

Refrigerants for Commercial Refrigeration Applications

May 2009

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Summary

The refrigeration industry has supported global efforts to protect the environment by phasing out chlorine-containing refrigerants in accordance with the Montreal Protocol. These actions have significantly reduced chlorine in the atmosphere and are starting to repair the ozone layer.

Today, there is increased attention on global warming and the reduction of greenhouse gases. Carbon dioxide is by far the most significant greenhouse gas, produced primarily by the combustion of fossil fuels for electrical generation and transportation. To the extent that refrigeration equipment consumes energy, refrigeration system design and the corresponding choice of refrigerants also contribute to this global warming. Equipment manufacturers have significantly improved energy efficiency, which has resulted in less carbon dioxide production.

For a refrigerant to be considered a long-term option, it must meet three criteria – it must be safe; it must be environmentally friendly; and it must provide excellent performance benefits – thus resulting in zero ozone depletion with low Global Warming Potential (GWP).

Several non-halogen substances, including ammonia, carbon dioxide and hydrocarbons, will also work as refrigerants. All of these substances can be viable refrigerants for the right application if the system can be designed to meet key selection criteria. Component and equipment manufacturers continue to research how these refrigerants perform in systems.

Hydrofluorocarbons (HFCs) are non-ozone-depleting, nonflammable, recyclable and energy-efficient refrigerants of low toxicity that are currently used safely throughout the world. While HFCs are the best environmental and economic choice today, the global sustainability of HFCs requires a focus by the industry on the real environmental issues of refrigerant containment and energy efficiency.

Research has shown that properly designed and maintained systems using HFC refrigerants provide the lowest overall GWP and zero ozone depletion. They are also a safe and cost-effective solution that will serve us well into the future.

In this paper, the long-term, non-ozone-depleting replacements for hydrochlorofluorocarbon (HCFC) R-22 are also discussed. The experience to date shows that these alternatives, when used in optimized systems, generally provide performance superior to that achieved with the baseline HCFC refrigerant. Other refrigerant choices, such as carbon dioxide and hydrocarbons, are also discussed, along with their relative merits to HFCs.

Emerson Climate Technologies has committed itself to providing solutions that improve human comfort, safeguard food and protect the environment. We recognize that this is a difficult balance to achieve, but remain optimistic. We are confident that we can develop solutions that provide efficient commercial refrigeration without compromising our global environment. The following paper discusses the factors that we feel are most important for meeting this challenge.

DISCLAIMER

Use only refrigerants and lubricants approved by and in the manner prescribed by Emerson. In some circumstances, non-approved refrigerants and lubricants may be dangerous and could cause fires, explosions or electrical shorting. For more information, contact Emerson and your original equipment manufacturer (OEM).

Introduction and background

Scientific data support the hypothesis that chlorine from refrigerants is involved in the depletion of the earth's ozone layer and linked to an increase in skin-related diseases¹. The air conditioning and refrigeration industry has supported global efforts to protect the environment by introducing non-chlorine-containing refrigerants. The Montreal Protocol, established in 1987 and revised in 1990, provides guidelines for individual country legislation, setting appropriate timetables for the phaseout of chlorine-containing refrigerants. At present, 191 nations have become party to the Montreal Protocol.

The effort began with an emphasis on reducing chlorofluorocarbon (CFC) refrigerants. The efforts of the late 1980s and early 1990s centered on the elimination of CFCs, primarily used in foam blowing, cleaning and refrigeration applications and centrifugal chillers for air conditioning. By the end of 1995, the production of CFCs ceased in developed countries, and they are no longer used in new equipment today. These actions have proven to significantly reduce atmospheric chlorine and are starting to reduce ozone depletion.

In 1997 the Kyoto Protocol, signed and ratified by many nations around the world, focused attention on the impact of human activity on climate change. As a result, there is now increased attention on global warming. While the Kyoto Protocol does not apply to the United States, our industry has worked to reduce the impact of refrigerants on climate change through the use of higher-efficiency refrigerants and system designs.

In 1997 the Air-Conditioning and Refrigeration Institute (ARI) completed a major international testing program entitled the Alternative Refrigerants Evaluation Program (AREP). The AREP report indicates that there are several suitable HFC replacements for HCFC R-22. In the USA and Europe, these HFC replacements are already being widely used. While some of these replacement refrigerants have different operating characteristics than HCFC R-22, they all eliminate chlorine and potential ozone depletion, leaving climate change as the focus for future regulations and control.

¹According to Annika Nilsson in her book *Ultraviolet Reflections: Life Under A Thinning Ozone Layer*, related diseases may include skin cancer and cataract formation. (Chichester: John Wiley & Sons Ltd., 1996)

Environmental drivers

There are two factors important to the discussion of the environmental impact of refrigerants: ozone depletion and global warming.

Ozone depletion

The ozone layer surrounding the earth is a reactive form of oxygen 25 miles above the surface. It is essential for planetary life, as it filters out dangerous ultraviolet light rays from the sun. Depleted ozone allows higher levels of ultraviolet light to reach the surface, negatively affecting the quality of human, plant, animal and marine life.

Enough scientific data have been collected to clearly verify that there has been depletion of the earth's ozone layer. The data also verify that a major contribution to ozone depletion is chlorine, much of which has come from the CFCs used in refrigerants and cleaning agents.

Research has shown that even the chlorine found in R-22 refrigerants can be harmful to the ozone layer. The need to protect the earth's ozone has resulted in

