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Heat pump refrigerant guide

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Project team

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Heat pump refrigerant guide

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Cover image source: Mayekawa Australia

Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

What is RACE for 2030?

RACE for 2030 CRC is a 10-year co-operative research centre with AUD350 million of resources to fund research towards a reliable, affordable, and clean energy future. https://www.racefor2030.com.au

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Executive summary

Heat pumps

Heat pumps are an emerging technology in the context of decarbonising heating systems, which has typically been delivered using fossil gas boilers. The current range of commercially available heat pumps are ideal for heating hot water used in applications such as space heating, pool heating, industrial processes, domestic hot water and many others. Over the next two to five years, heat pumps for higher temperatures and larger capacities are expected to be commercially available and expected to support a large portion of Australia's decarbonisation targets. As described in the report *Harnessing Heat Pumps for Net Zero* (EEC, 2023)[1], "Ambitious deployment of heat pumps across residential and commercial buildings and industrial processes could cumulatively reduce energy usage by up to 14,391 PJ and save 746 Mt CO_2-e of greenhouse gas emissions by 2050".

Heat pumps offer substantially increased energy efficiency for heating water when compared to combusting fossil gas, and as such, heat pumps are set to play a key role in the transition to net zero emissions in Australia and across the world.

Heat pumps can vary in type with the inlet heat source potentially coming from either air, water or ground water. They can also be installed into systems of various configuration types, from simpler plug-and-play, off-the-shelf solutions to fully integrated and customised solutions.

Limitations exist on what type of systems and climatic conditions some types of heat pumps can operate in, depending on both technologies utilised inside the heat pump and the refrigerant. For example, some units are built to produce high-temperature hot water in very cold climates, and some are not. Selecting the right type of heat pump, based on the right climatic conditions is the key to success.

Refrigerants

Although heat pumps offer higher energy conversion efficiency compared to combusting fossil gas, they do require a refrigerant. When selecting a heat pump, the choice of refrigerant is a critical component because the design, installation and operating requirements can change based on the classification and rating of refrigerant.

Refrigerants have undergone significant transformation since initial creation as the world and wider industry came to realise the impacts of refrigerant leakage on ozone depletion, then on global warming, and more recently, their contribution to PFAS contamination.

Refrigerants have a classification and a rating, with ozone depletion potential (ODP) and global warming potential (GWP) clearly identified for each refrigerant type, alongside a classification that indicates flammability and toxicity.

[1] Energy Efficiency Council and Australian Alliance for Energy Productivity 2023, Harnessing heat pumps for net zero, available from https://www.a2ep.org.au/post/harnessing-heat-pumps-to-unlock-huge-energy-and-emission-savings-new-report-from-a2ep-and-the-eec

Classifications and ratings have significantly helped the development of standards, policies and regulations which have resulted in phase-out of refrigerants with high ODP ratings already and which are now focusing on phasing out refrigerants with higher GWP ratings.

The classifications and ratings for the refrigerant inside the chosen heat pump are drivers for identifying key design requirements, and operational considerations for a heat pump project.

Key takeaways

When trying to identify the right heat pump for a project, the following are key considerations:

- Environment impacts associated with direct refrigerant leakage.
- Operational requirements, such as climate, building/application type and required hot water temperatures.
- Financial considerations, such as capital cost, operating cost and on-going maintenance cost.

The overall view of the various impacts must be considered as a priority given that there are multiple situations to consider, for example:

- A project may deliver increased energy conversion efficiency compared to a traditional fossil gas combustion process, however, the carbon emissions saved may be negatively impacted or exceeded through carbon emissions if a refrigerant with a higher GWP is used and direct refrigeration leakage occurs throughout the lifetime of the equipment or during decommissioning.
- A project may be cheaper in terms of capital expenditure but have higher operating and/or maintenance costs. As an example, higher maintenance costs could be seen if a high GWP refrigerant is used, which is destined to be phased down and create supply scarcity.

The following key steps are provided in this report as a guide to assess different refrigerant options, with reference to relevant Australian Standards, when replacing a fossil gas boiler with a heat pump:

- Identify if the plantroom/area has adequate existing ventilation and signage.
- Identify the general occupancy category for the chosen location for the new heat pump(s), including all refrigerant locations.
- Choose a suitable heat pump technology.
- Identify and include all necessary modifications to the existing plant room/areas, and any other spaces in the design documentation for the project.
- Document the design and operational requirements, including all relevant safety manuals and clearly label them for easy access on the site.

As described in the report, *The Rising Threat of HFOs and TFA to Health and the Environment,* (ATMOsphere, 2022)[2], "Alternatives with natural refrigerants should be preferred and promoted", natural refrigerants are currently viewed as the best way to avoid environmental impacts from refrigerant leakage. However, utilising them is likely to come with either higher cost for the equipment, or higher costs to modify existing plantrooms/areas and surrounding spaces (retrofit).

Combinations of natural refrigerants and HFO refrigerants in various configurations such as cascade, can offer a low GWP solution that can deliver reliable heating hot water at high temperatures (i.e., >70 °C) and may prove an economically viable pathway if natural refrigerant options are unable to be utilised in totality for a given application.

[2] ATMOsphere 2022, The Rising Threat of HFOs and TFA to Health and the Environment, available from https://atmosphere.cool/hfo-tfa-report/

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1 Preface

This report aims to simplify the complicated topic of refrigerants. It provides a simplified view on which refrigerant may be suitable for use in a commercial or industrial heat pump project, focussing primarily on the decarbonisation of heating hot water systems using heat pumps, whilst also providing a general outline of relevant considerations that could translate through to other applications.

Ever since cooling systems effectively transitioned off using blocks of ice for cooling spaces or wetted hessian style sheets to achieve evaporative cooling in hot and dry climates, refrigerants have played an important role in our society.

Refrigerants provide end user services such as:

- Increasing food shelf life by keeping it cold at the farm, during transport, at wholesalers and retailers, and finally, at our homes.
- Maintaining comfortable conditions via cooling and heating the inside our buildings, homes and in transport vehicles, such as planes, trains and automobiles.
- Keeping medical supplies within necessary temperature ranges (e.g. vaccines).

The re-emergence of natural refrigerants has become more pronounced as the industry and society learns more about the impact of refrigerants on our planet, and on the people that inhabit it.

