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PHASE-OUT OF HFC REFRIGERANTS – DRAFT REGULATIONS FOR CONSULTATION

Summary

HFCs have high GWP and are being phased down under the Kigali Agreement. A set of phase-out schedules are proposed for adoption in NZ. The categories and timing proposed are based on the following analysis of the status of alternatives:

Non-flammable retrofit or drop-in options exists for most original HFCs (refrigerants R134a, R507, R404A, R410A) but generally have intermediate GWPs (about half of the GWP of the original HFCs). These alternatives already allow a quick reduction in GWP for most new systems and for service of existing systems without major changes in refrigeration practice, once prices and availability mean they are competitive.

Apart from R744 (CO_2), all near zero GWP alternatives (GWP<150) are flammable which limits their application to systems with low charge unless expensive safety precautions are undertaken. This can usually only be justified for large scale systems. R744 use is limited by its high pressure (non-standard equipment) and its poorer performances when rejecting heat to the ambient due to its low critical point (31^{o}C). New non-flammable low GWP refrigerants with good pressure/temperature match to the original HFCs are unlikely to be discovered.

Small scale applications especially those using small scale, hermetically sealed systems are in rapid transition to flammable low GWP refrigerants for new equipment. Domestic refrigerators and freezers have largely completed the transition, while the shift for dehumidifiers, stand-alone refrigerated display cabinets, domestic AC (air-conditioning) and some small commercial AC will be completed over the next 5 years. Some AC systems in new vehicles already contain low R1234yf but it is not yet clear when the majority of vehicle manufacturers will shift away from R134a.

Large scale systems will continue to use NRs (natural refrigerants) such as ammonia (R717) and/or they will transition to lower charge designs (e.g. indirect secondary refrigerants) that allow flammable low GWP refrigerants to be used safely and cost-effectively. Such applications include most industrial refrigeration for food processing, supermarkets and large-scale building AC using chilled water.

Applications with moderate charge sizes, that are too high to make use of flammable refrigerants cost-effectively, will be the most challenging to transition to very low GWP refrigerants. Examples include - medium scale AC systems, public transport AC, transport refrigeration, farm milk vats and walk-in cold rooms for retail, food service and restaurants. Non-flammable alternatives exist that allow GWP to be approximately halved relative to the original HFCs, and can be used for new equipment and retrofits as soon as refrigerant prices and availability incentivise such changes. Long term low GWP options are unlikely without significant changes to system designs that will be expensive.

1. Introduction

Under New Zealand's commitments under the Kigali Agreement of 2016 and the Paris Agreement of 2015, it will need to phase-out use of the high GWP HFC refrigerants. This paper proposes some draft regulations based on a technical analysis of the alternative refrigerants and the status of technologies to employ these refrigerants in a NZ context.

Historically, the main HFC refrigerants used in NZ are:

(a) R134a (GWP=1430) – mainly for medium temperature applications (>-10^{o}C)
(b) R404a (GWP= 3922) – for both low temperature (-40 to -40oC) and medium temperature applications (>-10^{o}C)
(c) R507A (GWP=2985) – quite similar to R404A but slightly better suited to lower temperature applications
(d) R410A (GWP=2088) – mainly for space air-conditioning and space-heating heat pumps
(e) Others – refrigerant such as R407C and R407F (in similar applications as R404A) are used in smaller quantities or as alternatives to the above.

2. Technical and Market Factors

Some important technical and markets factors affecting phase out of high GWP HFC refrigerants are:

1. GWP – Pure HFC refrigerants typically have GWP > 1500 whereas the ultimate desire is to move to refrigerants with GWP < 150.
2. Flammability – Most HFC are non-flammable (A1) while ammonia (R717) and most HFO alternatives are mildly flammable (A2L) and hydrocarbons are highly flammable (A3). Safe use of flammable refrigerants requires a combination of charge size limits plus system design and installation changes to avoid leakage, build-up of flammable mixtures of refrigerant and air, and minimise sources of ignition.
3. Toxicity – Most HFC refrigerants are non-toxic (e.g. A1). Most HFO and natural refrigerant alternatives are non-toxic except for ammonia.
4. Temperature/pressure relationship – A "well-matched" alternative synthetic refrigerant in terms of their temperature-pressure relationship can be used in similar equipment with only slight changes in capacity and efficiency (less than 5% different). The normal boiling point of the refrigerant is a key indicator of its pressure-temperature relationship.
5. Pressure – It is desired to operate systems above a vacuum (1 bar.a) and below 25 bar.a to keep equipment designs and systems operations simple and low cost. Most refrigeration componentry is designed for a maximum operating pressure of 25 bar.a although increasingly this limit is rising to 40 bar.a. The main exception is CO_2 for which equipment that operates up to 150 bar.a is readily available.

