It is possible that as many as 138,000 older vehicles on the road still have air conditioning that was originally charged with the much older gas, CFC-12 with a GWP of more than 10,000. If fully charged, these vehicles could, in aggregate, contain more than 73 tonnes of CFC-12, however most of this has leaked to atmosphere. Refrigerant Recovery New Zealand is still reporting collections of small quantities of CFC-12, although much of the refrigerant in the older vehicles has most likely already leaked to the atmosphere or been changed over to HFC-134a.

Figure 17 shows the number of registered passenger and light commercial vehicles in New Zealand from 1990 to 2016.[12] Total registered and unregistered vehicle numbers are predicted to continue to grow by about 2% per annum as vehicle sales outstrip vehicle retirements and write offs.[13]

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[11] *The Ministry of Transport fleet assumes that mobile air conditioning was pre-installed in 50% of imported new and 65% of second hand vehicles from 1994 to 1996; 75% and 90% respectively from 1997 to 1999; and, 95% and 95% respectively from 2000 to 2004.*

[12] *The number of registrations cited in 2016 is the number registrations published by Statistics NZ at the beginning of 2017.*

[13] *Average compound growth in registrations from 2006 to 2016 was 2.0% per annum (SNZ 2017).*

Registered passenger and light commercial vehicles

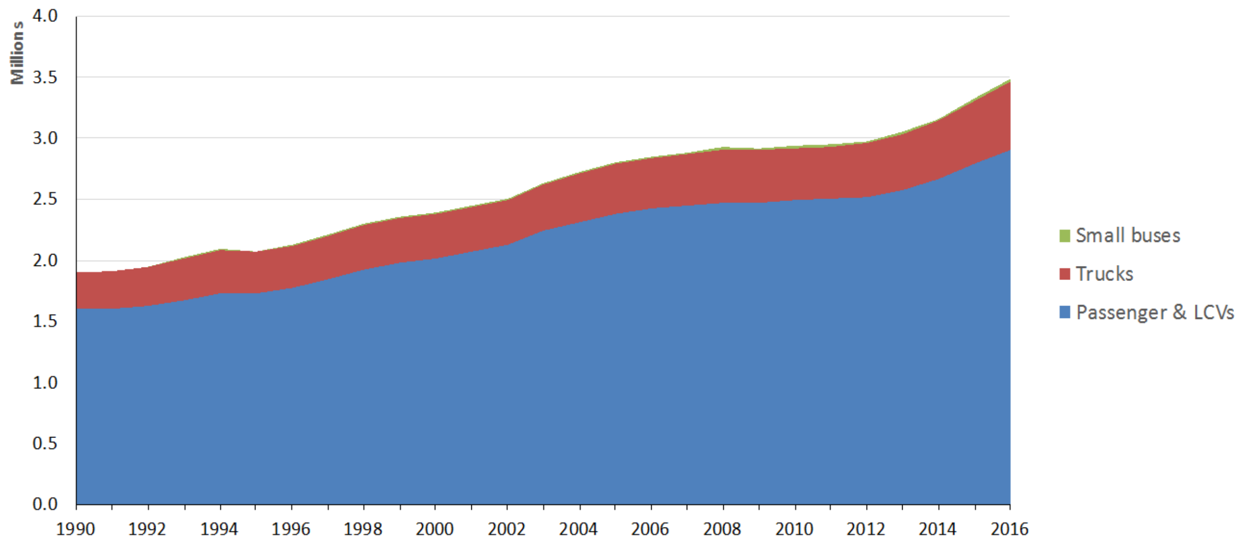

Figure 17: Registered passenger and light commercial vehicles in New Zealand from 1990 to 2016.

(Source: SNZ 2017)

The new generation of low GWP HFCs, known as HFOs (GWP <10), has been gradually entering use in international vehicle markets since mid-2014. With the conclusion of the Kigali Amendment and a clear timeline for HFC phase down, it is expected that new vehicles from leading manufacturers will be universally charged with HFO-1234yf by the mid 2020s.

There are regulations in the majority of major economies driving the technology transition to a refrigerant with a GWP less than 150. Japan's Act on the Rational Use and Proper Management of Fluorocarbons mandates a maximum GWP of 150 for refrigerants in air conditioners of new passenger cars, effective from 1 January 2023. The Expert Group model assumes that 90% of vehicles manufactured in Japan from this point will contain HFO-1234yf, and 100% in 2030.