It is critical that the right refrigerant is used in the right application for both our environment and safety. This paper will provide guidance on the safe application of both natural and synthetic refrigerants and assist in identifying key considerations that are refrigerant specific, rather than being equipment type or manufacturer-specific.

2 Reading guide

This document includes some refrigerants history, in addition to some basic information on refrigerants and the typical refrigeration cycle that many readers may already be familiar with.

A decision tree for a retrofit project is provided as the first section of this report, which helps to set the scene for intention of this report, which is to provide information on refrigerants that is easy to understand and apply into a thinking process for a heat pump upgrade/installation project.

Information is provided as context for those that have had limited prior exposure to refrigerants, and as such, for advanced readers that are focussing on standards, or more detailed considerations, it is recommended to commence reading from Section 4.

3 Retrofit decision tree

A decision tree process for a retrofit project is presented below where natural gas boilers where being used for heating. In this scenario, heating hot water is required only.

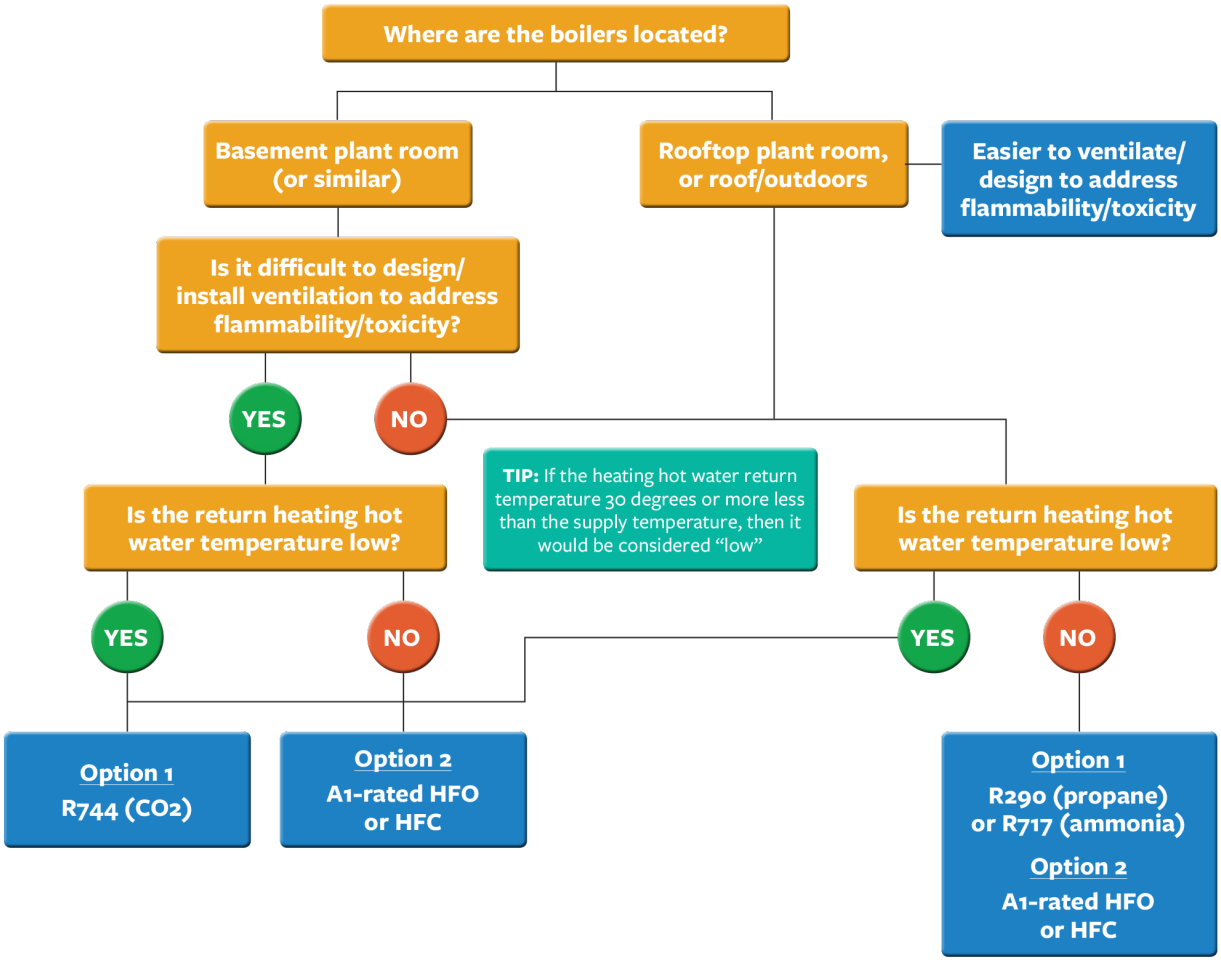

Figure 1: Refrigerant choice decision tree for boiler retrofit (heating only)

The decision referenced here refers to the simpler components of an overall decision, focusing on equipment location and the return temperature on the heating hot water loop.

At a simple level, the below key factors could be considered:

- The easier it is to ventilate to address the flammability/toxicity factor, the more natural refrigerants become preferable.
- If you have lower return water temperature on your heating hot water loop, R744 (CO_2) will almost always outperform other alternatives and will likely offer the best return on investment (ROI).
- If it is difficult to ventilate spaces onsite, and you must use indoor plantrooms, the A1-rated HFO or HFO/HFC blends will provide you an option to install a heat pump.
- At a basic level, there is always a suitable natural refrigerant option, and in general, a way to mitigate any risks associated with their use except in some rare cases where plantrooms are not able to be ventilated.

This decision process is provided at the beginning of the report to provide some initial context and key take-aways which can be considered as you read through the remainder of this report.

4 Background

4.1 The refrigeration cycle

Broadly speaking, a refrigerant is a fluid that is used to absorb heat from another medium, such as air, water or glycol. The refrigerant is fully contained inside an operating system, which in its simplest form contains an evaporator, condenser, compressor and expansion valve.

Many people hear the word refrigerant and immediately think of their car air conditioner as this is a common point of interaction with the term. Refrigerants are also contained in refrigerators, split systems air conditioners, and other items such as camping refrigerators.

The basic refrigeration cycle is shown below.

