# R22 REPLACEMENT STATUS

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## Introduction

**The next step in the transition to environmentally safer refrigerants is phaseout of R22. It is the most widely used refrigerant, both in the United States and on a global basis. Its application range in residential, commercial, industrial, and transport systems is broader than for any other refrigerant and spans cooling capacities from 2 kW to 33 MW (1/2 to 9,500 tons). The specific replacements depend on the applications.**

**Keywords:** refrigerants, Montreal Protocol, efficiency

### Introduction

Since its initial recognition in 1928 and commercialisation in 1936, R22 has been applied in systems ranging from the smallest window air conditioners to the largest chillers and heat pumps, including those for district cooling and heating. Individual equipment using this versatile refrigerant ranges from 2 kW to 33 MW (1/2 to 9,500 tons) in cooling capacity. R22 use includes equipment with rotary-rolling-piston, reciprocating-piston, scroll, screw, and centrifugal com-pressors and, experimentally, absorption cycles. No other refrigerant has achieved such a wide range of commercial capacities or applications.

However, R22 is one of a class of chemicals, hydrochlorofluorocarbons (HCFCs), being phased out for environmental protection pursuant to an international agreement, the *Montreal Protocol on Substances that Deplete the Ozone Layer* (UNEP 1997, 2003a). The Protocol's control measures address "consumption," defined as production plus imports minus both exports and qualifying amounts destroyed. The Protocol does not limit future use of chemicals once manufactured or imported, namely refrigerant that is already in use, recycled, or stockpiled be-fore the phaseout dates. It also does not restrict use of chemicals as feed stocks (intermediates to manufacture other chemicals).

Table 1 identifies the phase out dates for manufacture and importation of R22 pursuant to the Montreal Protocol and national requirements in both Canada and the USA. The dates shown are for full phaseout, though earlier freeze or progressive reduction steps apply. Some countries – notably many in Europe – have accelerated the schedule.

Due to its extensive prior and current use, a large inventory of equipment designed for R22 will remain in service for decades, long after R22 production ends. The primary sources to maintain this equipment will be limited production allowances for such service, inventories stock-piled before the end of production, and amounts recovered from converted or retired equipment. There also will be options to convert the equipment to replacement refrigerants, some of which were developed specifically to simplify aftermarket (not intended for original use) conversion.

A small number of countries, again notably in Europe, have tighter restrictions. They already prohibit R22 use and/or service, or will do so, by specified dates based on the type and size of equipment. Conversely, the Montreal Protocol allows developing countries (more specifically those identified in Article 5(1) based on their levels of use of controlled substances), to continue "consumption" (production plus imports less exports and destruction) until 2040.

| | New Equipment | Existing Equipment |
|---|---|---|
| Montreal Protocol | | |
| developed countries | 2020[a] | 2030 |
| Article 5(1) countries | 2040[a] | 2040 |
| USA[b] and Canada | 2010 | 2020 |

NOTES:

**a** The Protocol imposes stepped reductions (a single freeze in 2015 for Article 5(1) countries) for collective HCFC consumption, but allows individual countries to determine how to meet those limits based on allocations between individual substances (weighted by their ozone depletion potentials, ODPs) and uses.

**b** Pursuant to the Clean Air Act Amendments (CAAA) of 1990 and implementing regulations at 40 CFR 82. Table 1: R22 production phaseout (by January 1 of year indicated): These dates affect produc-tion and importation of R22, not continued operation using existing or recycled R22.

*Table 1 – R22 production phaseout (by January 1 of year indicated). These dates affect production and importation of R22, not continued operation using existing or recycled R22.*

### R22 replacement options

There is no single-compound refrigerant to directly replace R22, but manufacturers have commercialised at least eight refrigerant blends to maintain existing equipment (with appropriate conversions) and several additional blends for new equipment. These quantities increase to more than 20 for conversions and more than ten for new equipment if R502 (a widely used blend containing R22 for low-temperature, commercial refrigeration) is considered. These blends are summarised in Table 2. The discussion below notes several single-compound refrigerants that replace former R22 use, but with differences in how they are applied.

Complementing extensive research and development by individual chemical and equipment manufacturers, by university and other research organizations, and by government-sponsored laboratories, the air-conditioning and refrigeration industry organized a cooperative effort to ex-pedite a broad screening of alternatives for R22. This international program was known as the "R22 Alternative Refrigerants Evaluation Program" (AREP). It included a Japanese counterpart identified as "JAREP." The goal of the early 1990s test program was to eliminate duplication of work and wasting of limited resources in evaluating replacement options.