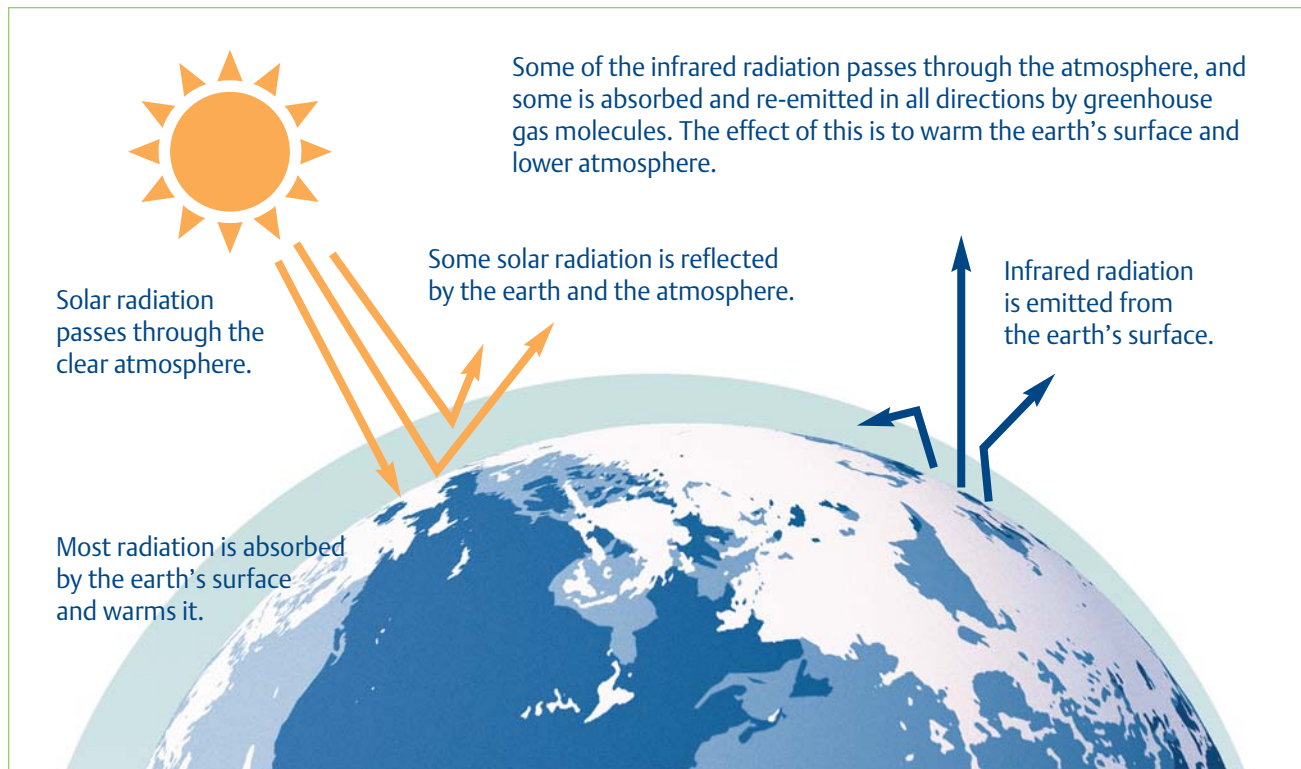
new government regulations and the creation of HFC refrigerants. Since HFCs are chlorine free, they will not damage the ozone layer.

Global warming

According to the National Academy of Scientists, the temperature of the earth's surface has risen by about one degree Fahrenheit (0.5 degree Kelvin) in the past century². There is evidence that suggests that much of the warming during the last 50 years is due to greenhouse gases, many of which are the by-product of human activities. Greenhouse gases include water vapor, carbon dioxide, methane and nitrous oxide, as well as some refrigerants. When these gases build up in the atmosphere, they trap heat. The natural greenhouse effect is necessary for life on earth, but scientists believe that too much greenhouse effect will lead to global warming. Figure 1 shows the mechanism of this global warming process.

Figure 1

The Greenhouse Effect



²www.epa.gov/climatechange/

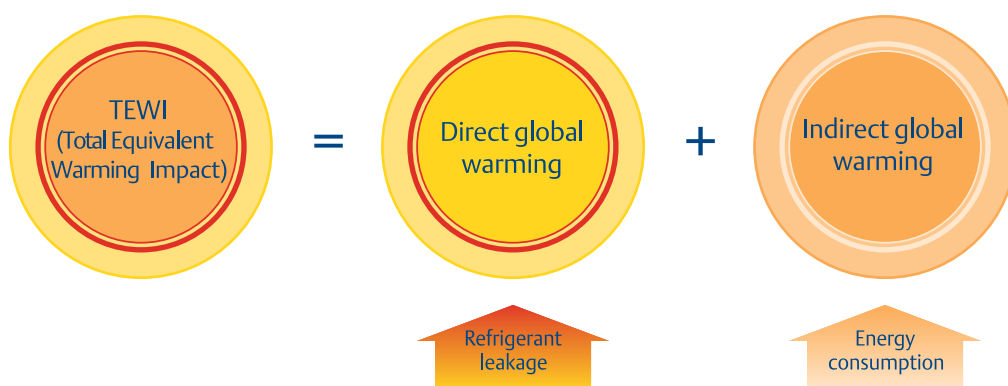
Carbon dioxide (CO₂) is one of the major greenhouse gases. Vegetation is the primary generator of CO₂, along with the natural decomposition of organic materials.

The combustion of fossil fuels also adds CO₂ to the atmosphere. Fossil fuels are used in power plants around the world to produce electricity for vital social needs. More than 22 billion tons of carbon dioxide are produced worldwide each year³, generated from fossil fuels, such as natural gas, oil and coal. In comparison,

however, some European countries are using 2,000 as a maximum GWP (reference GWP for R-11 = 4,000)⁴.

The refrigeration industry developed TEWI as a way to measure the impact of various activities on global warming. TEWI is widely accepted as the best measure of global warming, because it considers not only the direct GWP, but also the sizable indirect global warming resulting from the CO₂ produced by fossil-fuel energy, as seen in figure 2. This global warming calculation

Figure 2
Global Warming Impact



total annual HFC production globally is less than 0.001 percent of this figure. It is estimated that HFCs will contribute no more than three percent of greenhouse gas emissions by 2050. Energy-efficient refrigeration equipment reduces energy consumption even further, thus reducing energy-related carbon dioxide emissions.

Total Equivalent Warming Impact (TEWI)

Global Warming Potential (GWP) is a direct measure of global warming that considers only the direct effect of the refrigerant as a greenhouse gas when it escapes into the atmosphere. Essentially, all alternatives to R-12 and R-502 have substantially less direct GWP and are, therefore, considered a move in the right direction. As a result, refrigerants with a Global Warming Potential (GWP) of less than 4,000 have generally been accepted;

includes the effects of system efficiency and the source of the electricity (coal, nuclear, hydroelectric, etc.), as well as the direct effect of the refrigerant when it escapes into the atmosphere. The actual number varies according to the leakage rate and type of power used. Higher energy efficiency of some refrigerants can reduce the indirect effect and offset a somewhat higher GWP.