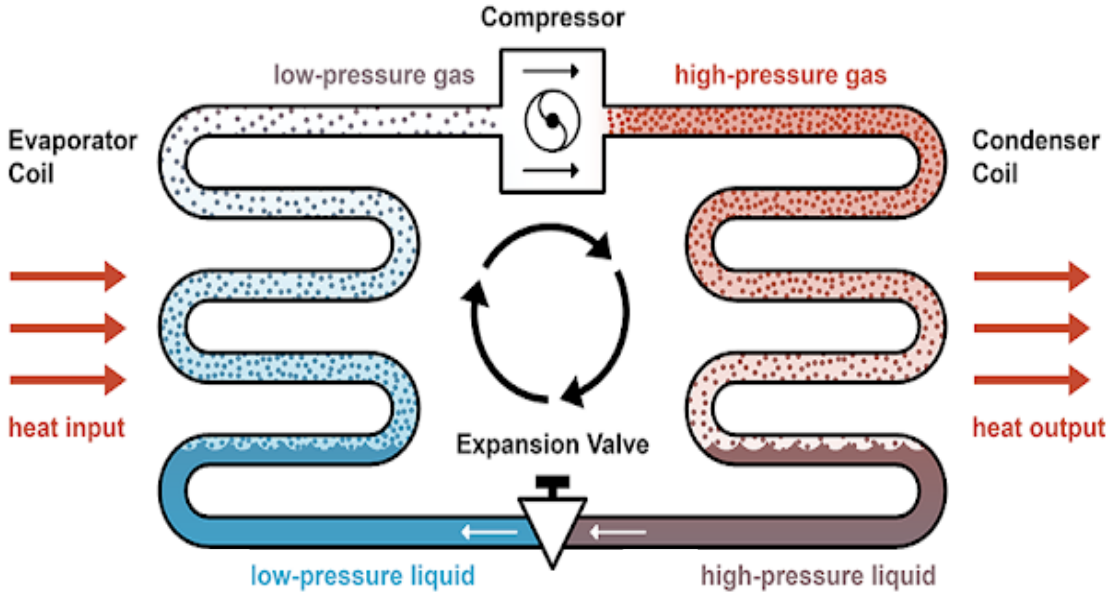

Figure 2: Basic refrigeration cycle[3]

The above image shows the refrigerant cycle is absorbing and rejecting heat by changing state within the systems, from a liquid to a vapour (gas) and vice versa. Beyond this simple diagram there are many variations of system design, many of which are bespoke based on refrigerant type.

Refrigerants vary in their heat transfer capability, pressure and general fluid composition. This report will identify some key characteristics of common refrigerants and identify some common use cases.

[3] Overbey, D, The Vapor-Compression Refrigeration Cycle, available from https://danieloverbey.blogspot.com/2021/11/the-vapor-compression-refrigeration.html

4.2 History of refrigerants

Refrigerants have been used in a variety of forms since the 1800s. Until around the 1930s, most refrigerants were commonly used solvents or fluids rather than specifically developed refrigerants.

Following this, specifically developed refrigerants were introduced, which were called chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

- CFCs consist of carbon, chlorine, and fluorine.
- HCFCs are the same structure as CFCs, except for the addition of a hydrogen atom.

During the initial developments of these refrigerants, it was identified that the chemical mix influenced some key aspects of a refrigerant, these being its boiling point, flammability and toxicity.

CFCs were identified as having high ozone depletion potential (ODP) ratings, with high leakage rates of CFCs identified as the leading cause of the depletion of the ozone layer, leading to CFCs being phased out rapidly under the Montreal Protocol in 1987. HCFCs where then added to the phase out, given they also contained chlorine, which was the key element that led to the degradation of the ozone layer. The phase out left focussing on hydrofluorocarbons (HFCs), which are comprised of hydrogen, fluorine and carbon.

HFCs were later identified as also having high global warming potential (GWP), with the industry now seeking refrigerant options that have both low ODP and GWP ratings. This has given rise to hydrofluoroolefins (HFOs), which still contain hydrogen, fluorine and carbon, but are a derivate of olefins in lieu of alkanes (paraffins). The key difference being that olefins have carbon atoms linked by a double bond, while alkanes having single bonds.

HFOs generally have increased flammability when compared to CFCs, HCFCs and HFCs, and this is considered the trade-off for lowering ODP and GWP. Many HFOs have also been linked to per- and polyfluoroalkyl substances (PFAS) contamination, driving the industry towards natural refrigerants, which are commonly referred to as carbon dioxide (CO_2), propane, ammonia and other hydrocarbons. Water is also utilised as a refrigerant in some use cases.

Natural refrigerants represent a pathway forward that minimises the impact of refrigerants on our environment, and as such, wider adoption is a key challenge in the fight against climate change.

Natural refrigerants have differing requirements to synthetic refrigerants, with compression technology and heat exchangers being key enablers for any natural refrigerant to gain traction in the more mainstream use cases. However, there are also constraints presented in the context of design, installation, and safe operation of natural refrigerant systems that need to be overcome. This paper presents high-level guidance for overcoming these constraints.

4.3 How refrigerants impact our climate

Refrigerants play a key role in the built environment, they impact both the cost and efficiency of equipment and systems, design and installation requirements, operational safety, and finally, greenhouse gas emissions.

The impacts of refrigerant on these areas can be broadly categorised into two following key areas.

4.3.1 Ozone depletion and global warming

There are two main categories that are used to identify the impact of a refrigerant on the environment.

Table 1: Refrigerant environmental impact measures

Category	Description
Ozone depletion potential (ODP)	ODP is associated with certain chemicals, such as chlorinated refrigerants, identified as CFCs and HCFCs. ODP is a measure of how much damage a chemical can cause to the ozone layer compared with a similar mass of CFC-11 which has an ODP rating of 1.0 and is used as the base figure for measuring ozone depleting potential. The lower the ODP rating, the better.
Global warming potential (GWP)	GWP is a measurement that expresses the ability of a given refrigerant to trap heat in the atmosphere. This ability is then scored against the equivalent impact of carbon dioxide (CO_2). The higher the GWP, the longer it will last in the atmosphere.

4.3.2 Greenhouse gas emissions

Greenhouse gas emissions from refrigerant leakage are direct emissions (Scope 1), meaning the refrigerant leaks directly into the atmosphere at the point of use. This is different from greenhouse gas emissions associated with the end-use of electricity, where direct emissions occur at the point of power generation, rather than the point of use (Scope 2).