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Thirty-nine companies in Europe, Japan, and North America participated. They shared analytical results as well as test findings from calorimeter and equipment tests, for both "drop-in" (minimal conversions) and for refrigerant-optimized designs.

AREP examined 14 candidate refrigerants selected as potential replacements for R22. The candidates included R134a; R32/125 (60.0/40.0); R32/134a (20.0/80.0), (25.0/75.0), (30.0/70.0), and (40.0/60.0); R32/227ea (35.0/65.0); R125/143a (45.0/55.0); R32/125/134a (10.0/70.0/20.0) [R407B], (24.0/16.0/60.0), and (30.0/10.0/60.0); and R32/125/290/134a (20.0/55.0/5.0/20.0). They also included R290 (propane) and R717 (ammonia), though actual tests of these two refrigerants were limited. Additional candidates included four replacements for R502, namely R125/143a (45.0/55.0), R32/125/134a (20.0/40.0/40.0) [R407A]; R125/143a/134a (10.0/45.0/45.0), and R125/143a/134a (44.0/52.0/4.0) [R404A].

| | Existing Equipment (may require conversion) | New Equipment |
|---|---|---|
| **R22** | R-407C R-421A R-411A R-421B R-417A R-419A | R-407C R-410A HCs R-407E R-410B |
| **R-502** | R-402A R-404A R-409A R-402B R-407A R-411B R-403A R-407B R-422A R-403B R-408A R-507A | R-404A R-507A HCs R-407A R-509A |

There are many additional refrigerants – mostly blends – in use, but their aggregate market share is very small. The table addresses only those blends that have obtained standard designations.

*Table 2 – Replacement blends for R22*

Based on the findings, most small compressor and unitary equipment manufacturers converged on the R32/125 binary blend, later reformulated to R32/125 (50.0/50.0) [R410A] to maximise performance while avoiding flammability. This near azeotropic blend operates at significantly higher condensing pressures – approximately 60% higher than R22 for air-cooled systems – but offers the promise of reduced equipment size.
One ternary blend, R32/125/134a, stood out as a service candidate by using different component ratios formulated to approximate the pressure – temperature properties of R22 and R502. R32/125/134a (30.0/10.0/60.0) garnered high interest as a near-term option and for future use as a service fluid. Manufacturers later revised the formulation to R32/125/134a (23.0/25.0/52.0) [R407C] to reduce the potential for flammability with fractionation.

The AREP effort addressed only pre-competitive evaluation. Individual manufacturers developed competitive approaches to design and optimize actual equipment. Minor (2004) summarises an extensive literature review of the tests and needed changes for actual equipment. They included changes to compressors, heat exchangers, and control devices in addition to lubricants (see discussion later). Most of the cited reports showed equivalent or improved energy efficiency for R410A compared to R22, specifically 1% to 7% increases for cooling and 3% decreases to 7% increases for heating.

While the service infrastructure and commonality of some compressors and control devices for residential and light commercial equipment practically demanded uniform selections, there is less consistency in larger equipment. R134a is the most widely used replacement in chillers with screw compressors (175-1500 kW, 50-450 tons), both air and water-cooled. Other choices include R410A and, to a limited extent primarily in Europe, R717 (ammonia) and R1270 (propylene). Early interest in R407C and, but less commonly, R404A to accelerate market entry is fading. A new product, also using R134a, offers a very compact, inverter driven, centrifugal compressor to replace reciprocating-piston and screw compressors to achieve dramatically improved efficiency in similar capacities.

Interest continues, particularly in Europe, in R407C for water-source chillers. Although efficiency generally is up to 7% lower than R22 for conventional designs, two developments are being considered. The use of a suction-liquid heat exchanger may enable 2% gains in efficiency. More significant improvements may be possible by taking advantage of R407C's high glide (evaporation and condensation temperature range) of 4°C to 5°C. Up to 5% improvement may be realised using counterflow heat exchangers to approximate a thermodynamic Lorenz cycle (one that exploits the glide to reduce net temperature lift by use of counterflow evaporators and condensers).