The European directive on mobile air conditioning systems (Directive 2006/40/EC) aimed at reducing emissions from air conditioning systems fitted to passenger cars mandates that impacted vehicles must use a refrigerant gas with a GWP of 150 or less. In practical terms, the use of HFC-134a is not permitted for servicing newly type-approved vehicles sold in the European Union from January 2011, and all new vehicles sold from January 2017. The Expert Group model assumes New Zealand will have a small portion of new vehicles charged with CO_2 entering the fleet (i.e. 1% of new vehicles in 2025, and 2% in 2030).

The US Environmental Protection Agency (EPA) and the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) have set standards to reduce Greenhouse Gases and Improve Fuel Economy for Cars and Light Trucks manufactured in 2017 to 2025. These emission standards are driving a rapid transition of mobile air conditioning technology to HFO-1234yf in new vehicles sold in the US.

While the Expert Group and NZ Ministry of Transport stock models predict that there may be around 4.3 million vehicles on New Zealand roads in 2030, it is expected that around 24% of those vehicles, or more than 1.0 million vehicles will, by that time, be charged with a refrigerant with a GWP less than 10, with the large majority (~99%) containing HFO-1234yf.

Larger mobile air conditioning systems

There is a market for large mobile air conditioning systems that are used in public transport such as in buses, trains and ferries, but also used in harvesters, heavy earth moving equipment and unregistered off-road vehicles. This technology could potentially migrate along a different path to the smaller private vehicle and light commercial vehicle systems.

There are around 3,000 registered bus and coaches in New Zealand which, in total, are estimated to contain a bank of around 12 tonnes of HFCs.

Modern passenger train carriages are also equipped with large mobile air conditioning systems, although in total, New Zealand's passenger urban and regional passenger rail services are relatively modest. Auckland's metro rail has the largest passenger use and integrated rail network and reports having 57 three car electric trains operating. Wellington has a much smaller network and less than half the annual rail passengers, although rail car numbers could not be located. However, even if Wellington had half the number of passenger rail cars as Auckland, all together large mobile air conditioning systems in passenger rail would not have much more than about 2 tonnes of total HFCs to add to the large mobile air conditioning bank.

Because they are unregistered, it is very difficult to determine the numbers of specialised off-road, earthmoving and heavy mobile equipment in the economy, all of which is likely to include mobile air conditioning.

However, based on industry interviews and using the registered vehicle and railways data it is estimated that the large mobile air conditioning bank is around 30 to 40 tonnes of HFCs.

The service rate for large mobile air conditioning is estimated at 8% per annum, slightly less than service rates in higher ambient economies (i.e. Australia 11% per annum) and significantly higher than the low service rate of 5% for small mobile air conditioning. Large mobile air conditioning, generally employed in commercial vehicles and public transport, is expected to be kept maintained and operational, thus the higher service rate than the data suggests for private vehicles in New Zealand.

This suggests annual service consumption of around 6 tonnes per annum including charging new equipment.

9 Fire protection

Fire protection applications consumed around 4 tonnes of all bulk HFCs imported into New Zealand in 2016. FM-200 (FE-227, HFC-227ea, GWP 2,900) is the main gas used in the vast majority of HFC charged fire suppression applications. However, HFCs are not generally the substance of choice for the New Zealand fire protection industry so this HFC consumption represents only a small part of total annual installations of inert substances employed in fire protection.

HFCs can be used in fire suppression applications for their efficacy and safety properties where the application of water (by hose stream or sprinkler heads); dry chemical agents; or aqueous salt solutions is problematic. HFC fire protection systems can be found in telecommunication facilities, computer rooms, data centres, process control centres, military vehicles, ships, aircraft, museums, art galleries and major libraries, archive vaults for document storage and other electronic facilities.

However, for reasons not fully understood, it appears as if the major facilities requiring fire suppression systems in New Zealand skipped straight from the earlier generation of HCFC charged fire suppression applications, to a variety of inert gases with zero GWP such as Inergen, and Novec 1230.

HFCs were introduced into fire suppression applications as one of the replacements for Halon 1301. However, some New Zealand facilities that still use Halons, such as electrical switch rooms and computer bunkers, are reported to have the capacity to decant and recycle Halons. This domestic capacity to recover and recycle Halons may have extended the life of many Halon facilities so that they were then able to move directly to the new range of non-HFC inert gas products introduced to the market in the early 2000s.

It is estimated there are around 4 tonnes of Halons recovered and transported to the Australian Government Halon bank per annum.