For quick reference, a non-exhaustive list of emissions scopes in the context of refrigerants and heat pumps is provided.

Table 2: Refrigerant and heat pump emissions scope identification/guide

Scope 1 (direct)	Scope 2 (indirect)	Scope 3 (indirect)
Refrigerant leaks from equipment onsite	Electricity consumption to operate equipment containing refrigerant (sourced from the electricity grid)	Emissions associated with: • Equipment manufacturing (including raw material processing, fuel, energy, etc.) • Transport of equipment to and from site • Installation of equipment onsite • Future recycling of equipment onsite (including refrigerant)

For direct greenhouse gas emissions to occur from refrigerant, leakage must occur. Leakage is not considered normal in the context of operating equipment containing refrigerant, and most often occurs due to poor equipment selection or quality, or poor maintenance.

4.3.3 PFAS

For those reading this report who pay attention to the heating, ventilation, air conditioning and refrigeration (HVAC&R) industry in some more detail, you will possibly have also heard of PFAS, which refers to per- and polyfluoroalkyl substances.

Whilst other products containing PFAS are being used in a variety of industries and applications, refrigerants that can introduce PFAS into our waterways have recently been discussed more. This report will provide indication on the potential for PFAS implications by refrigerant and will assist to identify refrigerants that have long term pathways. In general, these will be substances that do not contribute to this growing global problem as it is a reasonable expectation that these may be banned from use in the future.

There is an Australian Government PFAS Taskforce, which is responsible for the whole-of-government coordination and oversight of Australian Government responses to PFAS contamination.

Refrigerants that have been associated with PFAS are identified in Section 5.

5 Refrigerant classification

Refrigerants are classified according to their toxicity and flammability, in addition to their ozone depletion potential (ODP) and global warming potential (GWP).

5.1 Toxicity and flammability rating

The following table represents the matrix utilised for the classification of refrigerants with respect to their flammability and toxicity rating.

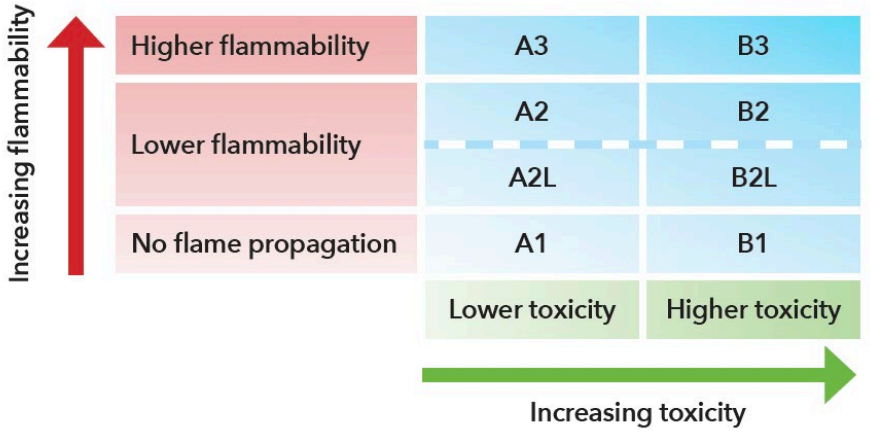

Figure 3: Refrigerant classification matrix[4]

As a reading guide, an A1 rating references low toxicity and no flammability, while a B3 rating being both highly toxic and highly flammable.

[4] A2EP, Commercial and industrial air source heat pump water heaters – Technical Guidelines, available from https://www.a2ep.org.au/post/a2ep-delivers-technical-guidelines-for-commercial-and-industrial-air-source-heat-pump-water-heaters

5.2 Ozone depletion and global warming potential

The following table shows the GWP and classification of some common refrigerants. No ODP values are shown as they are all zero for the shown refrigerants. If the refrigerant is potentially impacted by PFAS, it is also noted.

Table 3: Classification, ODP and GWP with PFAS identification for common refrigerants

Type	Refrigerant	Refrigerant composition (mass %, if blended)	GWP (100-year)	GWP (100-year – Montreal Protocol)	Classification	Impacted by PFAS?[5]
HFC	R134a	N/A	1,470	1,430	A1	Yes
	R410a	R-32/125 (50.0/50.0)	2,285	2,088	A1	Yes
	R32	N/A	675	N/A	A2L	No
	R407c	R-32/125/134a (23.0/25.0/52.0)	1,892	1,774	A1	Yes
	R404a	R-125/143a/134a (44.0/52.0/4.0)	4,808	3,922	A1	Yes
HFO	R1234ze(E)	N/A	1	N/A	A2L	Yes
	R1233zd(E)	N/A	4	N/A	A1	Yes
	R514a	R1336mzz(Z)/1130(E) (74.7/25.3)	1.7	N/A	B1	Yes
	R1234yf	N/A	<1	N/A	A2L	Yes
HFO/HFC blend	R513a	R-1234yf/134a (56/44)	647	629	A2L	Yes
	R454b	R-32/1234yf (68.9/31.1)	516	465	A2L	Yes
	R515b	R1234ze(E)/227ea (91.9/8.9)	320	287	A1	Yes
Natural	R744 (CO_2)	N/A	1	N/A	A1	No
	R717 (ammonia)	N/A	0	N/A	B2L	No
Hydrocarbon	R290 (propane)	N/A	<1	N/A	A3	No
	R600a (isobutane)	N/A	<1	N/A	A3	No

These GWP and ODP values are referenced from a report completed by the International Institute of Refrigeration (IIR)[6].

The Montreal Protocol established regulation of certain substances and at time of development, the GWP ratings were included in the annexes. These GWP values apply under the *Ozone Protection and Synthetic Greenhouse Gas Management Act 1989* in Australia, and they are also the 100-year GWP listings from Intergovernmental Panel on Climate Change (IPCC) fourth assessment report, 2007 (AR4). Detail on the Montreal Protocol is provided as Appendix 1.