### Environmental properties

While the decision to phase out R22 is based on its potential to deplete stratospheric ozone, consideration of alternatives must consider additional environmental data. Table 3 compares the atmospheric lifetime ($\tau_{atm}$), ozone depletion potential (ODP), and global warming potential (GWP) for R22 to those of selected alternatives.

| Refrigerant | Atmospheric Lifetime (yr) | ODP | GWP (100 yr) |
|---|---|---|---|
| R22 | 12.0 | 0.034 | 1780 |
| R123 | 1.3 | 0.012 | 76 |
| R134a | 14.0 | ~ 0.0 | 1320 |
| R407C | a | ~ 0.0 | 1700 |
| R407E | a | ~ 0.0 | 1400 |
| R410A | a | ~ 0.0 | 2000 |
| R32 | 4.9 | ~ 0.0 | 543 |
| R32/600 (95.0/5.0) | a | ~ 0.0 | 520 |
| R32/600a (90.0/10.0) | a | ~ 0.0 | 490 |
| R290 (propane) | b | 0.0 | ~ 20 |
| R717 (ammonia) | b | 0.0 | < 1 |
| R744 (carbon dioxide) | > 50 | 0.0 | = 1 |
| R1270 (propylene) | b | 0.0 | ~ 20 |

**a** Atmospheric lifetimes are not given for blends since the components separate in the atmosphere.
**b** Unknown.

*Table 3 – Environmental properties of R22 and its replacements based on Calm and Hourahan (2001), IPCC (2001), and WMO (2003)*

$\tau_{atm}$ indicates the average persistence of refrigerant released into the atmosphere until it decomposes, reacts with other chemicals, washes out, or is otherwise removed. It suggests average atmospheric residence time and therefore the potential for accumulation. Long atmospheric lifetime implies the potential for slow recovery from environmental problems, both those already known and additional concerns that may be identified in the future. Hence, short atmospheric lifetime is desirable.

The values shown for the refrigerant lives are composite atmospheric lifetimes. The lifetimes also can be shown separately for the tropospheric (lower atmosphere where we live), stratospheric (next layer where global depletion of ozone is a concern), and higher layers since the primary removal mechanisms change between layers.

The ODP is a normalised indicator, relative to R11, of the ability of refrigerants (and other chemicals) to destroy stratospheric ozone molecules. The data shown are the modeled values adopted by international scientific assessment. The ODPs shown for blends are mass-weighted averages.

Both the ODP and GWP are calculated from the $\tau_{atm}$, measured chemical properties, and other atmospheric data. The $\tau_{atm}$, ODP, and GWP all should be as low as possible for an ideal refrigerant, but those goals must be assessed along with criteria for performance, safety, and both chemical and thermal stability in use. Calm and Hourahan (2001) discuss these parameters, other ways to determine ODPs, and their significance.

## Comparative Efficiencies

The comparative efficiencies of refrigerants depend primarily on five factors:

**Thermodynamic properties:**

1. How far the refrigeration cycle operates below the critical point (which affects the ratio of the latent heat of evaporation to the liquid specific heat at constant pressure).

2. The slopes of the saturated suction and liquid lines, which dictate the comparative effects of superheating, subcooling, and throttling. The slopes are largely influenced by the molar heat capacity.

**Transport properties:**

3. Thermal conductivity and viscosity, which influence the heat transfer and fluid friction.

**Application:**

4. Heat transfer affected by the refrigerant glide and heat exchanger configuration.

5. Cycle optimisation for the fluid by control of superheat, subcooling, staging with economisers, and inclusion of such features as liquid-line/suctionline heat exchang-ers.

Figure 1 shows the temperature-entropy relationship of R22 and selected replacements to facilitate qualitative evaluation of impact of thermodynamic properties on the coefficient of performance (COP). The figure plots entropy as a dimensionless quantity by normalising it to the width of the two-phase dome (i.e., saturated liquid = 0 and saturated vapor = 1). Note that the critical point temperature, at the top of the two-phase region, is higher for R134a than for R22. Similarly, the critical temperature is lower for R410A and also for R125, a component (50% by mass) of the R410A blend. For the same evaporating and condensing temperatures, a cycle using R134a operates further from its critical point than R22 and much further than R410A and R125.