6. Capacity – The capacity is the amount of cooling or heating that a system can perform. Capacity is strongly related to the mass flowrate generated by the compressor (which has a near constant volumetric flowrate). Therefore for synthetic refrigerants, capacity is strongly related to the boiling point (generally lower boiling points correspond to higher capacity in the same system).
7. Efficiency – The efficiency is the amount of energy used to do a fixed amount of cooling or heating and is often measured by the Coefficient or Performance (COP) of the system. For most "well-matched" refrigerants the differences in efficiency are low. Some exceptions are - ammonia which tends to be more efficient for most applications and carbon dioxide (R744) which is usually significantly less efficient when operating above about -5^{o}C and/or rejecting heat to the ambient (due to operating in a trans-critical rather than the more common sub-critical cycles under these conditions). Even with high level of renewable electricity, if a change to a low GWP refrigerant significantly reduces efficiency then the increase in energy use is both a cost barrier and the increase in energy related CO_2 emissions can easily more than offset the refrigerant GWP savings.
8. Glide – Refrigerant blends (R400 series) have glides due to different boiling points of the component refrigerants (R500 series blends are azeotropes with zero glide). Low glides (less than 1^{o}C) are desirable to simplify component and system design and help ensure high operational performance (efficiency and capacity). For a few applications, high glides are not a significant disadvantage (e.g. if fluid being heated or cooled undergoes a significant temperature change). Further, high glide refrigerants can have differential leakage of one component and are not well suited to flooded or pump circulation systems mainly used in large scale systems because differential separation of the components can occur between the low and high pressure parts of the system.
9. Lubricants – Drop-in alternatives must be compatible with the same oil used for the refrigerant they are replacing to avoid the need for multiple oil changes (a retrofit rather than a drop-in). Most HFC systems use POE or PVE oils and most HFOs are compatible with such oils.
10. Charge Size – Reducing charge size is desirable to reduce refrigerant costs and reduce risk if the refrigerant is flammable or toxic. Charge size is related to system capacity and detailed system design. High efficiency can be harder to achieve if the charge is low and for a given system, efficiency is significantly reduced if the charge is too low. For hermetically sealed systems, the charge limits were recently raised to 500 g and 1200 g for A3 and A2L refrigerants respectively. For other systems the maximum change for flammability is set so the risk of getting to the lower flammability limit is low. For most applications, improved system designs are increasingly reducing charge sizes without impacting capacity and efficiency. Another method to reduce charge size is to employ indirect systems where a safe secondary refrigerant (e.g. water, glycol, brine) is circulated around the application so that the primary refrigerant is only present in a restricted and tightly controlled space with low charge. This allows flammable refrigerants to be used more widely but can have small efficiency penalties due to the energy to pump the secondary refrigerant and the extra heat transfer temperature differences.

11. Access to refrigerants - NZ imports all synthetic refrigerants and is a small isolated market with significant lead-times on orders. Many refrigerants are only available in large quantities a few months or even years after they become available in the large markets of the USA, Europe and Asia. Sometimes which refrigerant become available is dependent on choices between similar alternatives made by the importers. Patent ownership for alternative refrigerants can affect availability in NZ as not all chemical companies operate here.
12. Availability of equipment and systems – NZ imports most refrigeration componentry and many small-scale systems. In most cases, NZ can only change to alternative refrigerants after overseas manufacturers make the change to alternatives. For "well-matched" refrigerants the changes to equipment can be minor, except for the changes required if the alternative refrigerant has a different safety classification e.g. if changing from an A1 to a A2L or A3 refrigerant.
13. Design, installation and operating experience. Many refrigeration system designers, installers and operators in NZ that have specialised in synthetic refrigerants have limited experience with flammable refrigerants such as HFOs. This will grow as HFO refrigerants are introduced and increasingly used but is still a significant barrier to the wider adoption of flammable refrigerants.
14. Cost – HFC refrigerants are relatively easy to manufacture so their base cost is moderate, but their price will be strong affected due to the ETS carbon prices due to their high GWPs. Natural refrigerants are all low cost to manufacture and are unaffected by the ETS carbon price. HFOs tend to be harder to manufacture (less stable and/or lower yields) which means their base cost is higher than HFCs but are less affected by the ETS carbon price. As manufacturing of HFO's is "geared up" internationally the base price may reduce, but long-term there is likely to be a premium to the base price above most HFCs base prices.
15. Refrigerant reuse – Refrigerants recovered from existing systems can be reprocessed and reused in other systems. This practice is growing in NZ as high GWP refrigerant prices increase due to the import limitations and the ETS carbon charges. Such practice is a positive as it reduces the need to import new refrigerants under the Kigali phaseout. It also allows systems that cannot be easily converted to an alternative low GWP refrigerant to be used until the end of their economic life. However, the reused refrigerant may leak in the future so this practice can be a negative from a GWP emissions inventory perspective – it would probably be better to destroy the refrigerant and replace it with a lower GWP refrigerant thereby reducing the net GWP of the refrigerant inventory with the potential to be emitted.
16. Maintenance and leakage – If systems did not leak refrigerant, then there would be zero GWP emissions if the refrigerant is recovered and destroyed at the end of the economic life of the system. Higher levels of maintenance to reduce the likelihood of leakage is desirable but the cost to do so is a barrier for refrigeration system owners.
17. Destruction – NZ operates a free refrigerant destruction services (funded by a voluntary levy on purchase of new refrigerants). However, there is a significant technician time cost to recover refrigerants and deliver them for destruction that can incentivise venting of the refrigerant when a system is decommissioned,

rather than refrigerant recovery.

18. Export of refrigeration systems and refrigerants – There are a small number of NZ business that export refrigeration and air-conditioning equipment. They are subject to import restrictions on components and refrigerants so if they do not get commensurate credit when they export equipment containing refrigerants then it can act to make them less competitive in international markets.
19. Refrigerant in equipment – A significant quantity of refrigerants is imported and exported in equipment. Any restrictions should apply equally to both refrigerants and equipment containing equipment to avoid market distortions. Charge sizes per item should be known by manufacturers so the administrative costs to track should not be excessive. In some cases, use of a category-wide average refrigerant charge might be justified for simplicity but it can act as a disincentive for particular manufacturers or importers to reduce charge size.

The NZ refrigeration and air-conditioning sector would prefer to continue to use refrigerants that behave similarly and allow similar components and system designs as the HFC refrigerants that they replace. Changing to dissimilar refrigerants and system designs will be a barrier to adoption of low GWP refrigerants.

In general terms, small-scale and large-scale systems already have viable low GWP alternatives that are well-matched. Medium-scale systems are most problematic. Their charge sizes are too large to allow low cost and safe use of flammable refrigerants, yet they are usually too small to justify the extra cost of designs and safety systems required to use flammable refrigerants.

3. Refrigerant Phaseout Approaches

Any NZ phase-out schedule must be cognisant of the above constraints and international progress on alternatives. While some on-going adjustment of the exact phase-out dates might be possible as technical solutions are advanced or fail to materialise, any schedule needs to send strong long term signals to provide business certainty, and should challenge and signal the NZ sector to change as rapidly as possible.

