A brief review of refrigerants the HVAC industry used in the past, and a look at the refrigerants likely to be used in this new decade. – By Sam Ringwaldt

The HVACR industry is notoriously slow to react to external concerns, to adjust its practices, and to adopt new refrigerants and technologies, and yet, at long last, the lethargy around adopting more environmentally friendly refrigerants is finally being shaken off as new prospects emerge, promising a more sustainable future. Whilst there is a level of uncertainty about which emerging refrigerants are going to dominate this new decade, the current reality has ensured that environmental concerns are impacting purchasing decisions far more than they have in the past, allowing us to make some informed deductions.

For perhaps the first time since its inception, the HVACR industry is getting pushed hard by external pressures, and instead of dictating what people can use, the industry is now being dictated to, by legislation, governments, corporations, customers and environmental interest groups. In the recent past, HVAC equipment, such as chillers, were considered "out of sight and out of mind", unless of course they weren't running, but now how they operate, and what refrigerants they use, make a difference to the type of tenants, or future owners, a building owner can attract. Today's consumers are far more aware of the impact this equipment has on their operating cost, and on their environmental footprint, and the manufacturers who are providing better options, are eating into the market share of the traditional industry leaders, forcing them to move and adjust far faster than they have in the past 100 years.

An increasing number of organisations are promoting their corporate sustainability responsibilities (CSR) throughout their entire organisation, causing many companies to evaluate far more thoroughly the total environmental impact of all their operations and decisions, including their decisions about how they air-condition their properties. In addition, the steadily increasing number of building owners who are demanding more environmentally friendly refrigerants in their air conditioning equipment has been creating an industry movement towards ultra-low GWP refrigerants, and back towards, or you could say a re-adoption, of natural refrigerants.

The purpose of this article therefore is to take a quick look at perhaps 50 of the top refrigerants in the HVAC industry, out of hundreds of refrigerants, to determine which of these consultants, customers, and HVAC manufacturers, should be paying attention to, and perhaps using for this new decade.

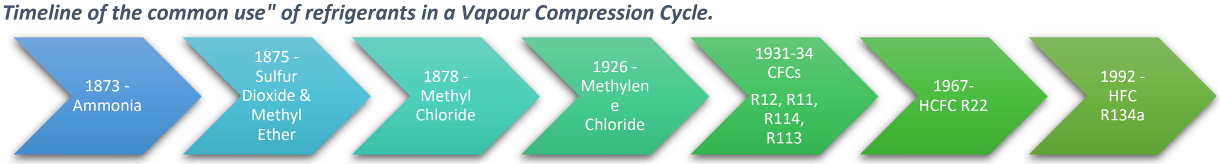
YESTERDAY, TODAY, & TOMORROW'S REFRIGERANTS

YESTERDAY

To better understand where the HVAC industry is in 2020, and where we might be heading, it is worthwhile to first briefly reflect back over the past 100 years to the start of the commercial air-conditioning industry as we know it, when natural refrigerants were in fact the norm. In the early days of this industry, there was a variety of "refrigerants" in use, such as Air, Water, Ammonia, CO2, Sulphur Dioxide, Methyl Chloride, Propane and Isobutane. By today's environmental standards, all these refrigerants are quite acceptable, due to their benign impact on the environment, however, each one of these refrigerants has some key issues which caused almost all of them to be phased out over time. Air, Water, and CO2 were not efficient enough with the equipment of that day and required operating pressure extremes. Propane and Isobutane are flammable leading to safety concerns. Ammonia conducts electricity, limiting its use for things like motor cooling, and both Ammonia and Sulphur Dioxide have safety concerns, as they are toxic, and they were also unpopular due to being very smelly. Finally, Methyl Chloride, whilst gaining popularity early on for not being smelly, is toxic and flammable, proving highly unsafe. These issues of efficiency, flammability, toxicity, pressure, conductivity (and smell) caused General Motors, in 1928, to give their research lab team, comprised of Thomas Midgley, Albert Henne, and Robert McNar, the task of finding a new refrigerant that was stable, non-toxic, non-flammable, capable of operating above atmospheric pressure, miscible with lubricating oil, a good electrical insulator, and had a low index of compression to keep compressors running cool.

The team, led by Midgley, perhaps amazingly given the vast number of compounds possible, managed to synthesize a virtually ideal refrigerant that satisfied all these objectives, a chlorofluorocarbon (CFC), commonly referred to today as R12, and the newly trademarked "Freon-12" became commercially available in 1931, followed closely by another ideal refrigerant, R11 in 1932. These CFC refrigerants resolved so many issues and introduced so many advantages that they rapidly pushed out of use almost all the "natural" refrigerants with the exception of Ammonia (due to its highly suitable thermal properties), and they dominated the HVACR industry for the next 50 years. This research lab continued to develop further refrigerants, and HCFC-R22 was introduced in 1932 but it only gained widespread popularity in the 1960s, perhaps as its properties allowed it to be used in physically smaller compressors for the same capacity compared to R12 compressors, making it the refrigerant of choice for the screw compressors which entered the market in the late 60s. R22 became the primary refrigerant in use well into the 1990s, despite its drawback of having a higher superheat which impacted compressor motor cooling.