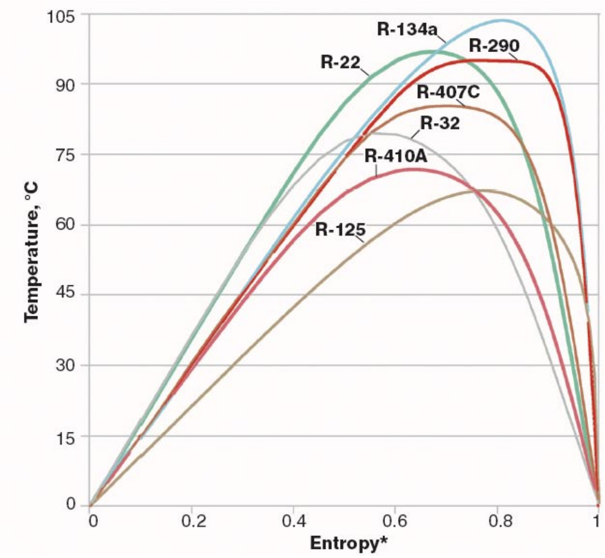


*Figure 1 - temperature-entropy diagram for R22 and selected replacements (* normalised entropy is plotted as dimensionless ratio to facilitate comparisons)*

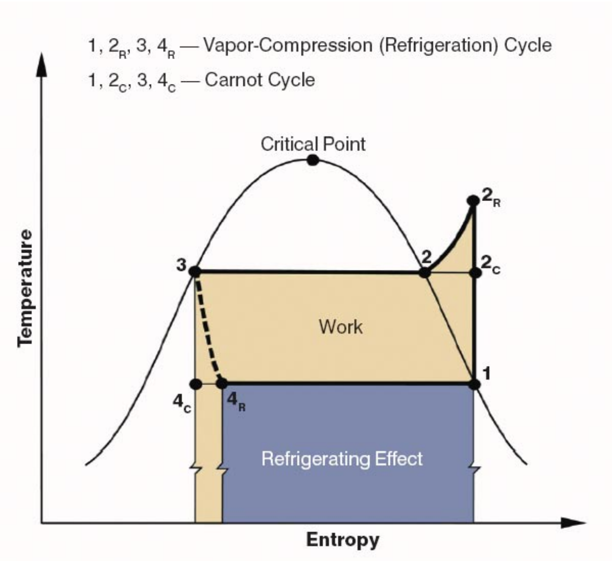


*Figure 2 - vapor-compression (refrigeration) cycle on temperature-entropy (T-S) generalised diagram*

Figure 2 depicts a basic vapor-compression (refrigeration) cycle on a simplified temperature-entropy (T-S) diagram. The refrigerating effect per unit of mass flow equals the area under the evaporation line, while the work needed to drive the cycle is the area under the condensing and desuperheating lines minus the area denoting the refrigerating effect. With reference to the Carnot cycle, the throttling-induced irreversibilities reduce the refrigeration effect by the area under line 4C-4R; this area also represents the additional work requirement caused by throttling (lost expansion work). The additional work required due to the superheated-vapor-horn is denoted by area 2-2C-2R. The throttling-induced and superheated-vapor-horn irreversibilities are affected by the slopes of saturation lines. These losses are greater near the critical point, where the saturation lines gradually become flatter to close the two-phase dome.

R410A has a lower critical temperature then R22, and for this reason the superheated-vapor-horn irreversibilities and throttling-induced irreversibilities are greater for R410A then for R22. Of the two components of R410A, R32 offers higher thermodynamic performance than R125 for the conditions of interest, though the R125 component offsets R32's limited flammability. The R125 component also increases the blend's GWP. Accordingly, other R32 blends might hold interest. Two examples, R32/600 (95.0/5.0) and R32/600a (90.0/10.0) are included in tables 3 and 4 for comparison. These azeotropic blends of R32 with n-butane and isobutane, respectively, offer performance advantages (Yoshida et al., 1999) and could be used with mineral-oil lubricants. Both blends, however, are somewhat flammable.

Thermodynamic simulations offer insights into attainable efficiencies with theoretical cycles, namely excluding the impacts of transport properties, cycle customisation, and the effects of lubricants. Tables 4 and 5 provide calculated cooling efficiencies for selected R22 replacements in unitary air conditioners and in water-cooled chillers with simple cycles (single stage and no customization for individual properties of specific refrigerants). The tables indicate both COP and specific power (reciprocal of efficiency) values, the latter of which is more common for discus-sion of chillers.

Refrigerants with lower heat transfer may not perform as well as those with superior heat transfer despite thermodynamic advantage, but design compensation may offset this difference. Likewise, blends with high glide, such as R407C, may not achieve the performance indicated with cross-flow (air or, but less commonly, water movement perpendicular to the refrigerant flow) heat exchanger designs, but may exceed it with counterflow heat exchangers.