New Zealand also does not have the same degree of military and air force applications that generally use specialised HFCs for fire suppression in many countries.

Some demand for FM 200 is thought to be created by marine applications in visiting vessels. Small amounts of FE-25 (HFC-125, GWP of 3,500) and FE-13 (HFC-23 GWP 14,800) are likely used in some flooding applications, and FE-36 (HFC-236fa, GWP of 9,810) is likely to be found in specialist streaming applications such as portable fire extinguishers for oil platforms, petroleum processing and storage facilities, etc. There were small amounts of HFC-23 destroyed by Refrigerant Recovery NZ prior to 2013, which provides historical evidence of HFC-23 use as a gaseous fire suppression agent.

The main market participants in delivery of fire suppressions systems and services in New Zealand are Chubb, Wormald, Fire Watch, Argus, and Fire Fighting Pacific. All of these companies are members of the Fire Protection Association of NZ.

There is a range of low GWP alternatives that provide an immediate transition path for the majority of applications where HFC fire protection systems are currently used; they include a fluoroketone called Novec 1230 and inert gases:

- Inergen (Nitrogen/Argon/CO_2 blends)
- IG-01 (Argon)
- IG-100 (Nitrogen)
- IG-55 (Nitrogen/Argon blend)

Novec 1230 (GWP of 1), a patented 3M product, is reported to be the most widely used replacement for HFC fire protection systems around the world. There are technical challenges in applications involving large spaces as Novec 1230 cannot be piped long distances (i.e. it boils off) and requires pocket systems that need to discharge together to be effective. In addition to this, inert gas systems are heavier, have a larger footprint and can take 60 seconds to discharge when compared to 10 seconds for HFC systems. These are important technical disadvantages in certain applications such as military planes or naval vessels.

The relatively low level of annual consumption of HFCs in fire suppression mean that it is one of the smallest annual consumers of the bulk imported gas. Further fire protection systems are not designed to emit gas except in response to a fire emergency. The whole design intent of a fire protection system is to ensure effective containment to guarantee the gas charge is available when it is required.

Accidental discharges of fire protection systems do occur. Although the frequency of such events is not known, they are thought to be quite rare. In general, it is safe to say that losses to air from fire protection systems is a very small fraction of the total installed HFC bank.

10 Foam

Foam blowing agents comprised around <3% (~15 tonnes) of all bulk HFCs imported into New Zealand in 2016. Unlike almost every other major and minor application of HFCs, a proportion of this material is emitted to air in the year of import, and the balance is gradually released over several decades as the foam cells and structures break down either whilst in use, or in land fill.

HFC formulations are generally used where thermal insulation properties are critical and the application does not allow a great deal of space for thick foam insulation, for instance in hot water storage systems where the foot print of the system is important for ease of installation in confined spaces.

Wherever the application allows for a thicker wall pentane foam blowing systems tend to be used, although it has to be noted that HFC foam blowing systems require much lower investment costs compared with using a flammable blowing agent.

End use applications include commercial refrigeration cabinets, refrigerated transport for road and intermodal containers (road and rail), insulation panel produced in batches on a small scale, block or moulded foam, and spray insulation in agricultural applications.

The foam sector is a very specialised sector and HFCs are consumed via systems houses that are supplied in various blends that comprise HFC-365mfc (GWP of 794) and HFC-245fa (GWP of 1030), with small volumes (~7%) of HFC-227ea (GWP of 2900).

Rheem manufactures about 85% of all hot water storage services sold in New Zealand, and manufactures the foam insulation at its factory in Auckland using non-HFC foam blowing systems with a GWP of 1.

11 Aerosols (including medical)

The main synthetic gas used in aerosol applications is HFC-134a (GWP of 1,300) with some HCFC-123 consumed for sports medicine applications.

The main applications for HFCs in aerosol formulations include:

- Technical aerosols (including dusters for computers and instrumentation, freeze sprays, flux removers, mould release agents, and electronic contact cleaners);
- Products for use in hazardous areas (including paint marking applications, and blast bags for setting explosives);
- Safety aerosols (including tyre inflators, safety signal horns and insecticides for use in planes and restricted areas);
- Medical inhalers for asthma or sports medicine pain relief;
- Consumer aerosols (including cosmetic and hair care products), and
- Novelty aerosols (including silly string, wine cork removers, spray snow and noise makers).

All of these uses are serviced by aerosol products filled and packed overseas.

Up until 2012 Arandee was consuming more than 10 tonnes of HFC 134a annually for manufacturing of aerosol formulations, mainly as a propellant for insecticides for use in planes and restricted areas.