[5] ATMOsphere, Refrigerants: Real GWP and PFAS (PDF), available from https://enrad.se/app/uploads/2023/10/Real-GWP-new-version-1.pdf

[6] International Institute of Refrigeration (IIR), Montreal Protocol on substances that deplete the ozone layer. 2022 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC). 2022 Assessment., available from https://iifir.org/en/fridoc/montreal-protocol-on-substances-that-deplete-the-ozone-layer-2022-146932

It is noticeable that most of the lower-GWP HFO, HFC or HFC/HFO blend refrigerants have an increased flammability rating, when compared to the higher-GWP HFC refrigerants. This is a key take-away and forms the basis of the discussion around impacts that may be encountered from utilising these refrigerants as replacements for existing HFC refrigerants with higher GWP ratings.

The classification of a refrigerant plays a large part in the potential use cases, and standards are in place to ensure safety in operation. For example, there is a standard identifying the maximum volume of refrigerant that can be present in an occupied space.

5.3 Classification systems

It has been identified in this report that some refrigerants can be either toxic, or flammable, and as such, there are numerous standards and regulations in place to ensure that people within spaces that contain refrigerant are not adversely impacted.

In general, refrigerant quantities are restricted according to the level of risk posed; based on the following.

- Classification of the refrigerant (i.e., A2L, A2, B2L or A3)
- The occupancy category
- The application (human comfort or other)
- If the system is located above, or below ground.

Occupancy category refers to the nature of the space the refrigerant is contained within and has the following three categories according to the standard, shown with examples. The examples here are not intended to be exhaustive, rather, to be generally illustrative.

Table 4: Occupancy categories, with comments and examples

Category	General comments	Examples
General occupancy (Category 1)	Rooms or parts of buildings where people can sleep, or are restricted in movement, or where an uncontrollable number of people may be present who are not personally acquainted with the necessary safety precautions.	• Hospitals • Supermarkets • Education facilities • Accommodation (i.e., hotels) • Restaurants
Supervised occupancy (Category 2)	Rooms or parts of buildings where only a limited number of people can assemble, with not all being acquainted with the necessary safety precautions.	• Offices • Laboratories • Manufacturing facilities (buildings, walkways)
Authorised occupancy (Category 3)	Rooms or parts of buildings where only authorised people have access. All those with access are therefore expected to be acquainted with all necessary safety precautions.	• Manufacturing facility (operating floor area) • Plant/machinery rooms • Roof of a building (plant area, or general roof area)

Following the identification of the occupancy category, the next consideration is the location of the refrigerant charge:

- **Class I:** Refrigerant containing parts located in occupied space (e.g., self-contained drinks cabinet).
- **Class II:** Compressors and pressure vessels in machinery room or open air (e.g., split system).
- **Class III:** Refrigerant containing parts located in machinery room or open air.
- **Class IV:** Refrigerant containing parts located in ventilated enclosure.

For a quick reference, if the occupancy category is understood, and the classification of the space itself, one has the basis for identifying key requirements and limitations for usage of a given refrigerant.

5.4 Natural refrigerants

Natural refrigerants have been utilised for many years, and in most heat pump related scenarios they are, and should be, a viable consideration. It is worthwhile for us to explore some more details of some of the key natural refrigerants, identified here. These refrigerants are identified specifically due to their suitability for use in heat pump technology, with the below table identifying some key technical and safety considerations.

Table 5: Natural refrigerant considerations overview

Type	R718 (water)	R717 (ammonia)	R744 (carbon dioxide)	R290 (propane)
Description	• Water (H_2O)	• Compound of nitrogen and hydrogen.	• Naturally occurring, abundant in the atmosphere and non-toxic.	• Hydrocarbon, colourless and odourless.
Technical	• Very high boiling point, which can be altered by lowering pressure. • Specialised compression technology required. • Can absorb a lot of heat during boiling, providing a high cooling effect.	• Corrodes copper, meaning the compressor motor must be decoupled from the refrigerant circuit (open drive) and system pipework cannot be copper. • Characteristics offer high efficiency heat transfer with lower quantities of refrigerant comparative to synthetic refrigerants	• Requires specialised compression technology, piping and fittings due to high operating pressures. • Efficiency advantages at both lower (freezer) and higher temperatures (hot water) • High heat transfer rating, making for an excellent refrigerant.	• High efficiency levels at higher temperatures, making for an excellent refrigerant for heat pumps. • Byproduct from natural gas processing and petroleum refining, which links to oil and gas industry. • Lower quantities of refrigerant comparative to synthetic refrigerants
Safety	• Limited safety requirements, non-toxic and non-flammable.	• Toxic, flammable and has a strong odour. • Can be deadly if concentration in a space exceeds 300 parts per million (ppm). • Irritant to both eyes and skin. • Leak detection and ventilation are critical design factors.	• Operates at three to four times the pressure of most refrigerants, posing safety risks in design and operation. • Very dangerous in high concentration due to risk of asphyxiation. • Leak detection and ventilation are critical design factors.	• Highly flammable, and therefore subjected to very similar safety in design considerations as Natural Gas installations. • Leak detection and ventilation are critical design factors.

It must be noted that other natural refrigerants exist, such as isobutane (R600a), M50 and M60, which are identified as potential replacements for refrigerants previously used in some heat pump applications, such as in reverse-cycle air conditioners. These will be explored through the considerations identified in this report for R290 given they are all hydrocarbons, and M50 and M60 are in fact blends containing R290.

5.5 Standard identification

Before modelling some potential heat pump installation, or system upgrade scenarios, relevant standards need to be identified and should be reviewed.

It should be noted that the standards identified here do not constitute a complete set of standards as required for a mechanical and electrical plant upgrade, rather, the standards identified are in the context of impacts that might occur if a heat pump is added into a building. Additional standards may be identified as relevant, relating particularly to unit compliance with local electrical and mechanical standards.

Table 6: Refrigerant-related Australian Standards

Standard	Parts/sections/notes
AS/NZS 5149 refrigerating systems and heat pumps – Safety and environmental requirements	This standard superseded AS 1677 Part 2. Separated into four (4) parts: • **Part 1** - Definitions, classification and selection criteria. • **Part 2** - Design, construction, testing, marking and documentation. • **Part 3** - Installation site. • **Part 4** - Operation, maintenance repair and recovery. Table A.2 in Part 1 contains charge limits for systems. **For refrigerating systems not in scope of AS/NZS 60335.2.40 or AS/NZS 60335.2**.89 the flammable refrigerant charge limits must be in accordance with AS/NZS 5149.1 Table A.2. AS/NZS 5149.3 Clause 9 identifies requirements for leak detection for cases where the practical limit of refrigerant can be exceeded.
AS/NZS ISO 817:2016 refrigerants – designation and safety classification	This standard superseded AS 1677 Part 1 and it identifies the designation and safety classification for refrigerants.
AS/NZS 60335	Annex GG contains charge limitations for appliances (i.e., heat pumps and air conditioners), while AS/NZS 60335.2 also contains relevant information in sections 40 and 89.
AS/NZS 60079 – Australian Hazardous Area Standards	Requirements for the design, selection, and installation of electrical equipment in hazardous areas. These requirements are in addition to the standard requirements for the installation of electrical equipment in non-hazardous areas. These standards also provide a guidance on sources of ignition and safe application.