Direct global warming is an issue only if the refrigerant leaks or is released from the refrigeration system; thus, refrigerant containment in the system is the key to reducing the direct global warming effect. This is accomplished through system designs that reduce the stored volume of refrigerant, the quick repair of all leaks and the recovery of refrigerant during service operations.

³cnie.org/pop/CO2/greenhouse.htm

Indirect global warming is a function of the efficiency of any piece of equipment. In a refrigeration system, the compressor efficiency, system design, and thermodynamic and heat-transfer properties of the refrigerant affect the overall energy efficiency of the equipment. Indirect global warming takes into account the energy efficiency, as well as the power source. Electrical generation can come from fossil fuels, hydropower or nuclear power. The implication is that a less efficient system uses more electricity, and thus has a higher TEWI.

It is likely that global warming will play an important role in driving the trend to more efficient refrigerants, as energy consumption is the main contributor to overall global warming by most equipment.

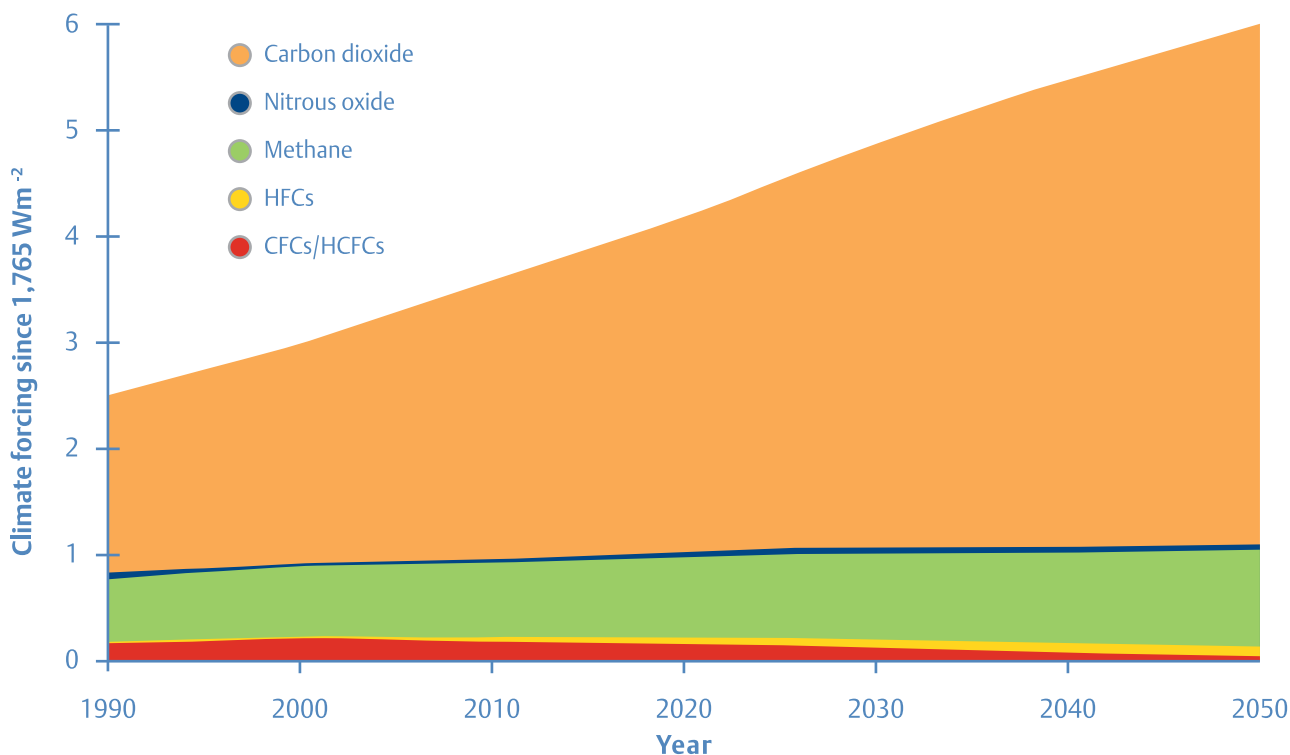
Many in the scientific community agree that there is evidence that the earth is warming; however, it is not yet fully known whether this is the result of normal climate variations or the result of greenhouse warming from man-made compounds in the atmosphere, specifically CO₂. Computer models point to the greenhouse effect, but with all the variables and possible unknowns included either inaccurately or not at all in the

models, a lot of room for doubt remains. If the models are accurate and the warming is caused by CO₂ and other man-made chemicals, the long-term temperature rise will raise the sea level dramatically and change the world's climate, unless the process is reversed now.

As a result of this scientific thinking, most lawmakers and regulators around the world agree that the only safe action to take is to significantly reduce or eliminate the production of greenhouse gases as soon as possible. In order to reduce the increase in greenhouse warming, the following gases must be capped and reduced: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), prefluorocarbons (PFCs), sulphur hexafluoride (SF₆), HFCs and CFCs.

Carbon dioxide is by far the most significant, as can be seen in Figure 3. CO₂ is produced primarily by the combustion of fossil fuels during the generation of energy to power transportation and electric generation. To achieve the needed CO₂ reduction from what is predicted as shown in Figure 3, a dramatic change in energy consumption from fossil-fuel combustion must be realized.

Figure 3
Relative Projected Contributions of Greenhouse Gases to GWP



Source: IPCC; IS92A Scenario

In dealing with the changing refrigerant environment, Emerson has adhered to a strategy that permits us to serve our markets with products that provide proven performance, demonstrated reliability and minimum risk, while moving as rapidly as possible to chlorine-free alternatives.

TEWI and refrigerants

The issue of global warming is a significant consideration in the selection of future refrigerants. Some refrigerants have a higher direct GWP than others; however, direct global warming alone can be misleading in understanding the overall effect of various refrigerant alternatives. TEWI helps to assess the climate-change impact fairly, as it accounts for both the direct (refrigerant emissions) and indirect (system power consumption/efficiency) effects in evaluating global warming. Today's HFC refrigerants appear to be very good options when comparing the total global warming impact to that of halogen-free refrigerants.

TEWI highlights the importance of effectively controlling leaks in order to reduce the global warming from the refrigerant itself. As shown in Figure 4, indirect global warming – that which can be most effectively dealt with through the use of higher-efficiency refrigerants and the design of higher-efficiency systems – can have

a far greater impact than direct global warming. Refrigerant that does not get into the atmosphere does not cause global warming.