Arandee moved its manufacturing to Thailand in 2012, probably as a result of the economic impact of the ETS on the cost of HFCs, but also due to the low wages in Thailand relative to New Zealand.

There is no known consumption for aerosols in New Zealand in 2016 and a reasonable prediction is to assume there will be no change until 2030.

Imported aerosol product is expected to be found in New Zealand for at least the following applications:

- HFC-134a is widely used as the propellant in medical treatments for asthma and chronic obstructive pulmonary disease, none of these products are manufactured in New Zealand and must be imported;
- Laser hair and skin treatments consume HFC-134a where it is used as a cryogen spray cooling, whereby the laser treatment device delivers a spurt of HFC-134a to the treatment area just prior to the laser treatment pulse;
- Cosmetic and hair care products such as TRESemme imported into Australia by Alberto Culver (a division of Unilever) contains HFC-152a in order to comply with volatile organic compound requirements under the US Federal Clean Air Act. It is thought that this sort of product is likely to be found on the market in New Zealand as well, and likely imported by the same companies;
- Novelty aerosols products, sold in party supply stores for instance, which are all imported, mostly from China. In a similar study of HFC use in Australia it was noted that most of these products, while readily available in various retail outlets, were obviously not being reported by importers, possibly because they were simply unaware that these ‘harmless’ party products contained a reportable substance. It is thought likely that the situation is the same in New Zealand.

HFO-1234ze (GWP of 6) is considered the main low GWP alternative to replace HFC-134a or HFC-152a (GWP of 140) as a non-flammable propellant in non-medical applications.

Metered dose inhalers have no near-term low GWP alternative and HFCs will be required for many years in order to provide reliable and effective therapy for asthma and chronic obstructive pulmonary disease.

However, dry powder inhalers are already used in some instances as a not-in-kind technology, and hydrocarbons are being trialled as an alternative to HFC-134a in Argentina as part of a UNDP program, these are promising developments.

Aerosols are increasingly becoming the accepted delivery mechanism of choice for medications and although dry powder is a proven technology it could not replace aerosols in all instances. If HFO-1234ze(E) or other unsaturated HFCs were found to be a suitable substitute, it could still take many years to displace HFC-134a, as any new medium would require approval for medicinal use in New Zealand.

12 Conclusions

There are very few industries in the world that have the opportunity to plan global and co-ordinated adoption of a new generation of technology. And of the few that could, the opportunities to do so are rare. For various reasons, the refrigeration and air conditioning (RAC) industry is one such industry, where the supply lines are effectively so concentrated, and require such large capital investments to deliver, that the stakeholders are capable of co-ordinating generational change in the core technology – the refrigerant gases.

These substances are the thermal media that play a central role in the global economy, particularly in the essential role of preserving food along the cold food chain, but also in innumerable health, science, industrial, manufacturing and building environment applications. The scale of the global industry, and its central role in our modern way of life, also mean that a great deal of refrigerant gases are required, and a great deal of energy is consumed in delivering the energy services that refrigerating technology provides.

Decisions on the nature and performance of refrigerant gases can have profound impacts in the long term on the global economy, and as has been previously proven, on the global environment. In recent decades for instance the world has witnessed both a serious threat to global health, the impact of CFCs on the ozone layer, minimised and indeed reversed by global action, and a resulting co-benefit in avoided greenhouse climate forcing.

For these reasons, participating in and possibly influencing a generational change in this technology is both a significant responsibility and an important opportunity.

New Zealand is in a strong position to meet HFC consumption limits of an eventual international phase down.

There is reasonable confidence that lower or zero GWP working gas options and technologies are either viable now, or will be viable and commercially available on the near horizon – 2 to 5 years - for the majority of applications.

A small number of very demanding applications – for instance the fishing fleet – do not have a clear, economically and technically viable path to a low GWP option at this time, however those applications are in the minority.

The industry is rapidly approaching a fourth wave of evolution in the core technical elements of RAC equipment, that is the refrigerant gas employed as the thermal medium, and dozens of incremental but significant improvements in component design including to compressors, heat exchangers, condensers and materials employed. As a result, a new wave of design options is opening up for equipment designers, and further diversification of product lines and of refrigerants can be expected.

This raises a number of potential supply line, trade practice and work skills obstacles that need to be addressed to prepare for the inevitable diversification of the working bank to include a higher proportion of flammable and mildly flammable refrigerants.