Timeline of the common use" of refrigerants in a Vapour Compression Cycle.

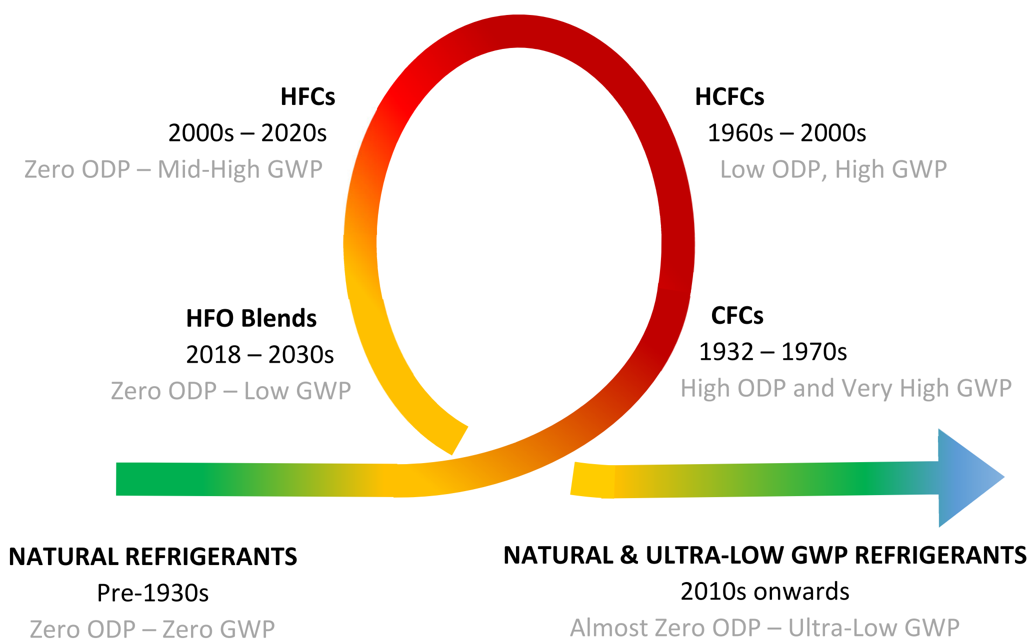


With the discovery in 1985 that CFCs were causing the depletion of the Ozone layer, the world responded quickly, and in 1987, the Montreal Protocol established a rapid phase out of the production of CFC refrigerants. R22 as a HCFC was still heavily utilised, and gained popularity over R12, and HCFC-R123 arose as a replacement for R11, despite being classified as toxic, but then in 1992, in Copenhagen, an amendment was made to also include a phase out for HCFCs. Therefore, as R123 was ultimately destined for phase out and was already being shunned in Europe due to its toxicity being linked with benign tumours, most manufacturers retired their negative pressure chillers in the early 90s. The long-term phase out plans for HCFCs, resulted in the rise in popularity of the Hydrofluorocarbons (HFCs) such as HFC-R134a, which had been synthesised in 1936 by Albert Henne but never really utilised widely by industry until that point. Over the last 20 years, other HFCs, such as R410a were also introduced to phase out R22. However further studies linked HFC's to global warming, and as such they were targeted for reduction and phase outs under the Kigali amendments (2016) to the Montreal protocol, pushing the industry to once again consider more environmentally friendly refrigerants.

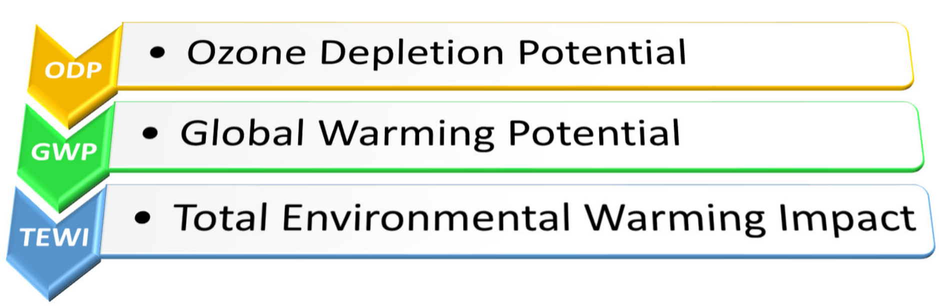
TODAY

For the last couple of decades the HVACR industry relied primarily on R134a, R407C, R410a, which were zero ODP, had lower GWPs that HCFCs, and quite easy and safe to use, but it is apparent that each of these are now firmly on the industry chopping block and will disappear in new equipment relatively quickly. This brings us back to the present where the industry is once again attempting to readopt some of the original natural refrigerants despite their various challenges, of flammability, efficiency, toxicity, pressure, cost etc. that originally caused them to be phased out, as the weighting on the refrigerant's environmental impact is now the primary driver for adoption. For example, 10 years ago, CO2 was nascent, but now it is common across the developed world, particularly in refrigeration, and more recently even utilised in air-conditioning applications. H20 (R718) is also starting to re-emerge as a refrigerant option, which was practically inconceivable until very recently, due to the extreme low pressures a system has to be kept at in order for water to work practically as a refrigerant, which results in complex and costly system designs. New refrigerant solutions with ultra-low GWP figures are also emerging which have the potential to become the new market standards, with some safety concerns over toxicity and flammability being willingly overlooked for the sake of the low GWP score.