Standard	Parts/sections/notes
AS/NZS 1200:2000 – pressure equipment	Covers design, materials, manufacture, examination, testing, installation, conformity assessment, commissioning and operation, Inspection, maintenance, repair, alteration, and disposal of pressure equipment (boilers, pressure vessels and pressure piping). Specifically, pressure vessels in Australia are to be designed and registered to AS1210 standards.
AS 4343 – pressure equipment – hazard levels	Specifies criteria for determining the hazard levels of various types of pressure equipment to AS/NZS 1200.
AS/NZS 3788	Specifies the minimum requirements for the inspection, repair and alteration of in-service boilers, pressure vessels, piping, safety equipment, and associated safety controls.
AS1319 – Safety signs for the occupational environment & ISO 7010	These standards would identify the signage standards required for the rooms that contain refrigerant.
AS/NZS 60417	This standard would assist in identifying the graphical symbols that should be in use on the proposed equipment.
SAA HB40.1 – The Australian Refrigeration and Air Conditioning Code of Good Practice.	Covers all systems classifiable as commercial and industrial refrigeration and air conditioning systems, including heat pumps, which use refrigerants listed in Appendix 3, or any other fluorocarbon refrigerant. The Code was developed with the intention of reducing emissions into the atmosphere from refrigerants.

In addition to the above, there is a very useful guide published by Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), called the *Flammable Refrigerants Safety Guide 2013*. This guide was updated in 2018 and is available from here https://airah.org.au/site/site/resources/flammable-refrigerants-safety-guide.aspx.

6 Heat pumps

6.1 How they work

Reverse-cycle air conditioners are heat pumps, if you're looking for a simple way of describing them that is immediately relatable. They transfer heat from air to water or air, or water to air or water. This is shown below, in context of the basic refrigeration cycle already discussed earlier in the paper.

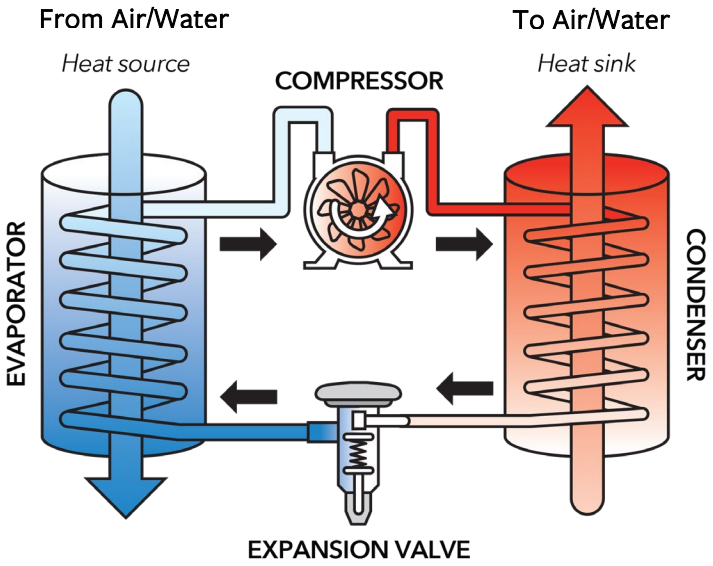

Figure 4: General heat pump schematic in context of basic refrigeration cycle

The different types of heat pumps provided here for reference, intention is to provide a differentiation on heat pump terminology, notably the difference between an air source and water source heat pump as these are the source of the heat that is transferred. Beyond this simple cycle, this paper does not get into any further detail.

6.2 Types of heat pump

6.2.1 Air-source heat pumps

Air-source or 'air-to-water' heat pumps utilise air as the heat source, with ambient air being drawn across the outdoor heat exchangers which contain refrigerant. The refrigerant is pumped around the system by the compressor(s) to another heat exchanger where a secondary fluid, in this case water, absorbs the heat, creating hot water.

Figure 5: Example of an air-source heat pump. Image source: Geoclima Australasia

In the case of the unit shown in the above image, air is drawn through the unit using the fans and heat from this air and from inside the system itself, which is generated due to mechanical work, is transferred to water that is pumped through the heat exchanger.

This type of unit can be provided in the following configurations as a high-level guide:

- Heating only
- Reverse-cycle heating and cooling
- Four-pipe (polyvalent, or multi-function) – capable of providing hot and cold water simultaneously.

Units that can provided simultaneous hot and cold water are inherently more complex and are often limited in terms of overall refrigeration capacity when compared to the heating only or reverse cycle product types.

Units of this type require outside air to operate and are most often located outdoors, however, they can also be located in a ventilated machinery room.

6.2.2 Water-source heat pumps

Water-source or 'water-to-water' heat pumps utilise water as the heat source, with a source loop being connected to the heat pump heat exchanger. The source loop can be from a ground source (for example, geothermal), or from an ambient loop type arrangement. An ambient loop is described in the following section of this paper for reference.

A water-source heat pump absorbs the heat from the source loop, via the refrigerant. The refrigerant is pumped around the system by the compressor(s) to another heat exchanger where a secondary fluid, in this case water, absorbs the heat, creating hot water.

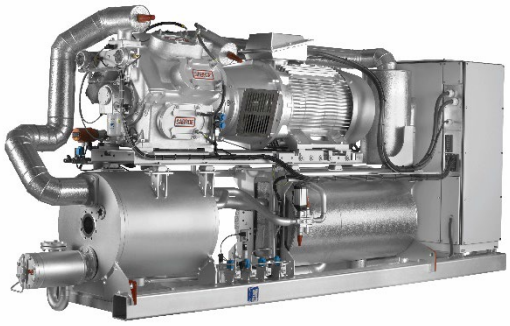

Figure 6: Example of a water-source heat pump. Image source: Johnson Controls

This type of unit can be provided in the following configurations as a high-level guide:

- Heating only
- Reverse-cycle heating and cooling.