Significant churn of equipment and appliances before their optimal end-of-life could flow from a rapid increase in HFC prices towards the end of a HFC phase down, with subsequent increases in direct emissions of older generations of refrigerants from retiring equipment. Enhanced controls on end of life emissions from retiring equipment could significantly alleviate that potential environmental impact.

None of the obstacles to transition to a lower and zero GWP refrigerants are deemed to be insurmountable. Government has a range of options to consider in regard to the role it could play in preparing for this next phase of evolution of the central technologies employed in this sector, in supporting industry adoption of new technology, and in facilitating a smooth and least costly transition.

Finally, as the technology involved consumes a significant proportion of all sent out electricity in the country, a detailed assessment of the potential costs and benefits of a HFC phase down, and the potential for magnifying cost savings with appropriate energy efficiency policy settings, is recommended.

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SNZ 2014	2013 Census, Statistics New Zealand 2014.
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E3 2015	Residential Energy Baseline Study: New Zealand, Department of Industry and Science, prepared by EnergyConsult on behalf of the trans-Tasman Equipment Energy Efficiency (E3) programme, August 2015.
ECCA 2017	Energy Efficiency (Energy Using Products) Regulations 2002, Energy Efficiency and Conservation Authority, 2002 to 2016.
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EPA 2016	Synthetic Greenhouse Gas Levy Report, Environmental Protection Authority, FY 2013/4 to FY 2015/6.
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MfE 2012	CRL Energy Ltd, Hennessy W, Gazo G. Inventory of HFC, SF6 and Other Industrial Process Emissions for New Zealand 2011. A report by CRL Energy Ltd to the New Zealand, Ministry for the Environment, 2012.
MoT 2017	Ministry of Transport, Motor vehicle stock model for new and used vehicles, 2017.

RT 2017a	Report of the Corporate Trustee – Year ended 31 March 2017, Recovery Trust for the Destruction of Synthetic Refrigerants, 2017.
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SNZ 2017	Infoshare: Group Transport - TPT: Table Motor Vehicles Currently Licensed by Type (Annual and 6 Months), Statistics New Zealand 2017.
UNEP 2013	Report of the Technology and Economic Assessment Panel, Decision XXIV Task Force Report, Additional Information on Alternatives on ODS, United Nations Environment Programme, 21 October 2013, September 2013.

Glossary

Article 5 Countries	Article 5 countries are developing countries (e.g. African nations; China, India and Thailand; and South American and most Middle Eastern countries) and non-Article 5 countries are developed countries (e.g. Australia; European Union members such as Germany, Denmark and United Kingdom; Japan; Canada and the United States).
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.
Azeotrope	See refrigerant glide.
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, demand estimates (i.e. leakage plus local manufacture minus exports) is reconciled with the top down data (i.e. bulk imports), except in 2011/2 where stockpiling occurred and adjustments were made to account for changes in industry behavior.
Bulk importers	Companies registered to participate in the NZ Emissions Trading Scheme to import bulk HFCs that mostly arrive in disposable cylinders nominally 11 to 14 kg depending on the species and ship borne ISO containers each carrying between 10 and 18 tonnes of gas (depending on the type).
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 New Zealand 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'.
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.
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 kWr to 20 kWr, 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 is a measure that quantifies different greenhouse gases in terms of the amount of carbon dioxide that would deliver the same global warming.
Direct emissions	Global warming effect arising from emissions of refrigerant, or any other 'greenhouse gas', from the equipment over its lifetime.
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.
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_2O); 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.
High GWP substances or refrigerants	This term is used to refer to refrigerants commonly used today with GWPs greater than 1400. This includes the widely employed HFC-404A (GWP of 3922), HFC-410A (GWP of 2088) and HFC-134a (GWP of 1430) (Also refer to definition of Reduced GWP refrigerants and Low GWP Refrigerants). This term is used to refer to substances commonly used today such as HFC-404A (GWP of 3922), HFC-410A (GWP of 2088) and HFC-134a (GWP of 1430). Whereas HFC-32 (GWP 675) and future blends with reduced GWPs are defined as reduced GWP substances as they have reduced GWP relative to those historically used by application. For example, N40 (R-448A) with a GWP of 1387 is a zeotropic blend designed to serve as a replacement for HCFC-22 and HFC-404A in supermarket refrigeration retrofits or new systems is defined as a reduced GWP refrigerant versus the substances it replaces (also refer to low GWP substance definition).
Hydrocarbons (HCs)	The term hydrocarbon refers to the main types and blends in use in New Zealand 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 deplete the ozone layer, but have less potency compared to CFCs. Many HCFCs are potent greenhouse gases. HCFC-22 is the most common refrigerant in the New Zealandn 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.
Hydrofluoro-olefins (HFOs), and HFO blends	Chemicals known as hydrofluoro-olefins that contain hydrogen, fluorine, and carbon, and are described as unsaturated HFCs. They do not deplete the ozone layer and have very low GWP values. For example, HFO-1234yf, with a GWP of 4 and HFO-1234ze with a GWP of 6.
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.
kWr	Refers to kilowatts of refrigeration capacity whereas kW relates to kilowatts of electrical power.
KWh	Kilowatt hour (1 watt hour x 10^3).
Low GWP substances or refrigerants	This term is used to refer to refrigerants with a GWP of less than or equal to 10, including the 'natural' refrigerants (CO2, Ammonia, hydrocarbons), and the newly commercial HFOs being scaled up by the major synthetic greenhouse gas manufacturers for use in all new passenger vehicles in Europe by 2017, that are also sometimes referred to as low GWP HFCs (also refer to the definitions for High GWP Refrigerants and Reduced GWP Refrigerants).