PRIMARY HVAC REFRIGERANTS IN USE



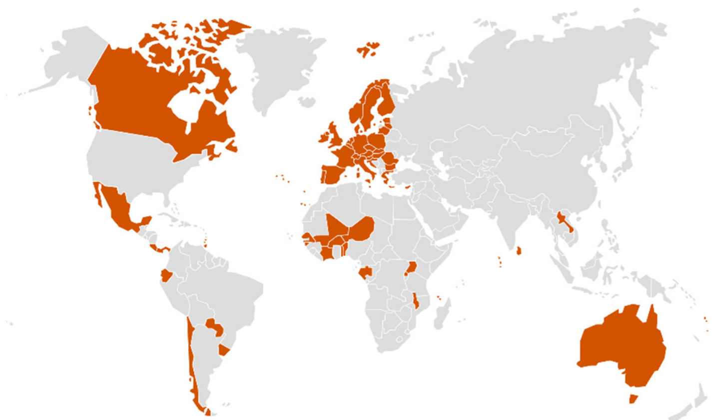
Just as a quick refresher, there are three main terms for scoring, or evaluating the environmental impact of a refrigerant: **ODP, GWP**, and **TEWI**.



YESTERDAY, TODAY, & TOMORROW'S REFRIGERANTS

ODP stands for Ozone Depletion Potential, and is associated with certain chemicals, such as chlorinated refrigerants (CFCs & HCFCs), which due to their chemical structure cause a catalytic action that reduces ozone to oxygen when exposed to UV light at low temperatures. Refrigerants are given an ODP score against the equivalent impact of R11 and R12, which were assigned an ODP of 1. Positively, the widespread adoption of the Montreal Protocol, which focused on reducing the ODP of refrigerants in use to zero, by 197 UN nations resulted in a reduction in the production of ODP refrigerants against 1989 levels by over 99%. The severity of the potential consequence of Ozone Depletion has driven the industry globally to mandate that all refrigerants should have truly zero ODP, although it is worth noting that this is currently being challenged by some manufacturers seeking to use refrigerants that are very close to zero.

GWP stands for Global Warming Potential, which is a measurement that expresses the ability of a refrigerant to trap heat in the atmosphere, scored in comparison to the equivalent impact of Carbon Dioxide, which has been given a GWP of 1. The higher the GWP score, the longer it will last in the atmosphere, and the more heat it can trap, thereby contributing towards Global Warming. For example, R134a, a very commonly used HFC in the HVAC industry, has a GWP of 1300, which means that if released into the atmosphere, just 769grams of this refrigerant would have the same global warming impact over 100 years as 1 tonne of CO2. Currently, at time of writing, only 81 of the 197 countries who signed the Montreal Protocol have ratified the Kigali Amendment, so the reduction in high GWP refrigerants globally will likely be far slower unless truly viable alternatives are identified.



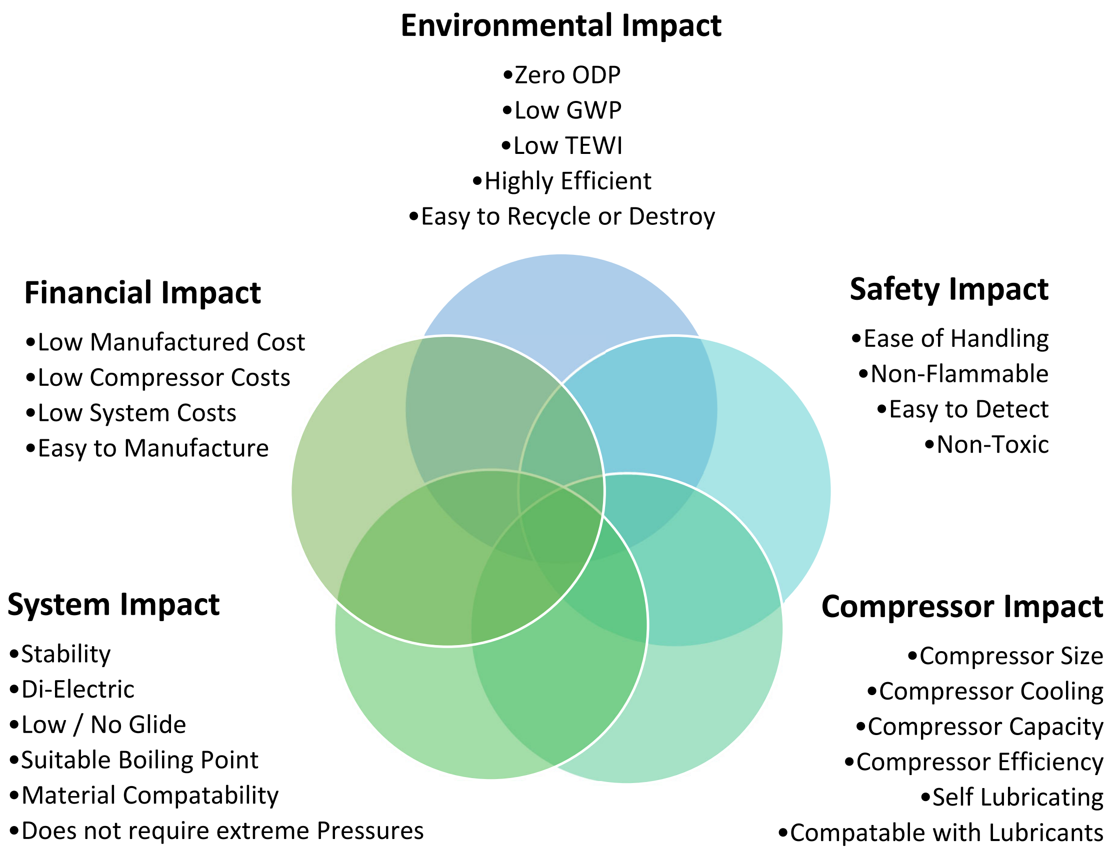
Key: ■ Country that has ratified Kigali Amendment ■ Country that has not ratified Kigali Amendment
Source: https://www.k-cep.org/wp-content/themes/kigali/page-templates/map/MapRatification.html