Units of this type do not require outside air to operate as they are drawing heat from water and are most often located in a machinery room, however, they could also be located in a weatherproof enclosure outdoors.

Water-source heat pumps are more compact in general than air-source heat pumps, and as such, when used in context of an existing boiler footprint, are more likely to fit within an existing machinery room. Ground loop systems (i.e., geothermal) in this context can be extremely compact and efficient.

6.3 Options for heat pump system configurations

With either an air or water heat source as previously discussed, heat pumps can be installed in a single system, and provide high enough temperatures for most applications, particularly if propane (R290), ammonia (R717) or carbon dioxide (R744) are used.

It is possible to have some more complex configurations to overcome challenges for a specific application. Two of these configurations are an ambient loop and a cascade system, which are described in the following sections for reference.

6.3.1 Ambient loop

An ambient loop is a water loop that is maintained to a specified temperature, and in this context, this could be achieved by a combination of chillers, and air source heat pumps. A series of pipes is run throughout a facility, with the intent being to provide a source of heat or a source of cooling for downstream equipment.

If, for example, the water loop was maintained at 25°C, a water-source heat pump can be used to increase that temperature to say 60 °C. Or the heat rejected from an air conditioning unit could be absorbed, for example, a water source heat pump in a café, or tenancy inside a building.

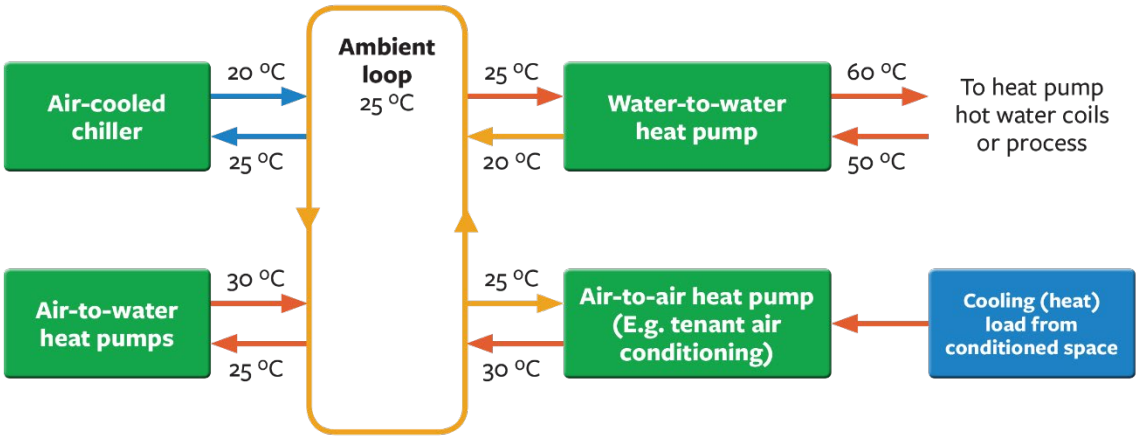

Figure 7: Example of ambient loop configuration.

Whilst ambient loops are not widely used throughout Australia, they are a potential key to unlocking a lower energy future when it comes to heating and cooling our spaces and/or processes.

Utilising centralised equipment offers opportunity to make use of large-scale renewables at the main source of energy use, with higher levels of utilisation possible.

As an example, think of a large heat pump and chiller plant, where thermal storage can be used to store large volumes of water.

- Heating and cooling output can be maximised throughout the day to cool and heat these large volumes of water, using a larger centralised solar PV array at its peak output.
- A solar PV array can be utilised at its lower output (i.e., shade or low light) to pump water from the tanks through the ambient loop.

- Smaller scale solar PV arrays can be used on individual buildings or systems to operate the downstream equipment, such as water-to-water heat pumps, or air-to-air heat pumps, which given most of the work is done by the larger system, is now smaller in footprint and energy input.

In this scenario, solar PV arrays can be right-sized, meaning less energy is exported. This increases the utilisation and efficiency of our total system.

6.3.2 Cascade systems

The above systems can also be used in what is referred to as a cascade arrangement, which simply means two stages or multiple stages.

In our context this is often two stages, and this type of approach may be used to achieve temperatures beyond the capabilities of a single stage heat pump. The utilisation of this approach may be due to technology or space limitations.

Cascading may be important to consider given the types of heat pumps that can achieve the necessary temperatures for your application may be either physically bigger than the space you have available, or your site constraints may dictate the need to split the system into two units.

Looking at this one as a simple example, let's reference a boiler that is currently operating at 80 °C temperature outlet, and it has been determined that 70 °C is needed for the new heat pump system. There are also some constraints to deal with, including a very small boiler room and limited roof space.

To achieve 70 °C, it is possible to utilise a single-stage heat pump, however, this is based on several other factors explored in the next sections of this report. For our example, it is assumed here that a single unit cannot be used due to a very low winter design ambient temperature.

Based on this, an air-source heat pump that delivers hot water at 35 °C to the inlet of a water-source heat pump, which then provides an outlet temperature of 70 °C for our heating hot water loop could be utilised. In this case, the air-source heat pump creates the source loop via an ambient loop arrangement for the water-source heat pump, and as the water-source heat pump absorbs the heat from the source loop, the air-source heat pump rejects more of the heat it has absorbed from the air into the source loop.

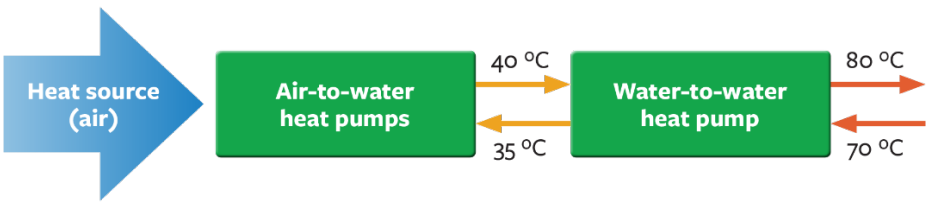

Figure 8: Example of cascade heat pump arrangement

For reference, if the above is considered in the context of geothermal, the ground water loop would add heat back into the source loop for the water source heat pump, using heat from the earth.