As we consider the refrigerants available to manufacturers and the potential global warming impact of each, we believe it is likely that most commercial refrigeration applications will eventually move to HFC options, such as R-404A, R-507, R-134a, R-407C and R-410A. Initial results show that the efficiency performance and cost advantages of these refrigerants outweigh the disadvantages associated with higher pressures and direct GWP. Further testing by original equipment manufacturers (OEMs) and efforts to optimize systems using HFCs are essential in validating these preliminary conclusions.

Emerson Climate Technologies supports the use of TEWI and expects that this measurement tool will become the representative criterion in selecting future refrigerants. By selecting the right refrigerant and optimizing the energy efficiency of the refrigeration equipment, greenhouse gas emissions can be minimized.

Timing

The Montreal Protocol was revised to call for a complete production phaseout of HCFC refrigerant applications by 2020; however, concerns about the proximity of the production cap and the impact of Environmental Protection Agency (EPA) regulations have caused many end-users and OEMs to work on system redesigns to eliminate the use of HCFC refrigerants.

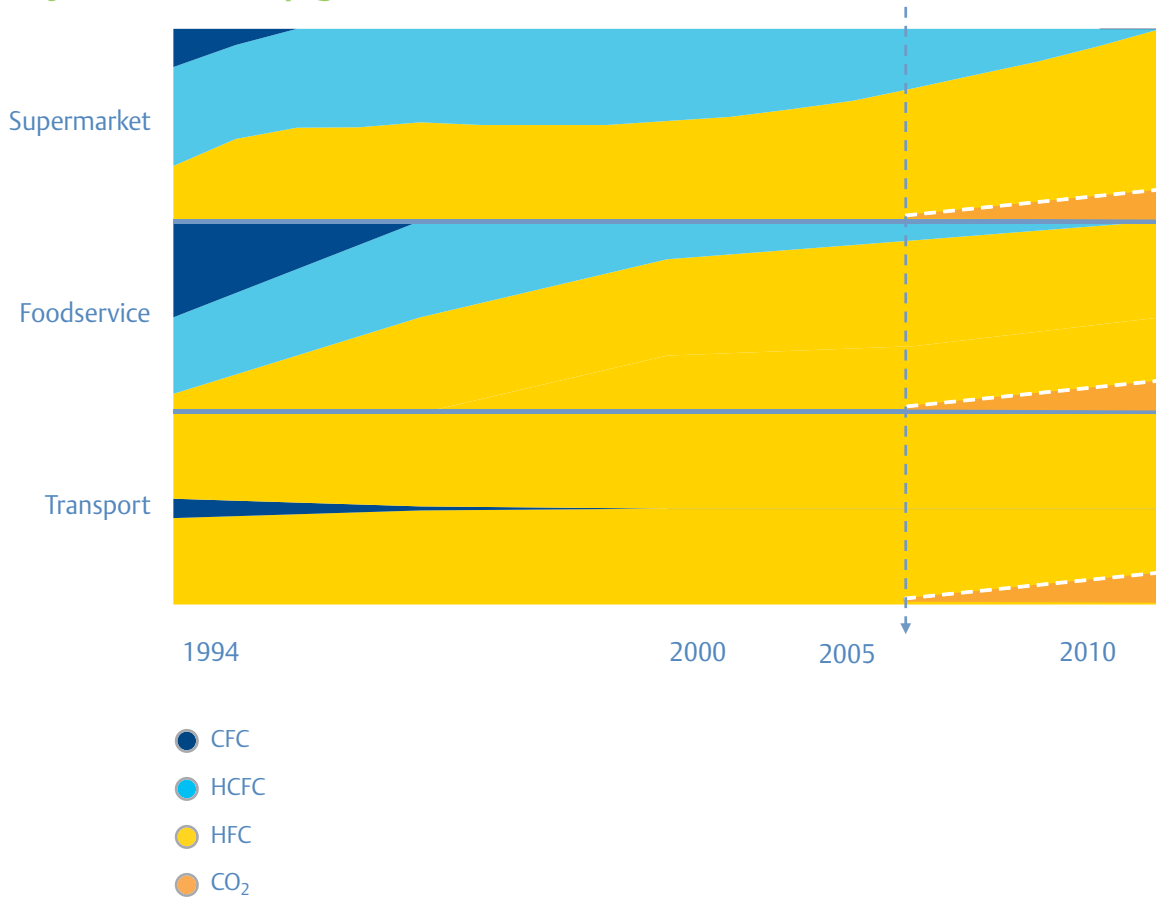
Regardless of regulations, many OEMs have already launched environmentally friendly systems in response to competitive pressures. Since 1990, Emerson has developed and released a series of new HFC products to support the industry's need for chlorine-free systems. Products designed to operate with R-404A, R-507, R-134a, R-407C and R-410A are now currently available.

While both reciprocating and scroll technologies are viable technologies for HFCs, the hermetic scroll-compressor technology has an inherent ability to adapt to higher-pressure refrigerants like R-410A and more standard-pressure refrigerants like R-407C. Emerson will continue to develop and support products using all compression technologies.

Figure 4 Direct Global Warming

Refrigerant	Type	GWP
R-12	CFC	8,500
R-502	CFC	5,260
R-22	HCFC	1,700
R-32	HFC	650
R-134a	HFC	1,300
R-407C	HFC	1,530
R-417A	HFC	1,938
R-410A	HFC	1,730
R-404A	HFC	3,260
R-507	HFC	3,300
Hydrocarbons	Halogen-free	<20
Ammonia	Halogen-free	<1
Carbon dioxide	Halogen-free	1

Figure 5
Projected Global Refrigeration Trends



Regulatory update

While CFC usage has declined significantly, developing countries worldwide are still using these refrigerants in new and service equipment and will continue to do so until CFCs are phased out of production globally in 2010. Additionally, HCFCs continue to support air conditioning and refrigeration equipment in a majority of applications around the world. Regulations have been developed to manage consumption of these refrigerants as the world moves toward full adoption of non-chlorine-containing compounds.

Montreal Protocol (1987)⁵

The Montreal Protocol, developed in 1987 in Montreal, Canada, was adopted by all developed countries and has resulted in the phaseout of CFCs. It also placed an initial cap on HCFC production at 1996 levels. As shown in Figure 6, allowable HCFC production levels continue to reduce with time, with the next significant reduction planned in 2010.