Some replacements, such as R134a in chillers, offer higher efficiency than R22. For others, manufacturers have improved equipment designs to offset theoretical efficiency losses.

Domanski (1995) and Calm and Didion (1997) examine some of the implications of and accommoda-tions for lower theoretical efficiency. Domanski and Payne (2002) show that R410A suffers a relative efficiency degradation compared to R22 at high condensing temperatures, although its performance may be comparable to R22 at typical operating conditions. Spatz and Yana Motta (2003) discuss the pressure drop and heat exchange considerations that yield efficiency im-provements. Yoshida et al. (1999) offer interesting ways to achieve higher efficiency using azeotropic or near-azeotropic blends of R32 with hydrocarbons and possibly enable a return to mineral-oil lubricants, though such blends are flammable.

Many conflicting claims exist regarding the efficiency of carbon dioxide (R744, $CO_2$). One reason is that most applications require a transcritical rather than a conventional vapor-compression cycle. This venerable refrigerant does offer significant potential in some applications. An example is in the low stage of cascaded industrial refrigeration systems, but it most commonly replaces ammonia in that use. Brown et al. (2002) offer a detailed evaluation for resi-dential applications using both conventional vapor compression and transcritical cycle models. They conclude that carbon dioxide results in significantly lower efficiency when equivalent heat exchangers are used. That suggests that the better transport properties and variously claimed increase in compressor isentropic efficiency do not compensate for the thermodynamic disadvantage. This disadvantage will be even more pronounced for efficiency levels significantly exceeding those commonly selected today.

Hydrocarbon performance is illustrated by the efficiencies shown for propane (R290) in Table 4 and for propylene (R1270) in Table 5 as contrasted to the environmental property advantages shown in Table 3. The key limitation for them is not performance, but safety as discussed next.

| | Ideal Cycle [a,b] | | Typical Conditions [b,c] | |
|---|---|---|---|---|
| **Refrigerant** | **COP (kW/kW)** | **Specific Power (kW/ton)** | **COP (kW/kW)** | **Specific Power (kW/ton)** |
| R22 | 9.85 | 0.36 | 4.06 | 0.87 |
| R-32 [e] | 9.55 | 0.37 | 3.84 | 0.92 |
| R-134a | 9.86 | 0.36 | 4.13 | 0.85 |
| R-290 (propane) [e] | 9.68 | 0.36 | 4.05 | 0.87 |
| R-407C | 9.60 | 0.37 | 3.97 | 0.89 |
| R-407E | 9.67 | 0.36 | 4.00 | 0.88 |
| R-410A | 9.29 | 0.38 | 3.77 | 0.93 |
| R-32/600 (95.0/5.0) [e] | 9.54 | 0.37 | 3.85 | 0.91 |
| R-32/600a (90.0/10.0) [e] | 9.43 | 0.37 | 3.81 | 0.92 |

a Conditions are those for the "A" condition of standard ratings for unitary air conditioners and heat pumps (ARI, 2003). The rating standard specifies only the entering indoor (26.7 °C, 80.0 °F) and outdoor (35.0 °C, 95.0 °F) air temperatures, but the evaporating temperature is con-strained in practice to 10 °C (50.0 °F) to provide dehumidification.

b Calculations were made with CYCLE_D 3.0 (Domanski et al., 2003)

c Conditions approximate those typically encountered on the refrigerant side of the cycle. The "typical" efficiencies shown can be exceeded by optimizing subcooling and superheat, em-ploying multiple stages, or using similar cycle modifications. Likewise, poor designsmay result in lower performance.

d Typical superheating and subcooling varies by refrigerant; the level shown is a representative selection for comparisons.

e Flammable

*Table 4 – comparative refrigerant efficiencies for unitary air conditioners*

| Refrigerant | Ideal Cycle [a,b] COP (kW/kW) | Ideal Cycle [a,b] Specific Power (kW/ton) | Typical Conditions [b,c] COP (kW/kW) | Typical Conditions [b,c] Specific Power (kW/ton) |
|---|---|---|---|---|
| R22 | 10.92 | 0.32 | 6.18 | 0.57 |
| R-32 [e] | 10.64 | 0.33 | 5.97 | 0.59 |
| R-123 | 11.42 | 0.31 | 6.52 | 0.54 |
| R-134a | 10.93 | 0.32 | 6.24 | 0.56 |
| R-407C | 10.69 | 0.33 | 6.09 | 0.58 |
| R-410A | 10.42 | 0.34 | 5.90 | 0.60 |
| R-717 (ammonia) [e] | 11.21 | 0.31 | 6.24 | 0.56 |
| R-1270 (propylene) [e] | 10.72 | 0.33 | 6.10 | 0.58 |

[a] Conditions are those for standard ratings for water-cooled chillers (ARI, 1998).