The desired end game is a reduction in the cumulative GWP of our refrigerant emissions so basing any schedule on refrigerant GWP is sensible and is supported. Further using a GWP criteria allow the sector greater scope for innovation with the prescribed limits.

The availability and suitability of alternative refrigerants is quite different for the various parts of the refrigeration and air-conditioning sector. Any phase-out schedule should differ by application type. A challenge in doing so is to clearly define each sub-sector to provide certainty and to minimise the possibility of game-playing by the sector.

Any schedule should consider both installation of new systems and service of existing systems separately. When a new system is being installed there are more opportunities to change refrigerants with low economic impact whereas refrigerant restrictions on servicing existing systems could be very disruptive and have large economic impact. For service of existing systems, then a by-refrigerant approach might be simpler than a by-application approach because the existing refrigerants are already known. A combination of by-refrigerant and by-application schedules (latest deadline of each option) is another possibility that might be needed so that systems with interim refrigerants (150<GWP<750 or 1500) are not unduly penalised.

For both new systems and service of existing systems, a latest phase-out date of 2032 has been chosen (10 years away). For new systems, this is considered enough time for development of GWP<150 options for all applications. For existing systems, in many cases this means that if service is required post-2032 then the whole system would require replacement if a GWP<150 alternative does not become available. The lead-time means that the sector has time to adapt (e.g. minimise installation of new systems with GWP>150 in the interim) and the youngest system that might be pre-maturely replaced because of this schedule should generally be at least 10 year old. For many smaller-scale applications where the typical design life of equipment is 10 to 15 years or less, then such a penalty should not be large.

Setting restrictions on refrigerants for service of existing systems could also help incentivise increased maintenance to reduce leakage.

Reuse of high GWP refrigerants recovered from decommissioned systems for service of other existing systems should only be allowed where there are no viable lower GWP alternatives and the existing system still has significant economic life remaining. However, restriction on reuse could significantly increase costs (must buy new refrigerant and the new refrigerant can be more expensive than the original refrigerant depending on ETA carbon charges, manufacturing costs and shortages due to phase-out).

However, restrictions to reuse of refrigerants could mean greater venting of refrigerants when system are decommissioned rather than recovery and destruction of the refrigerant (despite venting being illegal and destruction being free in NZ, venting quite frequently occurs because it saves a lot of refrigeration technician time which is a significant cost). Providing a financial incentive to encourage recovery and destruction may be required (e.g. ETS carbon charge credit and/or return of a “bond” paid when a refrigerant is purchased).

Any schedule should be applied to both systems imported into NZ and systems constructed in NZ to avoid market distortion. Ideally to avoid economic impact, systems manufactured in NZ but exported would be exempt from the schedules as they would be subject to the rules of the importing country. Similarly, any refrigerant contained in exported equipment should deducted from the NZ Kigali quota and receive ETS carbon charge credits so that exporters are not disadvantaged in international markets.

4. **Draft Refrigerant Phaseout Schedules for Sector Consultation**

The following refrigerant phaseout schedules are proposed as a starting point for consultation with the sector. A commentary is also provided to explain the rationale and to define the key factors that might influence the phaseout date.

Noting that an immediate phaseout is given a 2022 date so that there is a short time for importer and retailers to sell any existing stocks and forward order systems with alternatives in an orderly manner. Whether this is sufficient lead-time should be a specific consultation point.

Draft Schedule By-Application for New Systems and Service of Existing Systems

Application (previous HFC)	New Systems		Existing Systems (service)		Comments
	GWP <750	GWP <150	GWP <750	GWP <150	
Residential refrigerators and dehumidifiers (R134a)	2022	2022	2023	2028	New: Charge less than 150 g so using R600a or R290 already. Existing: R450A or R513A are likely drop-ins (assume available by 2022). Not sure if R600a could be safely used as drop-in so 5 year delay to GWP<150 (appliances may become unserviceable thereafter).
Residential space air-conditioning and heat pumps plus room air-conditioners (R410A)	2022	2026	2023	2032	New: Already using R32 or similar. 2026 for GWP<150 is 1 year after EU date but would need to match schedule in Japan as main system provider. Existing: R466A or similar are possible drop-ins (assume available and confirmed as OK as a drop-in for R410A by 2023). Unlikely that there will ever be a GWP<150 drop-in for service so date to signal inventory replacement.
Residential water heating heat pumps (R134a, R410A +others)	2023	2025	2023	2032	New: Some locally manufactured so some lead time needed. HCs, CO_2, R513A/R450A or R32 should be viable alternatives but system development may be needed to get to GWP<150. Existing: R513A/R450A+R466A are likely drop-ins (assume available

					and confirmed as drop-ins by 2023). Unlikely that there will ever be a GWP<150 drop-in for service so date to signal inventory replacement.
Vehicle air-conditioning excluding trains and buses (R134a, R410A)	2023 (new) 2028 (used)	2023 (new) 2028 (used)	2023	2032	New: Most vehicles are imported so the schedules depends on manufacturers (particularly in Japan and Korea). R1234yf is already the norm in Europe so date matches that in Japan. Flammability is a more significant constraint for buses and trains so they are treated separately. Existing: R513A/R450A+R466A are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely that there will ever be a GWP<150 drop-in for service so date to signal inventory replacement.
Passenger vehicle air-conditioning i.e. trains and buses (R134a, R410A)	2023 (new)	2032	2023	2032	New: A mixture of imports and local manufacture plus some export. Flammability and efficiency are both very significant constraints. R513A/R450A and R466A provide GWP<750 options but thereafter R744 is the only non-flammable option but has efficiency limits. It may be possible to bring the GWP<150 date forward if there are is international development and/or consensus on acceptable approaches. Existing: R513A/R450A+R466A are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely that there will ever be a GWP<150 drop-in for service so date to signal inventory replacement.
Commercial Air-Conditioning i.e. office buildings and retail including VRF systems (R410A, R134a)	2024	2029	2023	2032	New: Japan shifted to GWP<750 in 2020 so equipment options should become readily available soon. It is not clear when medium sized GWP<150 systems will be developed so 5 year lead-time assumed. Large scale building already using water chillers could go to GWP<150 almost immediately. Existing: R466A and R513A/R450A