TEWI stands for the Total Environmental Warming Impact of a refrigerant, which is an emerging method of "scoring" a refrigerant that takes into account both the direct warming effect (GWP) of a refrigerant, along with the indirect warming effect due to the potential for carbon to be emitted in the generation of electricity to power the system. It is worth noting that in a well-designed chiller with low rates of leakage, most of the global warming impact over the life of the equipment will be due to energy consumption. Therefore, perhaps in the HVACR industry, TEWI could be a more accurate reflection on the true environmental impact of a refrigerant, as a low GWP refrigerant with a low cooling efficiency may have a higher TEWI score than a high GWP refrigerant that has great efficiency. It should also be noted however, that the TEWI score is somewhat subjective as the rate of leakage used is not yet a standardised industry figure, and a poorly designed system may leak at a far higher rate, which would skew the results if the formula was adjusted accordingly.

As a small side note, I believe that it would be beneficial for the industry to adopt a higher degree of focus on leak prevention. There is a real danger that in the drive towards environmentally friendly refrigerants, that are zero ODP and ultra-low GWP, we may inadvertently sacrifice the HVAC system's overall efficiencies and thereby negatively impact the environment, a fact TEWI is trying to capture. Whilst some green building standards make some recognition of leakage, such as the LEED energy and atmosphere credit, there is no widespread global recognition of the importance of leakage vs efficiency. However, there are some helpful refrigerant leakage standards, such as AS/NZS 5149.4 that detail how frequently equipment should be inspected, how refrigerant leaks should be detected and what should be monitored and recorded. AS/NZS 5149.4 details that systems containing more than 300kg of refrigerant should have automated detection and alarm systems installed and should be inspected monthly. For systems containing between 30kg and 300kg, six monthly inspections are required, and for systems containing between 3kg and 30kg, annual inspections. Critically, all these systems should also have a refrigerant logbook to record the quantity of refrigerant installed, added, or recovered, however perhaps an official register should be introduced to allow the leakage rates of certain types and ages of equipment to be monitored and calculated.

TOMORROW

To determine which emerging refrigerants are going to be able to establish themselves as the dominant refrigerants for this next HVAC age, it is important to consider the ability for the refrigerant to adequately balance various, often conflicting, factors. An ideal refrigerant needs to balance the environmental impact, with the impact on safety, the compressor, the system, as well as considering any financial implications. Any refrigerant that satisfactorily balances all the impact points shown in the following chart will likely emerge as a truly dominant, and industry leading refrigerant. Focusing on reducing the Environmental Impact, whilst compromising on safety either in toxicity or flammability, could have disastrous consequences, and ignoring practical things such as the simplicity and cost of manufacturing suitable systems would also prevent widespread adoption.



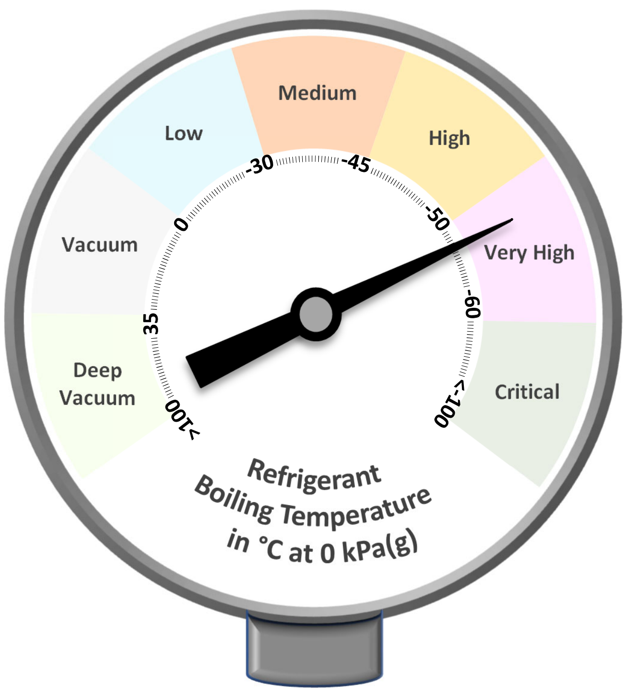
It is extremely unlikely that a single refrigerant can emerge as the overall industry champion, as one requirement that the HVACR industry faces, is that there are an extremely wide variety of applications. Refrigeration, heating, process cooling, comfort cooling, and district level heating and cooling, all have their own unique requirements, which in turn leads to very different operating pressures and temperatures, ultimately dictating the operating pressures and temperatures required for a refrigerant to satisfy their specific purpose.