The Montreal Protocol supports the use of HCFCs to aid in the transition from CFCs; however, HCFC consumption will be limited, relative to historic usage of CFC and HCFC on an ozone-depletion weighted basis, during the transition. The EPA has established U.S. regulations, which control future use of HCFCs according to a schedule that both the agency and industry believe is appropriate.

EPA schedule (1996)

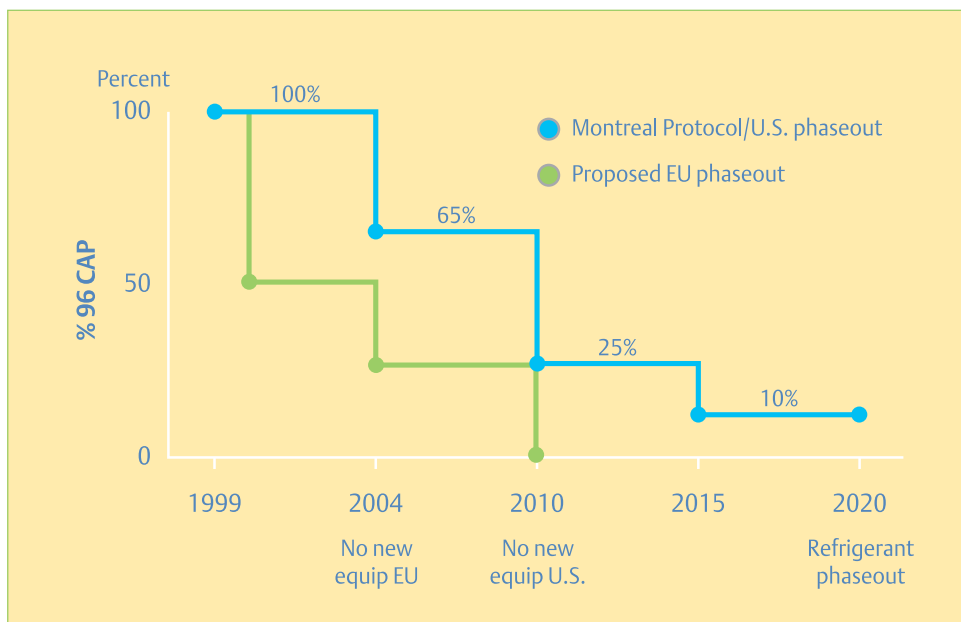
The EPA is monitoring continually the U.S. compliance with the Montreal Protocol and has even developed a schedule to monitor progress toward the total phaseout of HCFCs. The United States Clean Air Act established regulations for the implementation of this phaseout. For example, by 2010 there will be no production and no importing of R-22, except for use in equipment manufactured before January 1, 2010.

Below is the HCFC phaseout schedule developed by the U.S. EPA:

January 1, 2004

In accordance with the terms of the Montreal Protocol, the amount of all HCFCs that can be produced nationwide was reduced by 35 percent by 2004. In order to achieve this goal, the U.S. ceased production of HCFC-141b, the most ozone-damaging of this class of chemicals, on January 1, 2003. This production ban greatly reduced nationwide use of HCFCs as a group. The 2004 deadline had a minimal effect on R-22 supplies.

Figure 6 HCFC Phaseout Timeline



⁵The Montreal Protocol on Substances that Deplete the Ozone Layer is a landmark international agreement designed to protect the stratospheric ozone layer. The treaty was signed originally in 1987 and amended substantially in 1990 and 1992.

January 1, 2010

After 2010 chemical manufacturers may still produce R-22 to service existing equipment, but not for use in new equipment. Equipment manufacturers in the United States must not produce new systems utilizing R-22.

January 1, 2020

Use of existing refrigerant, including refrigerant that has been recovered and recycled, will be allowed beyond 2020 to service existing systems, but chemical manufacturers will no longer be able to produce R-22 to service existing systems.

Kyoto Protocol (1997)

The Kyoto Protocol was established in 1997 in response to increased global warming concerns. Per this protocol, developed countries are challenged with reducing greenhouse gases by an average of 5.23 percent from 1990 levels between the years 2008 and 2012. The protocol focuses on six gases, which it views as being considered and controlled as a total package. These gases include CO₂, CH₄, N₂O, HFCs, PFCs and SF₆.

European F Gas Directive (2001)⁶

In the European Union, the F-Gas Regulation became effective as of July 2007. It proposes to minimize the emissions of fluorinated gases by requiring leakage inspections, leak-detection systems, recovery, and training and certification. Manufacturers must comply with the requirements on labeling and leak checks and are preparing training and certification requirements by July 2009. The effectiveness of the F-Gas Regulations will be reviewed in 2011. See EPEEGlobal.org for further details.

Other regulations

Refrigerant decisions are also impacted by other regulations related to product design and application. For example, Underwriters Laboratories, Inc. (UL) modified the pressure standard for refrigerants within air conditioning and refrigeration systems, making it possible to safely apply the higher-pressure refrigerant alternatives⁷.

It is important for users to continuously monitor and understand the impact of all the various legislative actions to our industry. In Europe, refrigerant choices are also impacted by commercial incentives, such as refrigerant taxes, depending on GWP and energy-efficiency certification schemes.

⁶EPEEGlobal.org , EPEEs FAQ on the F-Gas Regulation

⁷The scope of UL Standard 2182.1 contains test procedures and methods to evaluate refrigerants and mark their containers according to the extent of the refrigerants' flammability.

⁸Azeotrope: A blend that, when used in refrigeration cycles, does not change volumetric composition or saturation temperature appreciably as it evaporates (boils) or condenses at constant pressure.

Criteria for refrigerant selection

Types of refrigerants

In the air conditioning and refrigeration industry, virtually all of the refrigerant experience has been limited to single-component ("pure") refrigerants; however, as we search for acceptable replacements for these compounds, refrigerant manufacturers have been unsuccessful in developing single-component replacements that meet all of the required or highly desirable characteristics for a widely used refrigerant. These requirements include:

- Environmental acceptability
- Chemical stability
- Materials compatibility
- Refrigeration-cycle performance
- Adherence to nonflammable and nontoxic guidelines, per UL
- Boiling point

Many of the R-22 refrigerant replacements under consideration are not pure, but instead are azeotropes⁸, zeotropes⁹ or near-azeotropes¹⁰, or of two or more compounds. Fortunately, the commercial refrigeration industry has already had considerable experience with each type.