					or similar are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely that there will ever be a non-flammable GWP<150 drop-in for service so date to signal inventory replacement
Commercial Refrigeration – Food Retail i.e. supermarkets and self-contained cabinet (R134a, R404A, R407F)	2023	2023	2023	2032	New: Self-contained cabinets can transition to R600a and R290 as charges are minimised (short development time require locally). Larger supermarkets can use R744. Smaller supermarkets or larger convenience stores more difficult but would be forced to use centralised R744 or shift to cabinets. Existing: R513A/R450A and R407H or similar are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely that there will ever be a non-flammable GWP<150 drop-in for service so date to signal inventory replacement.
	GWP <1500	GWP <750	GWP <1500	GWP <750	
Commercial Refrigeration with <40kW rated capacity excluding Food Retail and applications below -50ºC i.e. food service, restaurants, walk-in cold rooms, milj vats (R134a, R404A, R507A, R407F)	2023	2028	2023	2032	The charge size in such systems means that flammable refrigerants will be hard to use. Frozen application are more difficult than chilled applications as need lower boiling point refrigerants. New: R513A/R450A and R407H provide GWP<1500 options but thereafter R744 is the only non-flammable option but has efficiency and cost limits. GWP<750 is already feasible for chilled application so 2028 date provides 5 years grace for frozen applications. Existing: R513A/R450A and R407H or similar are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely that there will ever be a non-flammable GWP<750 drop-in for R404A/R407F for service so date to signal inventory replacement. A

					case where a by-refrigerant approach makes more sense.
Transport Refrigeration i.e. refrigerated trucks, shipping containers, fishing boats and reefer vessels (R134a, R404A, R407C)	2028	2032	2023	2032	The charge size in such systems and the nature of them (mobile & confined spaces) means that flammable refrigerants will be hard to use. Frozen applications are more difficult than chilled as need lower boiling point refrigerants. Many such systems are designed and installed outside NZ. New: R452A (GWP=2140) has replaced R404A (to meet international GWP<2500 limits) so time to transition to GWP<1500 is probably required and/or match international schedules. R513A/R450A and R407H provide GWP<1500 options but thereafter R744 is the only non-flammable option but has efficiency and cost limits. GWP<750 is feasible for chilled application so 2028 date provides 5 years grace for frozen applications but will need to match international trends. The GWP<150 date of 2032 may not be realistic due to on-going safety concerns. Existing: R513A/R450A and R407H or similar are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely that there will ever be a non-flammable GWP<750 drop-in for R404A/R407F for service so date to signal inventory replacement. A case where a by-refrigerant approach makes more sense.
	GWP <2500	GWP <150	GWP <2500	GWP <750	
Industrial Refrigeration i.e. stationary refrigerant systems with rated capacity	2023	2028	2023	2032	For these larger size systems then investment into safety systems for flammable or toxic refrigerants is more easily justified. New: Most very large systems will be R717. Secondary systems allow a

>40 kW excluding applications below -50°C (R404A, R507A, R407C, R407F, R134a)					variety of refrigerants to be used safely. The 2028 date for GWP<150 allows time for medium-sized designs to change. There are many options for GWP<2500 but fewer for GWP< 1500 (e.g. R407H and R513A) so the higher limit is used. Existing: R407F, 407H, R448A, R449A or R513A/R450A or similar are likely drop-ins and are mostly available already (although few with GWP<1500 so limit set at 2500). Unlikely that there will ever be a non-flammable GWP<750 drop-in for R404A/R407F for service so date to signal inventory replacement.

Draft Schedule By-Refrigerant for Service of Existing Systems

Refrigerant (applications)	Existing Systems (service)		Comments
	GWP <750	GWP <150	
R134a (all)	2023	2032	R450A or R513A are likely drop-ins (assume available by 2023). Possibility that R600a or R1234yf could be safely used as drop-in in low charge hermetic systems only. Unlikely to be non-flammable drop-ins or retrofits so GWP<150 date to signal inventory replacement.
R410A (all)	2023	2032	R466A or similar are likely drop-ins (assume available and confirmed as drop-ins by 2023). Unlikely to be non-flammable drop-ins or retrofits so GWP<150 date to signal inventory replacement.
R513A, R450A, R466A & other non-flammable refrigerants with 150<GWP <750	-	2032	These refrigerants are most likely to be used as drop-in or retrofit replacements or in the short term in new systems. Unlikely to be non-flammable drop-ins or retrofits so GWP<150 date to signal inventory replacement.