Low temperature refrigeration	Temperatures below 0^oC 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 New Zealand 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.
Ozone depleting substances (ODS)	Chemicals that deplete the ozone layer (e.g. HCFCs).
Pre-charged equipment (PCE)	Pre-charged equipment is defined as air conditioning equipment or refrigeration equipment (including equipment fitted to a motor vehicle) that is imported containing a hydrofluorocarbon (HFC) or hydrochlorofluorocarbon (HCFC) refrigerant charge.
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.
Reduced GWP substances or refrigerants	A number of recently developed or used HFC substances with a GWP lower than those commonly used today such as HFC-32 (GWP 675) and similar blends, with GWPs less than 1400 and greater than 10, are referred to as reduced GWP refrigerants as they have significantly reduced GWP relative to those refrigerants that they are designed to replace. For example, N40 (R-448A) with a GWP of 1387 is a zeotropic blend designed to serve as a replacement for HCFC-22 (GWP of 1810) and HFC-404A (GWP of 3922) in supermarket refrigeration retrofits, or in new systems (also refer to definition of High GWP Refrigerants and Low GWP Refrigerants).
Refrigerant	Working fluid in the vapour compression refrigeration cycle.
Refrigerant bank	The ‘bank’ of refrigerant gases is the aggregate of all compounds and substances employed as working fluids in the estimated 44 million mechanical devices using the vapour compression cycle in New Zealand.
Refrigerant charge	The original refrigerant charge of refrigerant used as the working fluid for heat transfer inside a piece of equipment.
Refrigerant consumption	The Montreal Protocol definition of consumption is bulk imports plus manufacturing minus exports. Australian has not manufactured refrigerant since 1996. Bulk refrigerant is imported and consumed largely for servicing the existing refrigerant bank of equipment, as well as charging new equipment not imported as pre-charged equipment (PCE) and in other applications including foams, fire protection, aerosols, export and other.
Refrigerant Demand	Refrigerant demand, as defined by the Expert Group for the purposes of this study, is refrigerant required to replace refrigerant lost in total calculated annual leaks from refrigerating equipment, plus refrigerant use in manufacturing and in commissioning of new equipment imported without a refrigerant charge.
Refrigerant glide	The difference between the saturated vapour temperature (or dew point is the temperature at which all of the refrigerant has been condensed to liquid) and the saturated liquid temperature (temperature at which a liquid refrigerant first begins to boil in the evaporator) is referred to as the temperature glide of the refrigerant. At a given pressure, single component refrigerants such as HFC-134a have zero glide and are therefore azeotropes. Refrigerant mixtures (blends) behave somewhat differently and have measurable temperature glide when they evaporate (boil) and condense at a constant pressure. HFC-507A is an azeotropic blend whereas HFC-404A is a near azeotrope.

Refrigerant leak rate or effective leak rate	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 plus; gas that is lost along the supply chain. 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.
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.
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 first Kyoto Protocol commitment period were calculated based on AR2.
Fourth Assessment Report (AR4)	Fourth Assessment Report of the United Nations Framework Convention on Climate Change, released in 2007. Australia's legally binding emission obligations under the second Kyoto Protocol commitment period are calculated based on AR4.
Self-contained RDC	Refrigerated display cabinet with its refrigerating machinery sited remotely from the cabinet structure.
Synthetic greenhouse gases (SGGs)	SGGs include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6).
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 modeling, 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 $2^{o}C$ and frozen $-20^{o}C$.
Walk-in cool room	A walk-in cool room is a structure formed by an insulated enclosure of walls and ceiling, having a door through which personnel can pass and close behind them. The floor space occupied by this structure may or may not be insulated, depending on the operating temperature level.