YESTERDAY, TODAY, & TOMORROW'S REFRIGERANTS

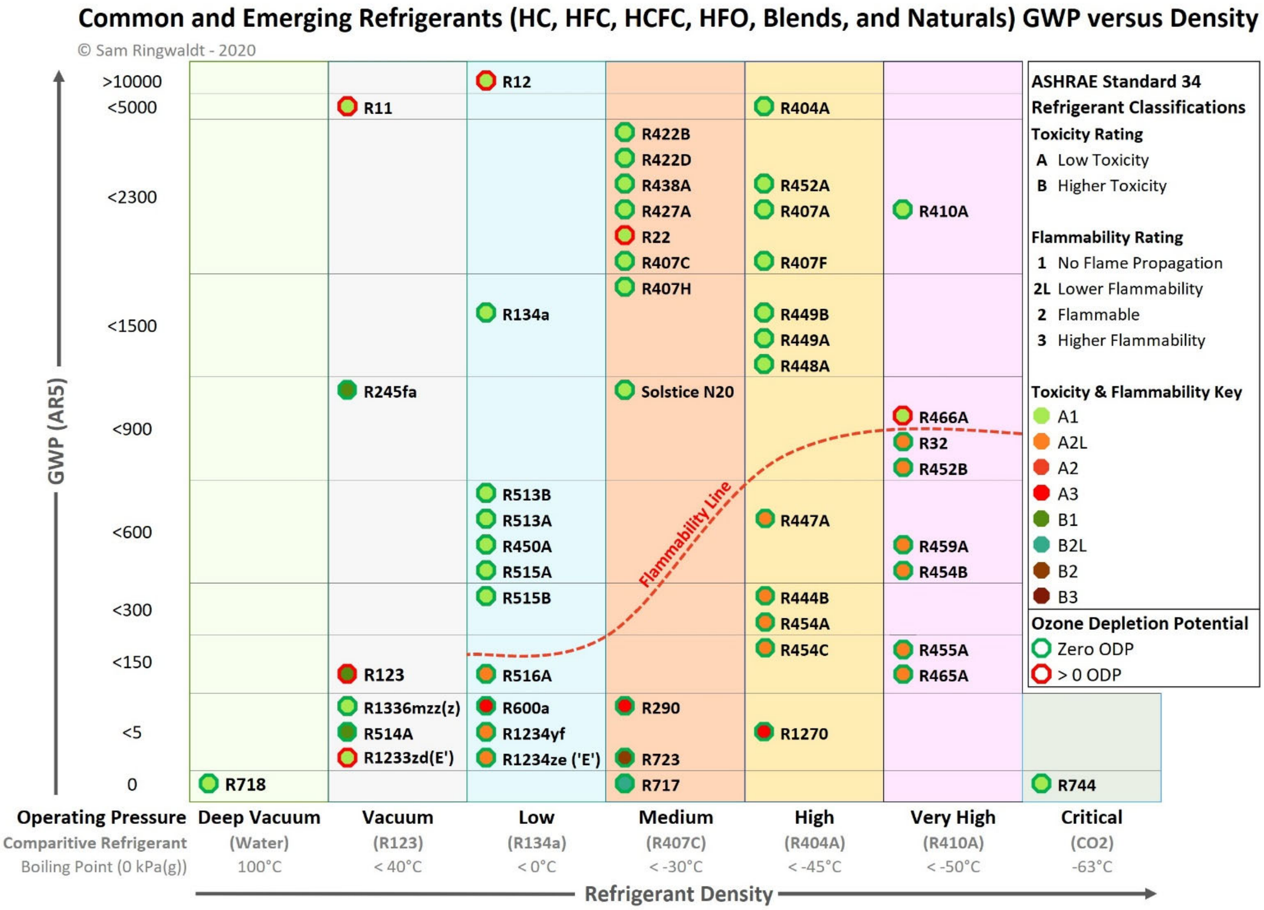
The following lists provides the primary pressure categories systems fall into, along with some information about the common refrigerants utilised by each of these categories presently.

- **Deep Vacuum Pressures** – R718, or H20/Water is unique in this category, and is not widely utilised, although the number of systems utilising this are growing, as the complexity in manufacturing such systems is becoming easier with modern, computer aided, manufacturing technologies.
- **Vacuum Pressures** – R123 has been the primary refrigerant in recent years, replacing R11, with a much lower GWP of only 79, however as a HCFC, this has an ODP value of between 0.02 and 0.06 (Sources vary on this number), therefore not strictly in compliance with the Montreal Protocol of zero ODP, as the causing the majority of the industry to not pursue this as a product solution.
- **Low Pressures** - R134a has been the primary refrigerant in use, with a true zero ODP, but a GWP figure of 1300, replacing R22, which replaced R12
- **Medium Pressures** – R407C is the primary refrigerant, replacing R22 due to its true zero ODP, and a GWP of 1624.
- **High Pressures** – more recently dominated by R404a, although despite its zero ODP, it had a very high GWP of 3943, which made this unfavourable and not used as widely as the other primary refrigerants. No clear lower GWP substitute in this pressure category has emerged.
- **Very High Pressures** – typically equipped with R410a, (GWP of 1924) or more recently with the slightly flammable R32 as it has a lower GWP of just 677.
- **Critical Pressures** – this category is solely the domain of R744, known more commonly by its real identification of CO2. This category has been growing in popularity, primarily in the refrigeration space.