R32, R447B, R452B, R454B, R459A & other flammable refrigerants with 150<GWP < 750	-	2032	These refrigerants are most likely to be used interim replacements in new systems. Unlikely to be non-flammable drop-ins or retrofits and also relatively unlikely to be well-matched flammable drop-ins or retrofits so GWP<150 date to signal inventory replacement.
	GWP <1500	GWP <150	
R404A (all)	2023	2032	R407H, R448A, R449A or similar are drop-ins or near drop-ins with GWP<1500 in the short term. Unlikely to be non-flammable drop-ins or retrofits with GWP<750 so GWP<150 date to signal inventory replacement. Some low charge systems may be suitable to retrofit with flammable alternatives but this is unlikely to be common.
R507A (all)	2023	2032	R407H, R448A, R449A or similar are drop-ins or near drop-ins with GWP<1500 in the short term. Unlikely to be non-flammable drop-ins or retrofits with GWP<750 so GWP<150 date to signal inventory replacement. Some low charge systems may be suitable to retrofit with flammable alternatives but this is unlikely to be common.
R407C, R407F, R452A & other non-flammable refrigerants with 1500<GWP <2500	2023	2032	R407H, R448A, R449A or similar are drop-ins or near drop-ins with GWP<1500 in the short term. Unlikely to be non-flammable drop-ins or retrofits with GWP<750 so GWP<150 date to signal inventory replacement. Some low charge systems may be suitable to retrofit with flammable alternatives but this is unlikely to be common.
R448A, R449A, R449C & other non-flammable refrigerants with 750<GWP <1500	-	2032	These refrigerants are most likely to be used as drop-in or retrofit replacements or in the short term in new systems. Unlikely to be non-flammable drop-ins or retrofits with GWP<750 so GWP<150 date to signal inventory replacement.
R444B, R454A and other flammable refrigerants with 150<GWP < 750	-	2026	These refrigerants are most likely to be used as R404A and R507A alternatives in new and retrofit low charge systems where flammability is not a constraint. R454C, R455A, R457A, R459B, R465A may be drop-ins or retrofit alternatives and a tighter GWP<150 deadline encourages a direct move to GWP<150 for flammable tolerant applications.

5. **Possible Sector Consultation Questions**

Some aspects of the above schedules identified for consultation include:

- Check the NZ availability of non-flammable GWP<750 refrigerants such as R450A, R513A, R407H and R466A
- Confirm that R450A/R513A, R407H and R466A can be used as drop-ins or minimal retrofit refrigerants for R134a, R404A and R410A respectively
- What is the minimum lead time need for a smooth market transition when clear alternative refrigerants already exist (set at 2022 in draft schedule)?
- Is 2032 too late or too soon to signal complete transition to GWP<150 refrigerants which could make some systems unserviceable before the end of their economic life?
- Are the definitions of categories sufficiently clear and unambiguous?
- Is >40 kW a reasonable size to define large-scale applications?
- For service of existing equipment is a by-refrigerant approach preferred over the by-application approach? A by-refrigerant is recommended.

A two-stage consultation is recommended. First, with some selected sector representatives to identify any major contentious issues and if necessary to modify the proposal, and second, with the whole sector publicly.

Table 1: Key Characteristics for CFCs, HCFCs, HFCs, HFOs and Natural Refrigerants.

Number	Trade Name(s)	Chemical Formula or Composition	BP (ºC)	GWP	Safety Class	Glide (K)	Oil Compatibility/Comment
ChloroFluoroCarbons (CFCs) – ODP > 0:							
R11	Trichlorofluoromethane	CCl_3F	24	4750	A1	0	M,AB; ODP=1
R12	Dichlorodifluoromethane	CCl_2F_2	-30	10900	A1	0	M,AB; ODP=1
R502		22 (49%); 115 (51%)	-45	4700	A1	0	AB; ODP=0.25
HydroChloroFluoroCarbons (HCFCs) – ODP > 0:							
R22	Chlorodifluoromethane	$CHClF_2$	-41	1810	A1	0	M,AB; ODP=0.055
R40	Chloromethane	CH_3Cl; methyl chloride	-24	13	B2	0	M,AB; ODP=0.02; reacts with Al+air; HCC
R13I1	Trifluoroiodomethane	CF_3I	-23	0	A1	0	POE; ODP=0.01; IFC
HydroFluoroCarbons (HFCs) – ODP = 0:							
R23	Trifluoromethane	CHF_3	-82	14800	A1	0	POE, PVE, AB*, PAG*
R32	Difluoromethane	CH_2F_2	-52	675	A2L	0	POE, PVE, AB*, PAG*
R125	Pentafluoroethane	C_2HF_5	-49	3500	A1	0	Blend component
R134a	Tetrafluoroethane	$C_2H_2F_4$	-26	1430	A1	0	POE, PVE, AB*, PAG*
R143a	Trifluoroethane	$C_2H_3F_3$	-47	4470	A2L	0	Blend component
R152a	Difluoroethane	$C_2H_4F_2$	-24	124	A2	0	POE, PVE, AB*, PAG*
R227ea	Heptafluoropropane	$CF_3CHFCHF_3$	-16	3220	A1	0	Blend component
R245fa	Pentafluoropropane	$CF_3CH_2CHF_2$	15	1030	B1	0	POE
R404A	Suva HP62, FX-70	125 (44%), 134a (4%), 143a (52%)	-47	3922	A1	0.7	POE,PVE,AB*,PAG*
R407A	Klea-60	32 (20%), 125 (40%) 134a (40%)	-46	2107	A1	6.6	POE,PVE,AB*,PAG*
R407C	Klea-66, Suva-9000	32 (23%), 125 (25%) 134a (52%)	-44	1774	A1	7.4	POE,PVE,AB*,PAG*
R407F	Performax LT	32 (30%), 125 (30%) 134a (40%)	-46	1825	A1	6.4	POE,PVE,AB*,PAG*
R407H		32 (32.5%), 125 (15%) 134a(52.5%)	-45	1490	A1	7.0	POE,PVE,AB*,PAG*
R410A	AZ-20	32 (50%), 125 (50%)	-51	2088	A1	0.2	POE,PVE,AB*,PAG*
R413A	ISCEON MO49	134a (88%), 218 (9%), 600a (3%)		2050	A1		M,PAG,AB, POE
R417A	ISCEON MO59	125(46.6%), 134a(50%), 600(3.4%)	-39	2346	A1	5.6	M,POE,PVE,AB*,PAG*
R417B		125(79%), 134a(18.2%), 600(2.8%)	-42	2920	A1	3.4	POE,PVE,AB*,PAG*
R422A	ISCEON MO79	125 (85.1%), 134a (11.5%), 600a (3.4%)	-49	3143	A1	2.5	M,POE,PVE,AB*,PAG*
R422D	ISCEON MO29	125 (65.1%), 134a (31.5%), 600a (3.4%)	-45	2729	A1	4.5	M,POE,PVE,AB*,PAG*
R424A	RS-44	125 (50.5%), 134a (47%), 600 (1%), 600a (0.9%), 601a (0.6%)	-39	2328	A1	3.6	M,POE,PVE,AB*,PAG*
R426A	RS-24	134a (93%), 125 (5.1%), 600 (1.3%), 601a (0.6%)	-29	1382	A1	0.5	M,POE,PVE,AB*,PAG*
R427A	Forane FX100	32 (15%), 125 (25%), 143a (10%), 134a (50%)	-43	2138	A1	7.1	M,POE,PVE,AB*,PAG*
R428A	RS-52	125 (77.5%), 143a (20%), 290 (0.6%), 600a (1.9%)	-47	3495	A1	0.8	M,POE,PVE,AB*,PAG*
R434A	RS-45	125 (63%), 143a (18%), 134a (15.7%), 600a (3.3%)	-45	3131	A1	1.5	M,POE,PVE,AB*,PAG*
R438A	ISCEON MO99	32 (8.5%), 125 (45%), 134a (44.2%), 600 (1.7%), 601a (0.6%)	-42	2264	A1	6.6	M,POE,PVE,AB*,PAG*
R442A	RS-50	125 (31%), 32 (31%), 134a (30%),152a (5%),227ea (3%)	-47	1888	A1	4.6	POE,PVE
R444A	AC5	32(12%),152a(5%),1234ze(E)(83%)	-34	92	A2L	10.0	POE,PVE
R444B	L-20	32 (41.5%), 152a (10%), 1234ze(E) (48.5%)	-45	295	A2L	10.0	POE,PVE
R447B	L-41z	32(68%), 125(8%), 1234ze(E)(24%)	-50	740	A2L	4.0	POE,PVE
R448A	Solstice N40	32(26%),125(26%),134a(21%) 1234ze(E) (7%), 1234yf (20%)	-46	1387	A1	6.2	POE,PVE
R449A	XP-40	32 (24%),125 (25%), 134a (26%), 1234yf (25%)	-46	1397	A1	5.7	POE,PVE
R449B		32 (25.5%),125 (24.3%), 134a (27.3%),1234yf (23.2%)	-46	1412	A1	6.0	POE,PVE
R449C		32 (20%),125 (20%), 134a (29%), 1234yf (31%)	-44	1251	A1	6.1	POE,PVE
R450A	N-13	134a (42%), 1234ze(E) (58%)	-24	604	A1	0.6	POE,PVE
R452A	XP44	32 (11%), 125 (59%) 1234yf (30%)	-47	2140	A1	3.8	POE,PVE
R452B	XL55,Solstice L-41y	32 (67%), 125 (7%) 1234yf (26%)	-51	698	A2L	0.9	POE,PVE