A mixture's components are chosen based on the final characteristics desired. These characteristics could include vapor pressure, transport properties, lubricant and material compatibility, thermodynamic performance, cost, flammability, toxicity, stability and environmental properties. The proportions of the components are chosen based on the exact characteristics desired in the final product.

Behavior of mixtures

When an azeotrope, near-azeotrope or zeotrope is in the pure liquid or pure vapor state, the composition is totally mixed, and all properties are uniform throughout; however, when both liquid and vapor are present (such as in the evaporator, condenser or perhaps receiver), a mixture's behavior depends upon whether it is an azeotrope or zeotrope.

⁹Zeotrope: A blend that, when used in refrigeration cycles, changes volumetric composition and saturation temperatures to varying extents as it evaporates (boils) or condenses at constant pressure.

¹⁰Near-azeotrope: A zeotropic blend with a small temperature and composition glide over the application range and no significant effect on system performance, operation and safety.

The percentage composition of the liquid and vapor of an azeotrope will always be virtually the same when both liquid and vapor are present. If a leak occurs, there will not be a substantial change in composition of the refrigerant left in the system.

The composition of the vapor and liquid of a zeotrope is different when both liquid and vapor are present. If a leak occurs in this region of a system and only vapor leaks out, there can be a change in the composition of the refrigerant left in the system. Also, if the system uses a flooded evaporator or multiple evaporators, the composition of the liquid can be substantially different from the vapor, resulting in changes in the circulating refrigerant.

Since a near-azeotrope is still a zeotrope, the composition of the vapor and liquid will be different when both liquid and vapor are present, but to a small extent. If a leak occurs in this region and only vapor leaks out, there can be a small change in the composition of the refrigerant left in the system.

Since the composition of the liquid and vapor of a zeotrope (and near-azeotrope) can be different, it is important to charge a system with these types of refrigerants with liquid leaving the cylinder. If vapor is charged from the cylinder, the composition of the refrigerant in the system may not be the same as that in the cylinder because of the fractionation¹¹ of the refrigerant in the cylinder as vapor alone is removed. Refer to refrigerant manufacturers' guidelines for further details.

Additional information regarding pure compounds, azeotropes, zeotropes and near-azeotropes can be found in the Emerson publication "Introduction to Refrigerant Mixtures," Publication Number 92-81. It is available for download at EmersonClimate.com

Evaluation of refrigerant alternatives

Established by ARI, AREP was directed by an executive committee comprising senior executives from ARI

member companies and was focused primarily on identifying possible alternatives to R-22 and R-502 refrigerants. As part of the program, tests were conducted with 19 refrigerants identified as potential replacements for R-22. Individual test reports issued included compressor calorimeter, system drop-in, heat transfer and soft-optimized system tests for most of these refrigerants.

AREP also tested many types of compressors, including reciprocating, rotary, screw and scroll compressors. In addition, system performance was evaluated across a range of applications, including split-system heat pumps, both air- and water-cooled packaged heat pumps, window units and condensing units. More than 180 AREP reports were approved and released to the public when the committee completed its testing in 1997.

As the industry continues to evaluate HFC alternatives to replace R-22, it appears that many of the likely candidates are not as close to the characteristics of R-22 as the HFC alternatives were for R-12 and R-502 in refrigeration. A list of alternatives has been identified in Figure 7. As the table shows, the characteristics of these alternatives vary dramatically. Because of the unique risks and costs associated with litigation in the United States, U.S. companies are not pursuing flammable refrigerant options, since the likely solution requires a secondary loop configuration that adds cost and reduces efficiency. While R-290 (propane) and R-717 (ammonia) have the benefit of almost zero direct GWP, they have not been applied in the U.S. or Japan.

Of the options identified, several HFC refrigerants have emerged as candidates for R-22 replacement. These HFC alternatives were confirmed as viable options through the AREP studies. A summary of the advantages and disadvantages of each alternative is discussed in the following sections.

¹¹Fractionation: A change in the composition of a refrigerant blend by preferential evaporation of the more volatile component(s) or condensation of the less volatile component(s).

Safety

As the air conditioning and refrigeration industries move away from the relatively few CFC and HCFC refrigerants still in circulation, the issue of safety naturally arises. Of course, safety of new refrigerants is paramount when considering which HFC refrigerant to adopt.

Refrigeration safety issues typically fall into four major areas, including:

Pressure – Virtually all of the new refrigerants operate at a higher pressure than the refrigerants they replace. In some cases the pressure can be substantially higher, which means that the refrigerant can be used only in equipment designed to use it and not as a retrofit refrigerant.

Material compatibility – The primary safety concern here is with deterioration of materials, such as motor insulation, which can lead to electrical shorts, and seals, which can result in leaks.

Flammability – Leakage of a flammable refrigerant could result in fire or explosions. In addition, many of the new refrigerants are zeotropes, which can change composition under certain leakage scenarios. Consequently, it is important to completely understand the flammability of the refrigerant blend,

as well as what it can change into under all conditions. Using flammable refrigerants exposes individuals and the environment to unnecessary hazards, and Emerson Climate Technologies does not approve of the use of flammable refrigerants in any of its compressors.

Toxicity – During the course of the transition from HCFCs and CFCs to HFCs, some countries have explored and/or applied toxic refrigerant options, such as ammonia. These alternatives may offer system performance benefits, but they can also be highly dangerous. It is the view of Emerson that refrigerant options like ammonia should never be used, especially considering that HFCs can deliver the equivalent or better efficiency and overall performance. The major refrigerant manufacturers, equipment manufacturers and safety-standard-setting agencies, such as UL and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), have extensively studied and then rated the safety aspects of proposed new refrigerants according to each of the factors listed above. The intent is to use only refrigerants that are at least as safe as those being replaced.

Figure 7 Quick Reference to Refrigerants

	CFC	HCFC	HFC	Halogen-free
R-12	•			
R-502	•			
R-22		•		
R-123		•		
R-404A			•	
R-507			•	
R-134a			•	
R-410A			•	
R-407C			•	
Propane				•
Ammonia				•
CO ₂				•

Transitional refrigerants (HCFCs)

R-22 has been applied successfully in refrigeration systems of all sizes and temperatures; however, R-22 is an HCFC that is currently being phased out as part of the Montreal Protocol. Phaseout dates for the production of R-22 vary by country, but in the U.S. and Canada, new equipment can no longer be manufactured using R-22 after 2010. Refrigerant manufacturers believe that an adequate supply of R-22 will be available until that time. Figure 8 shows chlorine-free replacement options for R-22.