Abbreviations

AC	Air conditioning
AR2	Second Assessment Report of the IPCC
AR4	Fourth Assessment Report of the IPCC
CO_2-e	Carbon dioxide equivalent
EOL	End-of-life
GHG	Greenhouse Gas
GWh	Gigawatt hour
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HVAC&R	Heating, ventilation, air conditioning, and refrigeration
IPCC	Intergovernmental Panel on Climate Change
kt	Kilo tonnes, or thousand tonnes
MEPS	Minimum energy performance standards
MAC	Mobile air conditioning
Mt	Mega tonne, or million tonnes
ODS	Ozone depleting substances
OEM	Original Equipment Manufacturer
OLPA	Ozone Layer Protection Act 1996 and Ozone Layer Protection Regulations 1996, and amendments
RAC	Refrigeration and air conditioning
RCFC	Refrigerated cold food chain
SGG	Synthetic greenhouse gas
Tonne	Metric tonne
UNFCCC	United Nations Framework Convention on Climate Change

Appendix A: Registered Bulk Gas Importers

Bulk importers that participate in refrigerant recovery and pay the levy:

AHI Carrier NZ Ltd

BOC Ltd

Chemiplas NZ Ltd

Cooling Supplies (ILYS Ltd)

Heatcraft NZ Ltd

Patton Ltd (now Beijer Refrigeration)

Realcold Ltd (now Beijer Refrigeration)

Refrigeration Specialties Ltd

Companies registered with EPA to import bulk HFCs that are not captured in the levy data:

Axieo Operations NZ Ltd

B & C Martella Ltd

Blueon Ltd

CoolDrive Ltd

Ixom Operations Pty Ltd

Pan Pacific Auto Electronics Ltd

Polymer Group Ltd

Tauranga168 Asia Supermarket Ltd

Temperzone Ltd[14]

[14] *Temperzone is a local manufacturer of stationary air conditioning equipment, and importers of pre-charged equipment do not participate in refrigerant recovery and pay the levy.*

Appendix B: 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 the economy.

Data underlying the stock model

The structure of this stock model was first developed in 2006 during research for what became the first edition of Cold Hard Facts (CHF1), a study of the HVAC&R industry in Australia.

This Expert Group stock model for New Zealand includes estimates of stocks of equipment in all of the major classes of equipment and main applications from as early 1990 through to 2030.

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

Since 2007 when the CHF1 was published, the Australian 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, new sources of data and market intelligence have been incorporated into the Australian stock model that are relevant to the construction of the New Zealand model and included:

- Reviews of data included in Regulatory Impact Statements (E3 2016) and product profiles for air conditioning equipment (i.e. split systems, chillers, close control, portable, etc.), domestic refrigerators and freezers (E3 2015), non-domestic refrigeration (E3 2017), and other products;
- 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;
- 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.

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 Φ (x;μ,σ) 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 manufacturers' 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 pre-charged equipment import data in Australia 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 New Zealand new sales mix by refrigerant species over this period was assumed to be very similar.

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 C Technical resources and assumptions* for details of average charge and leak rate values used in calculations.

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 and fire protection.

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.

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.

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 5: 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)	3800	4750
CFC-12 (1)	8100	10900
HCFC-123	90	77
HCFC-22	1500	1810
HCFC-141b	-	725
HCFC-142b	1800	2310
HCFC-406A	-	1943
HCFC-408A	-	3152
HCFC-409A	-	1585
HCFC-225ca (3)	-	122
HCFC-225cb (3)	-	595
Hydrofluorocarbons (HFCs)		
HFC-125	2800	3500
HFC-134a	1300	1430
HFC-23	11700	14800
HFC-236fa	6300	9810
HFC-404A (2)	3260	3922 (3920) (4)
HFC-407C	1526	1774 (1770)
HFC-407F	1824	1825 (1820)
HFC-410A	1725	2088 (2090)
HFC-417A	1955	2346
HFC-428A	2930	2265
HFC-438A	1890	2265
HFC-507A	3300	3985
HFC-227ea (3)	2900	3220
HFC-245fa (3)	-	1030
HFC-365mfc (3)	-	794
Lower or nil GWP alternatives		
HC-600a (4)	-	3
HC-290	-	3