R452C		32 (12.5%), 125 (61%), 1234yf (26.5%)	-48	2220	A1	3.4	POE,PVE
R453A	RS-70	125 (20%), 32 (20%), 134a (53.8%), 227ea (5%), 601a(0.6%), 600(0.6%)	-42	1765	A1	4.2	M,POE,AB
R454A	XL40, ARM-20b	32 (35%), 1234yf (65%)	-48	239	A2L	5.7	POE,PVE
R454B	XL41	32 (68.9%), 1234yf (31.1%)	-51	466	A2L	1.0	POE,PVE
R454C	XL20	32 (21.5%), 1234yf (78.5%)	-46	148	A2L	7.8	POE,PVE
R455A	Solstice L-40X	32(21.5%),1234yf(75.5%), 744(3%)	-52	148	A2L	12.8	POE,PVE
R456A	AC5X	32(6%),1234ze(E)(49%),134a(45%)	-30	687	A1	4.8	POE,PVE
R457A	ARM-20a	32(18%), 1234yf(70%), 152a (12%)	-43	139	A2L	7.2	POE,PVE
R458A	TdX 20	32 (20.5%), 125 (4%), 134a(61.4%), 227ea (13.5%), 236fa (0.6%)	-40	1765	A1	4.2	M,POE,PVE,AB
R459A	ARM-71a	32 (68%), 1234yf (26%), 1234ze(E) (6%)	-50	460	A2L	1.7	POE,PVE
R459B	LTR11	32 (21%), 1234yf (69%), 1234ze(E) (10%)	-44	144	A2L	7.9	POE,PVE
R460A	LTR10	32 (12%), 125 (52%), 134a (14%), 1234ze(E) (22%)	-45	2103	A1	7.4	POE,PVE
R460B	LTR4X	32 (28%), 125 (25%), 134a (20%), 1234ze(E) (27%)	-45	1352	A1	8.2	POE,PVE
R463A	XP41	32 (36%), 125 (30%) 1234yf (14%), 134a (14%), 744 (6%)	-59	1494	A1	12.2	POE,PVE
R465A	ARM-25	32 (21%),1234yf (71.1%), 290 (7.9%)	-52	145	A2	11.8	POE,PVE
R466A		32 (49%), 1234yf (11.5%), 13I1 (39.5%)	-52	733	A1	0.7	POE,PVE
R507A	AZ-50	125 (50%), 143a (50%)	-47	3985	A1	0	POE,PVE,AB*,PAG*
R513A	XP10	1234yf (56%), 134a (44%)	-30	631	A1	0	POE,PVE
R513B		1234yf (58.5%), 134a (41.5%)	-29	596	A1	0	POE,PVE
R515B		1234ze(E) (91.1%), 227ea (8.9%)	-19	293	A1	0	POE
R516B	ARM-42b	1234yf(82%),152a(11%), 134a(7%)	-29	142	A2L	0	POE

HydroChloroFluoroOlefins (HCFOs) – ODP < 0.001:

R1224yd(Z)	(Z)chloro-tetrafluoro-propene	$CHCl=CFCF_3$	14	4	A1	0	POE; ODP=0.00012
R1233zd (E)	trans-chloro-trifluoro-propene	$CHCl=CHCF_3$	18	5	A1	0	M,POE; ODP=0.00034

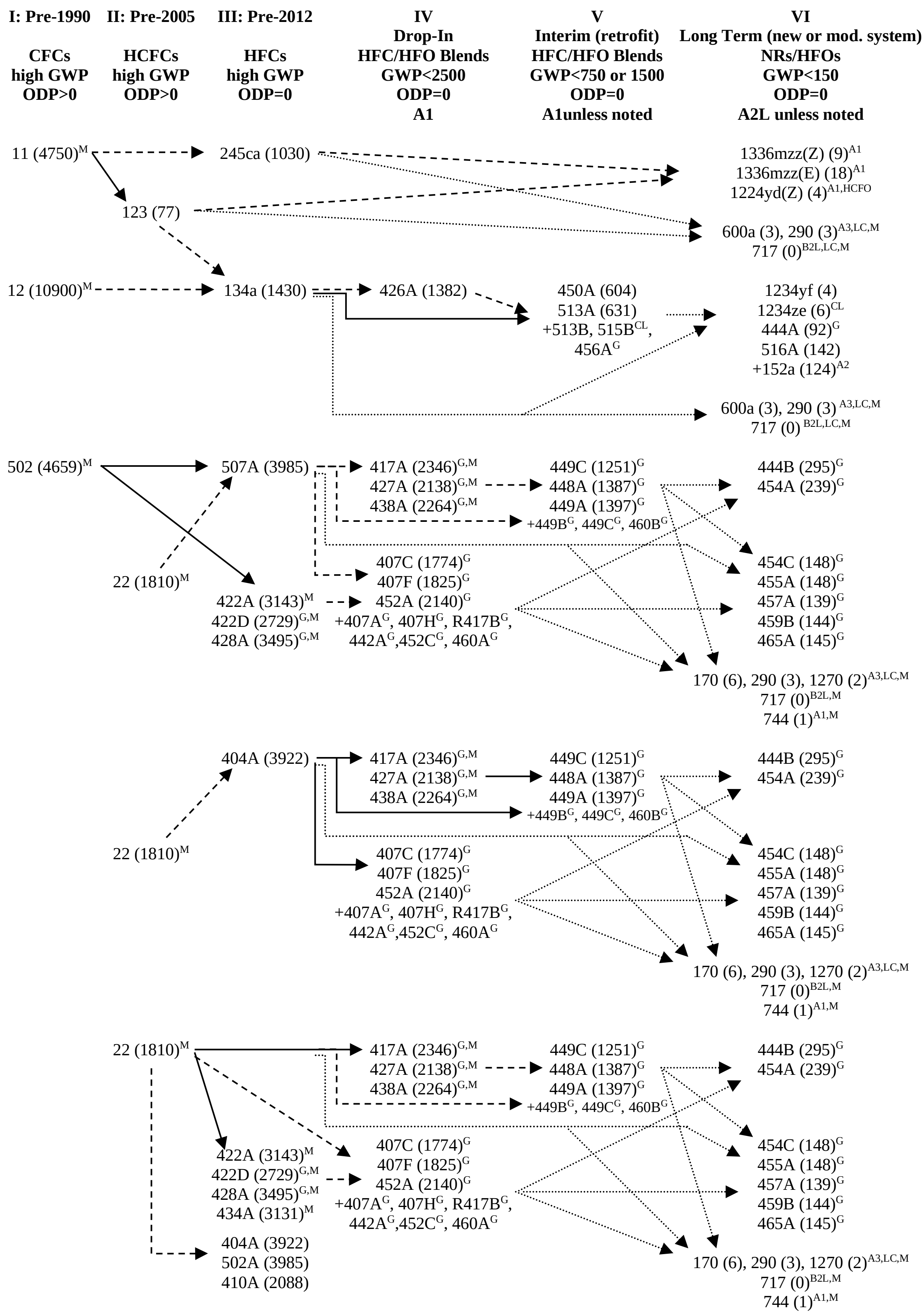
HydroFluoroOlefins (HFOs) – ODP = 0:

R1234yf	tetrafluoro-propene	$CH_2=CFCF_3$	-30	4	A2L	0	POE,PVE,PAG
R1234ze(E)	trans-tetrafluoro-propene	$CHF=CHCF_3$	-19	6	A2L	0	POE,PVE
R1336mzz (E)	hexafluoro-butene	$CF_3CH=CHCF_3$	8	18	A1	0	POE
R1336mzz (Z)	cis-hexafluoro-butene	$CF_3CH=CHCF_3$	33	9	A1	0	POE

Natural Refrigerants (NRs) – ODP = 0:

R170	Ethane	C_2H_6	-89	6	A3	0	M,POE,AB
R290	Propane, Care 40	C_3H_8	-42	3	A3	0	M,PAO,POE,AB*
R600	Butane	C_4H_{10}	0	20	A3	0	Blend Component
R600a	Isobutane, Care 10	C_4H_{10}	-12	3	A3	0	M,PAO,POE,AB*
R717	Ammonia	NH_3	-33	0	B2L	0	M,PAO,AB*,PAG*; reacts with copper
R744	Carbon Dioxide	CO_2	-78	1	A1	0	M,POE,PAG
R1270	Propylene	C_3H_6	-48	2	A3	0	M,PAO,POE,AB*

Notes: GWP = Global Warming Potential (100 year; AR4) relative to CO_2. ODP = Ozone Depletion Potential relative to CFC-11. BP = boiling point. M = mineral oil, AB = alkyl benzene oil, POE = polyol ester oil, PVE = polyvinyl ether oil, PAG = poly alkylene glycol oil, PAO = polyalphaolefin oils, * with restrictions. A1 = non-toxic and non-flammable, A2L = non-toxic and mildly flammable, A3 = non-toxic and highly flammable, B2L = toxic and mildly flammable, A2 = non-toxic and flammable.