Refrigerant Pressure Ranges



The "Common and Emerging Refrigerants GWP vs Density Chart", plots 50 common refrigerants, by placing them into their primary application pressure category, and positioning them according to their GWP score (as calculated using the most recent AR5 methods). It is interesting to note that as the GWP decreases, the flammability and the toxicity tend to increase, clearly demonstrating the trade-off between environmental and safety impact factors. For details of the data represented below, please see the table in Appendix 1.



This chart does not quite tell the whole story, as the refrigerants within each of these pressure categories still have considerable variability in both efficiency and capacity, against the typical base refrigerant currently in use. In this article, I will not go into detail on all the comparisons points for the sake of time, however I will highlight refrigerants in each category that I believe may emerge as the dominant refrigerants for this coming decade.

The **Deep Vacuum** category is the exclusive domain of R718 (H20/Water), and whilst equipment manufactured to use water as a refrigerant is complicated due to the deep vacuum pressures required, modern manufacturing techniques and tooling are making the production of viable systems now economically viable. If you were to assess R718 from the perspective of just safety, toxicity, and environmental impact, water would have to be considered a very good refrigerant, however the complexity of the equipment, and the pressures required to make use of it at HVACR temperatures will limit wide spread adoption, and likely keep this in the realm of specialty equipment for the coming decade.

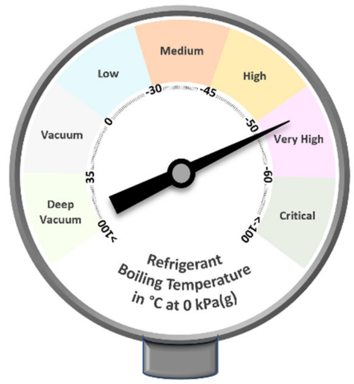
The **Vacuum** pressure category which once was extremely popular with many manufacturers before R11 was phased out, has been very limited for the past 20+ years, as most manufacturers retired their negative pressure chillers. In fact, only one major manufacturer persisted with R123, despite it not being compliant with Montreal Protocol, in most markets apart from Europe where the link to tumours made it unpopular, keeping their negative pressure chillers in production, until recently when they migrated to both R514A and R1233zd(E). Over the past few years, most of the other large multinational chiller manufacturers have also dusted off their negative pressure equipment lines that were essentially put into storage since the retirement of R11, and now re-released their chillers with R1233zd(E), which has a GWP of 1. These vacuum pressure chillers tend to be significantly larger than their higher-pressure cousins, but the reduced pressures lower the material thicknesses and strengths required, which balances out any additional costs that might have been incurred due to size. This refrigerant certainly appears to be here to stay and I believe it will become an extremely dominant refrigerant in the chiller market, however it is still being debated whether this is really the right solution, since it still does not comply strictly with the Montreal Protocol which called for zero ODP refrigerants, not "virtually" zero. In fact, there are certain parties in Germany currently, seeking a ban on R1233zd(E) due to the 0.00034 ODP value that it carries as a HCFO or Hydro-chloro-fluoro-olefin which is an unsaturated HCFC. Outside of Europe it is being adopted rapidly, as it offers good full load efficiencies, and is classified as both non-flammable and nontoxic. Perhaps a notable mention in this category is R1336mzz(z) as it is truly 0 ODP, and is also has an ultra-low GWP score of just 2, however as this is anticipated to be deliver around 25% less capacity than R123, and about 3% less efficiency, manufacturers will be unenthusiastic to adopt this unless R1233zd(E) is banned, and people shy away from the toxicity rating of R514A.

In the **Low**-pressure category, currently still dominated by R134a, there are several alternatives currently on the market. R1234ze is gaining popularity, as it has an ultra-low GWP of just under 1 and offers an efficiency very close to R134a. However it will be unlikely to achieve the dominance that R134a has enjoyed, as it actually reduces capacity by 25% for the same volume, causing the cost of the equipment to increase to meet the same capacity, and is rated as an A2L refrigerant, meaning it is slightly flammable and restricting where it can be utilised in a building. This flammability issue will likely make R515B emerge as a good substitute, as it has very similar efficiency and capacity figures as R1234ze, and has a GWP of just 299, placing it above the flammability line and rating it as an A1 refrigerant. R513a, which emerged as a potential drop in replacement for R134a, will also stick around for a while, as whilst it has a higher GWP of 573 than these previous options, and slightly lower efficiency, it has a similar capacity to R134a, keeping equipment cost down, and making a transition of equipment designs much simpler than moving from R134a to R1234ze or R515B, which would both require a higher degree of redesign.