Ammonia heat pump systems can deliver this type of outcome from a single piece of equipment, with two stages being contained within a single frame, and water being the input heat source, making it an excellent choice for higher temperature applications.

7 Refrigerant considerations in decision-making

7.1 General refrigerant information

Before more specific scenarios are discussed, where specific requirements can be identified, a general decision tree approach could be used to identify a suitable refrigerant. It is expected that this decision tree will sometimes produce a refrigerant that is not suitable for your application, however, it aims to give options, rather than a specific choice, the engineering should be completed by qualified consultants with the necessary licenses and experience.

Table 7: Refrigerant choice decision tree pros/cons guidance

Refrigerant	GWP	Heat pump cost per kW of heating	Operating cost	Product range	Heat source (Air/water)	Flammability/toxicity	Advantages	Key limitation	Domestic hot water (DHW) suitability	Space heating suitability (40 °C to 70 °C)
R290 (propane)	Low	Medium	Good	Increasing	Air	High	Broad suitability	Flammability	Good	Good
R744 (CO_2)	Low	High	Excellent in certain cases	Large	Air	Low	High temperatures with good COP	Poor performance with higher return water temperatures	Excellent	Good if lower return water temperatures
R717 (ammonia)	Low	High	Excellent in certain cases	Generally limited to large capacities	Water	High	High efficiency	Toxicity and cost per kW of heating output	Poor	Good
R718 (water)	Low	Medium	Excellent in certain cases	Only for industrial	Water	Low	High efficiency	Industrial only	Poor	Poor
HFO	Low	Medium	Good	Increasing	Both	Low	High temperatures	Possible PFAS implications	Poor	Good
HFC	High	Low	Good	Large	Both	Low	Low cost per kW of heating	High GWP and possible PFAS implications	Good	Good

Refrigerant	GWP	Heat pump cost per kW of heating	Operating cost	Product range	Heat source (Air/water)	Flammability/toxicity	Advantages	Key limitation	Domestic hot water (DHW) suitability	Space heating suitability (40 °C to 70 °C)
HFO/HFC blend	Medium	Low	Good	Large	Both	Low	Low cost per kW of heating	High GWP and possible PFAS implications	Good	Good

7.2 Heat pump upgrade pathway

Based on the information in this report, which identifies refrigerant and equipment options, in addition to relevant standards for refrigerant installations, let's look at a potential upgrade pathway based on a fossil gas boiler conversation to a heat pump, which is a very common scenario. The concept is to provide a basic checklist for when considering the project at an early stage.

Table 8: Guidance on heat pump upgrade pathway

Question	Action
Does your plantroom have existing ventilation?	If yes, document the ventilation system design and operation (controls) as is for reference in future design considerations. For example: location of fans, sensor(s), control system, manual overrides, and safety signage/documentation.
Does the plantroom have adequate signage?	Review against standard **AS1391.**
Identify the type of heat pump you are likely to utilise	For water-to-water, it is likely that plant-room ventilation should be considered. For air-to-water, the unit is likely located on a roof, or outside, meaning ventilation is likely adequate, but there could be sources if ignition to deal with. For cascade-type arrangement, there may be combinations of constraints.
Identify the general occupancy category for the location(s) of your new heat pump(s)	If General or Supervised Occupancy, identify the areas in which people not acquainted with safety standards would be present. If Authorised Occupancy (Category III), review access and safety systems in place and document.
Identify the refrigerant locations in your new design	If all contained within the unit itself, are there cabinets enclosing parts of the unit? If there is refrigerant piping between two units, does anything run through a space that is different from your previously identified general occupancy category? • If yes, review charge calculation limits for the spaces per standard **AS/NZS 60335 or AS/NZS 5149** Are the sources of ignition in the proposed area? If yes, identify the sources and review installation for compliance with **AS/NZS 60079**

Question	Action
Identify suitable heat pump technology, and refrigerant options	Understand the temperature limits and efficiency of the proposed equipment, suitability for the site and general classification of the refrigerant options per **AS/NZS ISO 817:2016.** Understand the equipment type, the proposed OEM and the relevant certifications for the equipment. Specifically for heat pumps, compliance of the unit against **AS/NZS 1200:2000** and **AS4343** which relate to the pressure vessels present inside the unit. Review your choice against **AS/NZS 60079** to identify if your plant area(s) are deemed hazardous.
Review heat pump options and standards to identify required modifications	Regardless of refrigerant chosen, the installation must comply with the standards, based on location of the equipment (general occupancy), and the refrigerant charge (class). Identify signage, ventilation, and plant-area design requirements for the proposed refrigerant against the requirements of the standards identified as relevant to the installation.

Any decision about refrigerants, heat pump types and overall plant configuration may change following this review. For example, if the review identifies that the required works at the site are not cost effective and there is a more economic pathway to install a heat pump that meets the project requirements and stakeholder criteria, then then final decision should be updated.

The general refrigerants decision tree should be used in parallel to identify suitable refrigerant options early on, at design concept level. This may assist in avoiding costs further into the detailed design process as the existing situation is documented, and a suitable set of refrigerant options is identified based on the generalised decision tree is understood.

8 Appendix 1: Montreal Protocol

The Montreal Protocol was a key landmark in the story of refrigerant and is widely considered the most successful environment protection agreement ever put in place. The agreement has encouraged innovation and development for refrigerants, leading to significant change.

The agreement sets out a mandatory timetable for the phasing out of ozone depleting substances, and is reviewed regularly, often being accelerated in accordance with advances in technology.

In October 2016, in Kigali, Rwanda, a HFC phase-down under the Montreal Protocol was agreed, with developed countries agreeing to phase down their production and imports of HFCs by 85% between 2019 and 2036. Developing countries will also phase down production and imports of HFCs, but at a slower rate.

The following describes some of the impacts on the market from refrigerant phase down.

- Refrigerants subject to phase down will remain available for service requirements for installed equipment beyond the phase down period, with timelines in place based on expected lifespans of installed equipment.
- It has historically been seen that the cost of refrigerants being phased down (and out) increases during the phase down period.
- Phased out refrigerants often have 'drop-in' replacements, which offer lower ODP and/or GWP ratings, which are made available to market to bridge gaps between equipment lifecycle and phasedowns.
- More stringent standards have continued to be developed for refrigerant import, handling, licensing, and usage reporting.

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