I: Pre-1990
II: Pre-2005
III: Pre-2012
IV
Drop-In
HFC/HFO Blends
GWP<2500
ODP=0
A1
V
Interim (retrofit)
HFC/HFO Blends
GWP<750 or 1500
ODP=0
A1unless noted
VI
Long Term (new or mod. system)
NRs/HFOs
GWP<150
ODP=0
A2L unless noted
CFCs
high GWP
ODP>0
HCFCs
high GWP
ODP>0
HFCs
high GWP
ODP=0
11 (4750)[M]
245ca (1030)
123 (77)
1336mzz(Z) (9)[A1]
1336mzz(E) (18)[A1]
1224yd(Z) (4)[A1,HCFO]
600a (3), 290 (3)[A3,LC,M]
717 (0)[B2L,LC,M]
12 (10900)[M]
134a (1430)
426A (1382)
450A (604)
513A (631)
+513B, 515B[CL],
456A[G]
1234yf (4)
1234ze (6)[CL]
444A (92)[G]
516A (142)
+152a (124)[A2]
600a (3), 290 (3) [A3,LC,M]
717 (0) [B2L,LC,M]
502 (4659)[M]
507A (3985)
22 (1810)[M]
422A (3143)[M]
422D (2729)[G,M]
428A (3495)[G,M]
417A (2346)[G,M]
427A (2138)[G,M]
438A (2264)[G,M]
407C (1774)[G]
407F (1825)[G]
452A (2140)[G]
+407A[G], 407H[G], R417B[G],
442A[G],452C[G], 460A[G]
449C (1251)[G]
448A (1387)[G]
449A (1397)[G]
+449B[G], 449C[G], 460B[G]
444B (295)[G]
454A (239)[G]
454C (148)[G]
455A (148)[G]
457A (139)[G]
459B (144)[G]
465A (145)[G]
170 (6), 290 (3), 1270 (2)[A3,LC,M]
717 (0)[B2L,M]
744 (1)[A1,M]
404A (3922)
22 (1810)[M]
417A (2346)[G,M]
427A (2138)[G,M]
438A (2264)[G,M]
407C (1774)[G]
407F (1825)[G]
452A (2140)[G]
+407A[G], 407H[G], R417B[G],
442A[G],452C[G], 460A[G]
449C (1251)[G]
448A (1387)[G]
449A (1397)[G]
+449B[G], 449C[G], 460B[G]
444B (295)[G]
454A (239)[G]
454C (148)[G]
455A (148)[G]
457A (139)[G]
459B (144)[G]
465A (145)[G]
170 (6), 290 (3), 1270 (2)[A3,LC,M]
717 (0)[B2L,M]
744 (1)[A1,M]
22 (1810)[M]
422A (3143)[M]
422D (2729)[G,M]
428A (3495)[G,M]
434A (3131)[M]
404A (3922)
502A (3985)
410A (2088)
417A (2346)[G,M]
427A (2138)[G,M]
438A (2264)[G,M]
407C (1774)[G]
407F (1825)[G]
452A (2140)[G]
+407A[G], 407H[G], R417B[G],
442A[G],452C[G], 460A[G]
449C (1251)[G]
448A (1387)[G]
449A (1397)[G]
+449B[G], 449C[G], 460B[G]
444B (295)[G]
454A (239)[G]
454C (148)[G]
455A (148)[G]
457A (139)[G]
459B (144)[G]
465A (145)[G]
170 (6), 290 (3), 1270 (2)[A3,LC,M]
717 (0)[B2L,M]
744 (1)[A1,M]

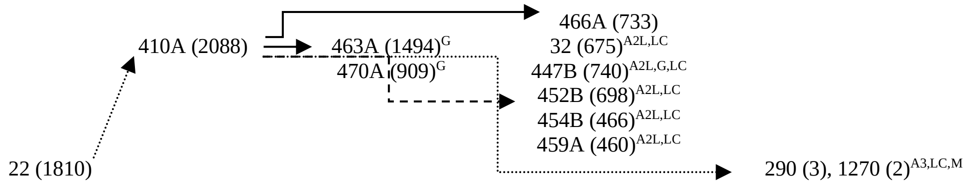


Figure 1: Pathways for refrigerant retrofit and replacement (⟶, drop-in or retrofit with minimal changes to equipment; - - - ►, significant modifications to equipment, ·········►, very different equipment). GWP values are given in brackets. The following are indicated if exception to column descriptor. [A1] = A1, [A2] = A2, [A2L] = A2L, [A3] = A3, [LC]= low charge, [CL] = capacity lower (by >10%), [G] = high glide (>2.5K), [HCFO] = HCFO (ODP>0), [M] = compatible with mineral oil.

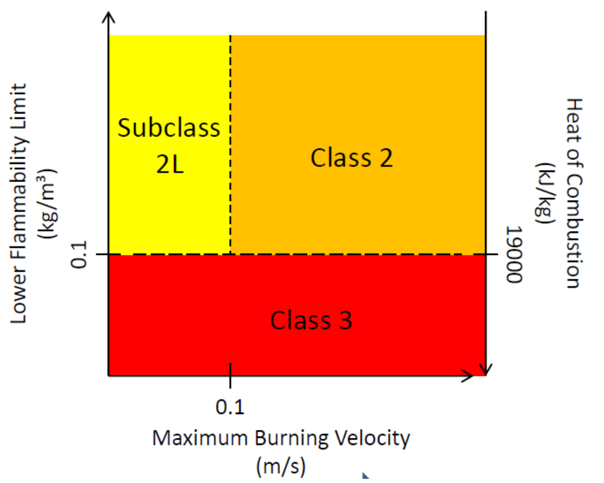


Figure 2: Criteria for classification of flammable refrigerants. Noting that prefix letters A or B indicate non-toxic or toxic refrigerants respectively.