In the **Medium** pressure category, both R407C and Ammonia (R717) have been dominant. The toxicity issues with Ammonia however have ensured that this has not been popular in a commercial setting and is typically found in larger industrial applications. There has been very little development in recent years of new refrigerants in this category, but one to keep an eye on would be Solstice N20 (which has not received a refrigerant designation yet), as it has a GWP of 891, approximately half the GWP impact of R407C (1624), and is both non-flammable and nontoxic, and reported to be comparable in terms of performance. This refrigerant is in early stages, but I believe it has the potential to displace R407C if it gets manufactured in sufficient quantity to drive the costs down.

The **High**-pressure category is a very narrow band sitting between the Medium and Very High-pressure categories. This band has typically been the domain of R404A, but with an extremely high GWP of 3943, it has been unpopular for many years, and if the application could be serviced by equipment from one of the surrounding categories, they have been selected in preference to using R404A, causing a steady decline in the quantity of equipment using this refrigerant. If an application demands this specific pressure range, then the best candidate currently appears to be R448A, which has a GWP of 1273, which is similar to R134a, but more than 3 times lower than R404a. The only slight issue with this refrigerant is that Discharge temperatures increase over R404a, but this is likely compensated for as it has slightly higher capacity, and its slightly better efficiency. Another option, that is more like a halfway step, is R407F, with a GWP of 1674. As you can see, with the best option still at 1273, when possible people will steer towards one of the other categories, with refrigerants offering lower GWP scores.

In the **Very High**-pressure category, R410a is likely still going to be quite dominant over this decade despite its high GWP of 1924. In this pressure range, the flammability line against GWP really jumps up, ensuring that an ultra-low GWP refrigerant is going to be able to be achieved at these pressures without compromising safety and using a flammable refrigerant. In my opinion, the only real potential contender is R466A, as this offers the lowest GWP possible whilst remaining non-flammable at just 696 , however like R1233zd(E), it does not have zero ODP, instead having a score of 0.015, which will make it unviable for most of Europe. It also reduces the equipment's efficiency and capacity, and as such, I think this category, in particular, will need to focus on leak prevention, as it will likely continue to use R410a until a more suitable refrigerant is developed.



Finally, the **Critical** pressure category, which is exclusively the domain of R744, or CO2. Like water, but at the opposite pressure extreme, this refrigerant operates at very high pressures in order to deliver the temperatures required for HVACR applications. This is almost as good as water when considering the environmental impact, with a GWP of just 1, and the pressures required are more manageable than water, which is why it has been steadily increasing in popularity. Over the past decade it has become relatively common to find CO2 systems in commercial refrigeration applications, and now it is starting to enter the air conditioning applications also, however a lack of development in large capacity compressors for CO2 is limiting the rate at which it is ramping up. I believe the trends towards more environmentally refrigerants, particularly in Europe, will push manufacturers to start embracing CO2 more over the coming decade, despite the system complexities involved in operating this at Trans-critical pressures.

CONCLUSION

As you can see there are a significant number of variables that need to be considered when a HVAC manufacturer is designing equipment to make use of a new refrigerant. Concerns about the environment, and safety, must be balanced with overall efficiency and the cost of manufacturing. Sometimes a refrigerant will emerge that seems to tick most of the boxes, but the cost of manufacturing the refrigerant may make it commercially unviable, either due to the complexity involved, or simply due to a lack of demand for large quantities. There is also a significant amount of money and time that needs to be spent to develop a new compressor, or system, and to complete the requisite research, development and testing that will ensure the compressor/system will operate efficiently, and can be built cost effectively. Few new refrigerants can simply be dropped into existing designs, as often compressors need to be modified or developed from scratch, material compatibility needs to be checked, and heat exchangers often need to be modified. As such, HVAC manufacturers are often reluctant to spend this money on what could be a gamble. If they were to take the lead in developing a new chiller line, using a new refrigerant, but no one else does, the refrigerant manufacturer will be unlikely to invest in building the supply capacity that could help lower the cost of the refrigerant, and the manufacturer will end up with a costly unicorn.

Fortunately however, other factors, such as government regulation, continue to push the industry and force them to adopt new refrigerants, and for those that gamble successfully, and produce equipment that leads the industry in a new direction, they often reap the financial benefits of being an early adopter. New refrigerants are being developed each year, but they do take quite some time to get into production, and gain market recognition, and as such, I am quite confident that the refrigerants I have outlined in each of the pressure categories above will be fairly dominant for at least the coming decade. Of course, I also remain hopeful that more new refrigerants will emerge that will finally achieve the perfect balance between all the competing factors, and that the HVAC industry can achieve efficiencies never before seen, with equipment that leads to a more sustainable future for this planet.

APPENDIX ONE: REFRIGERANT CLASSIFICATION, ODP, and GWP TABLE

The following table contains the data collected which has been represented on the "Common and Emerging Refrigerants GWP vs Density Chart". This table includes the 100-year time horizon global warming potentials (GWP) relative to CO2 and has been adapted in part from the IPCC Fifth Assessment Report, 2014 (AR5). The AR5 values have been shown wherever possible as they are the most recent, but where the GWP figures are in red font, this represents the AR4 figures from the fourth assessment report (2007), as I was unable to determine the AR5 value at the time of writing, however it is unlikely that the AR5 values would deviate significantly from the AR4 value given. For more information, please see the IPCC website (www.ipcc.ch).