[b] Calculations were made with CYCLE_D 3.0 (Domanski et al., 2003)

[c] Conditions approximate those typically encountered on the refrigerant side of the cycle. The "typical" efficiencies shown can be exceeded by optimizing subcooling and superheat, em-ploying multiple stages, or using similar cycle modifications. Likewise, poor designs may re-sult in lower performance.

[d] Typical superheating and subcooling varies by refrigerant; the level shown is a representative selection for comparisons.

[e] Flammable

*Table 5 – Comparative refrigerant efficiencies for water-cooled chillers*

The importance of efficiency is emphasised for two reasons. First, addressing global climate change will require significant improvements in performance to reduce energy-related green-house gas emissions. Second, the minimum efficiency level mandated for unitary equipment – the largest use of R22 – in the United States will increase by 30% during the transition from R22 in new equipment.

Kul et al. (Kul 2004) summarise performance evaluations for a range of hydrofluoroether (HFE) candidates including blends of HFEs with HFCs, proposed as alternatives for R22. They concluded that the calculated coefficients of performance (COPs) ranged from 80% to 90% of that for R22. They identified R-E125 (CHF2OCF3) and its ternary blends with R32 and either R134a or R152a as the most promising candidates, but even then suggest COPs reaching only 90% to 93% of that of R22.

### Safety considerations

Fluorochemical refrigerants were introduced to improve safety. With phaseout of some key refrigerants, including R22, some proponents advocate a return to what are dubbed "natural refrigerants." They include ammonia, carbon dioxide, and hydrocarbons. Ammonia (R717) offers significant appeal for its efficiency, as shown in Table 5, and it also is low in cost. It is the most widely used refrigerant in food and beverage processing and in cold storage warehouses, but concerns with its toxicity (and specifically corrosive action to skin) and flammability have retarded its use in systems for comfort. Carbon dioxide (R744) was one of the early refrigerants and still is used in industrial systems. However, it operates at much higher pressures than R22 and requires transcritical cycles, since conventional condensing temperatures exceed its critical temperature. Hydrocarbons, notably ethane (R170), propane (R290), n-butane (R600), isobutane (R600a), ethylene (R1150), and propylene (R1270), offer good efficiency and similar properties to some fluorochemicals. They are fairly low in cost and considered environmentally acceptable, but are highly flammable and raise significant safety concerns. Their use requires careful attention to safety factors.

European acceptance is higher for hydrocarbons, both in small systems (for example to replace R12 in domestic refrigerators and commercial beverage coolers) and in isolated large systems. Ammonia and propylene use is accepted in water-cooled chillers located in protected machinery rooms, but the aggregate market size is comparatively small. Liability considerations and safety codes dampen interest in their use in North America and in developed Asian nations. ASHRAE Standard 15 limits the amount of flammable refrigerants that may be used in large systems. Manufacturers have focused primarily on refrigerants classified in ASHRAE Standard 34 as A1 (lower toxicity and not exhibiting flame propagation by prescribed tests), particularly for residential systems and small commercial systems.

### Materials compatibility

The most significant change in introduction of R22 replacements relates to the related lubricant choice. Whereas R22 systems generally used additised, naphthenic mineral oils, the hydrofluorocarbon (HFC) alternatives require synthetic lubricants for miscibility to return the lubricant to the compressor(s). The primary new lubricants are a range of polyolesters (POEs) in appropriate viscosities. Alkylbenzene (AB) and polyvinylether (PVE) options also are available for special purposes. Although widely used with R134a in mobile air conditioners and transport refrigeration, polyalkylene glycol (PAG) lubricants are not common in stationery systems.