Figure 8

Chlorine-Free Replacements for R-22

Identification	Ingredients	Glide (°C)	GWP	Toxic/flammable
R-404A	125/143a/134a	0.50	3,260	No
R-134a	134a	0.00	1,300	No
R-410A	32/125	0.11	1,730	No
R-407C	32/125/134a	5.40	1,530	No
R-290	Propane	0.00	<20	Yes
R-717	Ammonia	0.00	1	Yes

Chlorine-free refrigerants (HFCs)

The selection and approval of acceptable long-term refrigerants is a complex and time-consuming task. Many factors must be taken into consideration. The ever-shifting legislative environment, the phaseout of CFCs and HCFCs, the availability of alternate refrigerants and numerous other factors are just a few of the issues that must be taken into account.

Based on these factors, Emerson has cited the following key criteria for evaluating and approving HFC refrigerants for use in Emerson Climate Technologies™ products:

- Global warming should be reviewed, based on the TEWI approach; therefore, the combined direct global warming and indirect global warming, which varies with energy efficiency, should be less than the refrigerants being replaced.
- Safety must be maintained. New refrigerants should be nontoxic, with a Threshold Limit Value (TLV) minus Time-Weighted Average (TWA)¹² greater than 400 parts per million (ppm), and nonflammable. If they are not, proper steps must be taken to ensure that the refrigerants are properly used in equipment and facilities designed to provide adequate safety protection. Maximum system pressures must be no greater than current acceptable limits for retrofit applications. Emerson approves only the use of refrigerants that meet UL standards. This currently does not include hydrocarbons, such as propane (R-290) and isobutane (R-600a). See Emerson Climate Technologies, Inc. Accepted Refrigerants/ Lubricants (Form 93-11).
- Reliability concerns require that compressor discharge temperatures not exceed the temperatures of the refrigerant being replaced.
- It is desirable that lubricants work with current oil-control technology, meet current or improved durability requirements and be backwards compatible with mineral-oil systems. Material compatibility between the new refrigerants, lubricants and materials of construction in compressor and system components must be maintained.

- It is highly desirable to have a single lubricant solution that works with all of the alternative refrigerants, including both HFC and HCFC retrofit chemicals. A single lubricant that works with all of the approved chemicals makes the service and long-term refrigerant strategies easier to implement.
- Service procedures for equipment should remain simple. The utilization of the refrigerants with respect to fractionation of blends must not require unreasonable service procedures.
- The performance of new refrigerants should be very similar to the refrigerants they are replacing.

Regardless of the specifications of individual manufacturers, a refrigerant must have zero ozone depletion and low GWP to be considered a long-term option. These refrigerants can be grouped into three primary classes, according to their vapor pressure/ temperature characteristics:

- Medium pressure (pressures similar to R-12)
- High pressure (pressures similar to R-502 or R-22)
- Very high pressure (pressures significantly higher than R-502 and R-22)

Most of the currently proposed long-term refrigerants are HFCs. The polarity of HFC refrigerants makes them immiscible with mineral oils. As a result, HFC refrigerants must be used with polyol ester oil. This is discussed in detail in the “Lubricants” section of this report.

HFCs

HFCs, or hydrofluorocarbons, are chemicals used in air conditioning and refrigeration applications. They are nonflammable, recyclable, highly effective, energy-efficient refrigerants of low toxicity that are being used safely throughout the world. HFCs were developed by the chemical industry as alternatives to ozone-depleting CFCs, which are being phased out under the Montreal Protocol, a landmark environmental agreement. The Montreal Protocol, the United Nations Framework Convention on Climate Change¹³ (which led to the formation of the Kyoto Protocol) and the Kyoto Protocol were created in an effort to protect the earth’s environment.

¹²TLV minus TWA presents a standard for limiting worker exposure to airborne contaminants. These standards provide the maximum concentration in air at which it is believed that a particular substance will not produce adverse health effects with repeated daily exposure. They are expressed either as parts per million (ppm) or milligrams per cubic meter (mg/m³).

¹³The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty aimed at reducing emissions of greenhouse gases. The treaty included provisions for updates that would set mandatory emission limits. The principal update is the Kyoto Protocol.

Technical and Economic Assessment Panel (TEAP) of the Montreal Protocol on Substances that Deplete the Ozone Layer reported in 1999 that HFCs are critical to the safe and cost-effective phaseout of CFCs and HCFCs and are essential substitutes for these products. Likewise, HFCs are necessary both technically and economically for the phaseout of HCFCs in developing – as well as developed – countries. As replacements for less energy-efficient, older equipment, HFC systems conserve energy and reduce the generation of global warming gases at electric power plants. These systems are being used in accordance with responsible-use principles, which range from recovery and reuse of HFCs to design of HFC-producing plants, with the goal of achieving zero HFC emissions.

HFCs offer potential solutions to global warming concerns, energy efficiency and energy costs without endangering users or workers or requiring extensive equipment modifications and relocations. With proper maintenance and service, energy-efficient products using HFCs reduce carbon dioxide emissions from power plants. Over the past decade, technology advances using CFC alternatives have reduced the impact of greenhouse gas emissions by 80 percent¹⁴.

An independent third-party report by Arthur D. Little, Inc. released in March 2002 stated that HFCs are emerging as the preferred replacement for CFCs and HCFCs because of their desirable characteristics – low toxicity and nonflammability – and their ability to reduce energy consumption.

HFCs are energy efficient, recyclable, low in toxicity, cost effective and safe to use. They can be used in a variety of applications, including metered dose inhalers, air conditioning, refrigeration, foam insulation, electronic components, technical aerosols and fire extinguishers.

HFCs are key to operating energy-efficient refrigeration and air conditioning equipment. The more energy efficient a system is, the less CO₂ is emitted by power plants to run the system. HFCs reduce energy

consumption in many applications. A household refrigerator using HFCs, for example, consumes 10 percent less energy than a comparable hydrocarbon unit. HFC systems often have a lower overall global warming impact than flammable-refrigerant or foam-insulation systems.

Substituting HFCs for CFCs has actually reduced the impact of greenhouse gas emissions, as HFCs reduce total greenhouse gas release. In fact, current technology has reduced greenhouse gas discharged by more than 80 percent since 1990. Projections show that by 2050, HFC emissions will account for less than two percent of potential future contributions for all greenhouse gases, as identified in the Kyoto Protocol¹⁵.