Type of Refrigerant	ASHRAE Refrigerant #	Refrigerant Brand / Chemical Name	Safety Group	ODP	GWP-AR5	Boil (0 kPa(g)) °C
DEEP VACUUM PRESSURE (WATER)						
Natural	R718	Water / Steam	A1	0	0	100
VACUUM PRESSURE (R123)						
HCFO	R1233zd(E')	Solstice zd	A1	0.00034	1	18.26
HFC/HFO	R514A	Opteon XP30	B1	0	1.7	29
HFO	R1336mzz(z)		A1	0	2	33.45
HCFC	R123	2,2-Dichloro-1,1,1-trifluoroethane	B1	0.02	79	27.82
HFC	R245fa	1,1,2,2,3-Pentafluoropropane	B1	0	858	15.05
CFC	R11	Tricholorofluoromethane	A1	1	4660	23.71
LOW PRESSURE (R134A)						
HFO	R1234ze ('E')	Solstice ze	A2L	0	0.999	-18.97
HFO	R1234yf	Solstice yf, Opteon YF	A2L	0	1	-29.49
HC	R600a	Isobutane	A3	0	3	-11.75
HFC/HFO	R516A	Forane 516a, Arkema ARM42a	A2L	0	131	-29.43
HFC/HFO	R515B	Solstice N15	A1	0	299	-18.8
HFC/HFO	R515A	Solstice R515a	A1	0	403	-18.74
HFO/HFC	R450A	Solstice N13	A1	0	547	-23.36
HFC/HFO	R513A	Opteon XP10	A1	0	573	-29.58
HFC/HFO	R513B		A1	0	596	-29.64
HFC	R134a	1,1,1,2-Tetrafluoroethane	A1	0	1300	-26.07
CFC	R12	Dichlorodifluoromethane	A1	1	10200	-29.75
MEDIUM PRESSURE (R407C)						
Natural	R717	NH3 / Ammonia	B2L	0	0	-33.32
HC	R723	Ammonia/Dimethyl Ether	B2	0	1	-36.52
HC	R290	Propane	A3	0	3	-42.11
HFO/HFC	-	Solstice N20	A1	0	891	-31.7
HFC	R407H	Daikin Creard R407H	A1	0	1380	-44.59
HFC	R407C	Klea 66, AC9000	A1	0	1624	-43.63
HCFC	R22	Chlorodifluoromethane	A1	0.055	1760	-40.81
HFC	R427A	Forane 427A	A1	0	1828	-42.96
HFC	R438A	MO99	A1	0	2059	-42.33
HFC	R422D	Genetron 422D	A1	0	2230	-43.2
HFC	R422B	ICOR XAC1	A1	0	2264	-41.31

HIGH PRESSURE (R404A)						
HC	R1270	Propylene	A3	0	1.8	-47.62
HFC/HFO	R454C	Opteon XL20	A2L	0	148	-45.56
HFC/HFO	R454A		A2L	0	239	-47.84
HFO/HFC	R444B	Solstice L20	A2L	0	295	-45.32
HFC/HFO	R447A	Solstice L41	A2L	0	572	-49.3
HFO/HFC	R449A	Opteon XP40	A1	0	1273	-45.72
HFC/HFO	R448A	Solstice N40	A1	0	1273	-46.12
HFO/HFC	R449B	Forane 449B	A1	0	1282	-45.75
HFC	R407F	Genetron Performax LT	A1	0	1674	-46.06
HFC	R407A	Klea, Suva 407A	A1	0	1923	-45.01
HFC/HFO	R452A	Optean XP44	A1	0	1945	-46.93
HFC	R404A	HP-62, FX-70	A1	0	3943	-46.22
VERY HIGH PRESSURE (R410A)						
HFC/HFO	R465A	Forane 465A	A2L	0	137	-51.8
HFC/HFO	R455A	Solstice L40X	A2L	0	145	-52.02
HFC/HFO	R459A	Forane 459A	A2L	0	461	-50.3
HFC/HFO	R454B	Opteon XL41	A2L	0	461	-50.49
HFC/HFO	R452B	Solstice L41y, Opteon LX55	A2L	0	675	-50.67
HFC	R32	Methylene Fluoride	A2L	0	677	-51.65
HFO/HFC	R466A	Soliste N41	A1	0.015	696	-54.02
HFC	R410A	AZ-20, Puron, Suva 9100	A1	0	1924	-51.44
CRITICAL PRESSURE (C02)						
Natural	R-729	Air	A1	0	0	-196
Natural	R744	CO2 Carbon Dioxide	A1	0	1	-62.89

BRIEF BIO OF THE AUTHOR

Sam Ringwaldt is Founder and CEO of Conry Tech, a business dedicated to developing new HVAC technologies. In his career, he has worked with compressor manufacturers, chiller manufacturers, and HVAC mechanical contractors, and has therefore been watching the development of new refrigerants closely for almost 20 years. Sam is passionate about seeing the HVACR industry become increasingly more environmentally responsible, to ensure a sustainable future for this planet for future generations.

You can find out more at www.conrytech.com

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