The choice of lubricant is complex and users should follow the recommendations of the equipment manufacturer or, in equipment design, the compressor manufacturer. Housekeeping requirements to keep moisture and other contaminants out of refrigeration circuits are much more demanding for most synthetic lubricants.

| Equipment Group | Typical Applications | Leading Replacement(s) |
|---|---|---|
| window air conditioners | residential | R410A |
| unitary single package and split system air conditioners and heat pumps (air-to-air) | residential, light commercial | R410A |
| applied systems: packaged terminal air conditioners, ground- and water-source heat pumps, multisplits | commercial, institutional | R410A |
| applied systems: multisplits | residential, commercial, institutional | R410A R407C |
| unitary large | commercial, institutional | R134a R410A |
| chillers | | |
| air cooled | central systems | R134a R410A R123 |
| water cooled | central systems | R123 R134a |
| commercial refrigeration | commercial | R134a R404A R410A R507A |
| industrial refrigeration | industrial | R134a ammonia |
| transport refrigeration | transportation | R134a |

*Table 6 – leading replacements for R22 by equipment type*

Retrofit conversions from R22 to replacements generally require special procedures for lubricant removal.  Several refrigerant manufacturers offer R22 alternatives specifically formulated to enable refrigerant conversions without changing the lubricant.
Since R22 is readily available at present and will be for the foreseeable future, most users will not require refrigerant conversions for existing R22 equipment, even that produced in future years, for its normal lifetime, with care taken to avoid and repair leaks.

Other materials compatibility issues are complicated.
The air conditioning and refrigeration industry conducted an extensive, multi-year study known as the Material Compatibility and Lubricant Research (MCLR) Program to assess compatibility of the alternatives with materials used in fabrication of refrigerant circuits.  Both equipment and component suppliers along with manufacturers of refrigerants and lubricants conducted extensive additional studies to qualify materials for the replacements.
Compatibility issues generally are resolved for the R22 replacements, but component and equipment designers must be attentive in selecting appropriate materials.

Ammonia is a unique replacement for R22.  The equipment used is quite different as ammonia systems typically are designed for immiscible lubricants.  While ammonia itself is compatible with copper, that is not true when moisture is present.  As a result, ammonia generally is not used with cuprous metals for heat exchangers, motor windings, or piping.  Conversion of R22 equipment to ammonia use normally is not feasible.

Hydrocarbon refrigerants generally are compatible with the materials used in systems designed for R22 and often can use the same or similar lubricants.  However, their substitution requires significant attention to safety issues including application specific considerations.

### Leading R22 replacements

The primary replacement in unitary air conditioners and heat pumps – the largest refrigerant use of R22 – is R410A, though the replacement is not direct since differences between these two refrigerants dictate different designs.  Most major equipment manufacturers already offer R410A products for common sizes. Approximately 10% of unitary products currently use R410A, but this fraction is likely to exceed 80% in the United States by the end of 2007 and approach 100% by the end of 2009.

R410A also is the leading replacement for redesigned window air conditioners, packaged terminal air conditioners, ground- and water-source heat pumps, and small chillers.  The choices change as equipment sizes increase, particularly for chillers using screw compressors.  R134a takes over as the most widely used refrigerant in these mid-size chillers, though some manufacturers use R410A and other refrigerants.  R134a operates at lower pressures while R410A operates at higher pressures, so the equipment designs again are different.  Manufacturers have ended most use of R22 in very large chillers using centrifugal compressors.  That shifts selection to designs using R123 and R134a, with R123 being more widely accepted at present.  It too is slated for production phaseout as an HCFC, but at later dates than R22 due to its lower ODP and recognition of important additional benefits (Calm and Didion 1997, Calm 2000, UNEP 2003b).

Table 6 summarises the leading replacements for R22 by equipment type and application.

Current R22 production is below allocated manufacturing quotas.  Significant future shortages of R22 are unlikely due to the production allowance for service, the potential to stockpile some for future use, existence of alternative service fluids, and large potential for reclaim of R22 already in use.  Any growing shortage for future service needs would lead to higher prices and, in turn, to accelerated replacements, shifts to alternative service fluids, and increased reclaim, so major shortages are not expected.

## Conclusions

All signs point to an orderly transition to replacements for R22. While no single-compound refrigerant has been identified as a suitable alternative for most applications, blends offer good options. The air conditioning and refrigeration industry has developed equipment that matches or increases efficiency with the replacement fluids. Favorable results with early products and experience with the prior phaseout of chlorofluorocarbons (CFCs) suggests that the R22 phaseout will be manageable and spur significant technology advances. And like the CFC phaseout experience, no significant shortages are expected for future R22 service needs despite the end of its production. ■

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## Note

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