CO_2 (R744)	-	1
Ammonia (R717)	-	0
HFO-1234yf [5]	-	4
HFO-1234ze(E)	-	6
HFO-1233zd	-	6
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. 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.
3. Not used as refrigerant in RAC applications, substances used for foam blowing applications, fire protection and as solvents.
4. The values in brackets for HFC-404A, HFC-407C, HFC-407F and HFC-410A are those used by the New Zealand Emissions Trading Scheme for calculating emissions.
5. HC-600a and HC-290 are not published in the AR2 or AR4.
6. These are new substances and were not reviewed, included or published in the IPCC, Fourth Assessment Report published in 2007. The GWP values of HFO substances are those cited by DuPont and Honeywell as based on AR4. The GWPs of HFOs has recently re-evaluated by the UN with HFO-1233zd and HFO-1234ze with a GWP of 1; and HFO-1234yf with a GWP of less than 1. This report uses previous cited values to maintain consistency.

The ASHRAE refrigerant mass chemical compositions are used to calculate the GWP values of these blends 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 New Zealand legislation that refers to the GWP of HFCs use the values listed originally in AR2, based on New Zealand’s obligation under the Kyoto Protocol.

Table 6: ASHRAE Refrigerant designation and refrigerant mass composition of common blends used in New Zealand.

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 are from ANSI/ASHRAE 34-2010, Designation and Safety Classification of Refrigerant, which is published on the ASHRAE website.

Table 7: 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%	3.0%	12	80%
AC2	Single split: ducted: 1 & 3 phase	4.7	8.0%	3.0%	15	80%
AC3	Non-ducted: unitary 0-10 kWr	0.75	4.0%	3.0%	12	80%
AC4	Portable and dehumidifier AC 0-10 kWr	0.5	1.0%	1.0%	7	90%
AC5-1	<500 kWr	60	8.0%	4.0%	15	80%
AC5-2	>500 & <1000 kWr	210	8.0%	4.0%	20	80%
AC5-2	>500 & <1000 kWr (HFC-123)	180	1.0%	n.a.	20	80%
AC5-3	>1000 kWr	620	8.0%	4.0%	25	80%
AC5-3	>1000 kWr (HFC-123)	670	1.0%	n.a.	25	80%
AC6-1	RT Packaged systems	12.2	8.0%	3.0%	15	80%
AC6-2	Multi split/VRF	8.0	8.0%	4.0%	15	80%
AC6-3	Close control	30.0	8.0%	4.0%	15	80%
AC6-4	HW heat pump: commercial	110.0	8.0%	4.0%	20	80%
AC6-5	Pool heat pump	2.8	8.0%	3.0%	15	80%
AC7	HW heat pump: domestic	0.9	3.0%	3.0%	10	80%
MOBILE AIR CONDITIONING			Crash	HFCs[15]		
MAC1-1	Passenger vehicles: new fleet	0.62	0.5%	6.0%	-	60%

[15] *The leak rate nominated in Table 7 for Passenger and light commercial vehicles is a service rate rather than a leak or emission which is estimated to be 10% per annum.*

MAC1-1	Passenger vehicles: used fleet	0.62	0.25%	3.5%	-	60%
MAC1-2	Light commercial vehicles: new fleet	0.62	0.5%	6.0%	-	60%
MAC1-2	Light commercial vehicles: used fleet	0.62	0.25%	3.5%	-	60%
MAC2-1	Rigid truck and other	1.00	-	6.0%	-	60%
MAC2-2	Truck: articulated	1.00	-	6.0%	-	60%
MAC2-3	Commuter buses	1.00	-	6.0%	-	60%
MAC2-4	Buses (> 7m)	9.00	-	8.0%	-	60%
MAC3-1	Passenger rail	7.00	-	8.0%	10	60%
MAC3-2	Locomotive	4.00	-	8.0%	10	60%
MAC4	Off-road, defence and other (boat, etc.)	2.75	-	8.0%	15	60%
DOMESTIC REFRIGERATION						
DR1	Domestic refrigerators & freezers	0.140	n.a.	1.0%	-	80%
DR2	Portable and vehicle refrigerators	0.06	n.a.	1.0%	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	25.0%	20.0%	25	70%
RCFC3-1	Supermarket refrigeration: small	160.0	15.0%	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	15.0%	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 7* 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.

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.