The manufacture of HFCs requires longer, more complex processes and more sophisticated technology than the methods for making CFCs. Stringent purity standards are necessary for manufacturing refrigerants. Modern HFC plants have sealed systems and closed loop transfers both for internal transfers and for loading and delivery of bulk shipments to customers. Leaks of HFCs in the process are limited to about 0.1 percent of total production, resulting in negligible environmental impact.

The Arthur D. Little report analyzed the cost savings associated with the use of HFCs. Not only do HFCs provide the most cost-effective combination of superior environmental performance and safety, but they also provide significant cost savings in the range of \$15 billion to \$35 billion, compared to poor-performing and less safe alternatives, such as hydrocarbons.

Depending on the country of use, HFC emissions management is being conducted through mandatory recovery and non-regulatory means, voluntary measures and industry-government partnerships. The latter involves engaging jointly in research, communication and other activities to find new technologies, designs and processes to manage HFC emissions and to enhance overall product energy efficiency.

¹⁴The Alliance for Responsible Atmospheric Policy, arap.org/textonly/docs/hfc-value.html

¹⁵The Alliance for Responsible Atmospheric Policy, arap.org/print/docs/responsible-use.html

HFCs are included among the Kyoto Protocol's six greenhouse gases, and it is believed that they should not be singled out for regulation or restriction. Instead, HFC emissions should be considered only as part of a comprehensive climate-change plan that fully considers collective emissions reductions of all greenhouse gases.

Several HFC refrigerants became commercial reality in 1994, at least for the commercial refrigeration portion of the HVACR industry. Several chemical manufacturers began full-scale manufacture and distribution of chlorine-free refrigerants to replace those containing chlorine. As a result of the availability of HFCs, OEMs began to design equipment specifically for use with the new refrigerants, while components manufacturers began the production of components that had been optimized for use in these unique, new systems. Few, if any, problems have been reported.

In the air conditioning industry, substantial progress has been made toward the phaseout of HCFC R-22. Data compiled by the AREP has been disseminated to the industry for evaluation. Each system manufacturer will be able to choose from the tested refrigerants and select the one that makes the most sense for the type of application it serves.

The HFCs and equipment being produced for refrigeration appear to be satisfactory for these applications; however, there are several areas in which they differ from the refrigerants they are replacing:

- They require the use of polyol ester (POE) oil instead of mineral oil.
- Most of the HFCs are mixtures, which can behave differently than pure compounds under some conditions.
- Virtually all of the HFCs have higher vapor pressures than the refrigerants they are replacing, which can affect the settings of controls, valves and safety devices. Certain hermetic compressors are not approved for operation with R-507, due to high pressure-ratio stress on bearing surfaces.

One benefit of the new HFC refrigerants is that several of them have demonstrated better efficiency in the equipment in which they are used, as compared to the old refrigerants that they replace. In addition, some of the new refrigerants have lower compressor-discharge temperatures, which should help improve the compressor's reliability and durability.

A negative aspect of POE oils is that they are higher in cost than the mineral oils they replace. As a result, there is research under way to determine if there is any way of solving the miscibility issue of mineral oils in HFCs, perhaps through the use of additives. It is not known at present if this work will be successful.

In summing up the status of HFC refrigerants, virtually all of the experience to date has been positive. Many system manufacturers have converted their products to HFCs, which seem to be well received by their customers. The viability of the new refrigerants has been proven by several years' history of successful operation in a wide variety of systems.

Mixtures

As mentioned earlier in this paper, refrigerant manufacturers have been unsuccessful in developing single-component, high-pressure alternatives to CFCs that have zero-ozone-depletion potential, adequate performance, good reliability and safety. Consequently, the possibility of using mixtures (also called blends, azeotropes, near-azeotropes and zeotropes) has gained increased attention.

Mixtures have both advantages and disadvantages when compared to pure substances. Mixtures allow the advantage of tailoring the final refrigerant characteristics for superior efficiency, performance and reliability. Disadvantages of zeotropic mixtures include the following:

Temperature glide – Because the composition of a zeotrope alters during a phase change, there is a slight change in evaporating and condensing temperature at constant pressure. This phenomenon is known as "glide." Most zeotropic mixtures under consideration exhibit low glide. The magnitude of this phenomenon

is a little different from similar effects seen with single-component refrigerants due to normal pressure drop within the heat exchanger. As a result, little or no effect on system performance is expected.

Fractionation – Since the components of a zeotropic mixture possess different vapor pressures, under certain conditions they may leak from a system at different rates. As a result, the refrigerant composition may change over time, with a corresponding change in performance.

Zeotropic mixtures currently available in the marketplace with a glide of less than six degrees Fahrenheit (3.3 degrees Kelvin) approximate an azeotrope so closely that fractionation should not be a serious problem. The only exceptions to this are systems that use multiple evaporators or flooded evaporators.

To ensure fractionation does not occur during charging, it is recommended that zeotropic mixtures be liquid charged rather than vapor charged. Liquid must be removed from the refrigeration cylinder. It then can be flashed through a metering device and charged into the system in its vapor state. The refrigerant manufacturer's recommendation should be closely followed.

R-134a

R-134a is the first non-ozone-depleting fluorocarbon refrigerant to be commercialized. Developed more than 20 years ago to have characteristics similar to R-12, it is a viable candidate for use in medium- and high-temperature applications in which R-12 has been used. R-134a has been generally accepted by the automotive air conditioning industry because of its low hose permeability and high critical temperature. Domestic refrigerator producers also find R-134a to be a viable refrigerant for their products. R-134a is available from most refrigerant manufacturers.

R-134a has the benefit of being a single-component refrigerant and, therefore, does not have any glide. In addition, the direct HGWP of R-134a is low, relative to other options that have been evaluated.

The disadvantage of R-134a lies in its relatively low capacity compared to R-22. To utilize this refrigerant, all of the tubing within the heat exchangers and between the components of a system would need to be significantly larger to minimize pressure drops and maintain an acceptable operating efficiency. This, combined with the greater compressor displacements required, results in a system that will be more costly than R-22 systems today. The heat-transfer coefficient of R-134a is also lower than that of R-22, and tests show that system performance degrades with its use. In summary, manufacturers would need to invest significant time and capital to redesign refrigeration systems from R-22 to R-134a and ultimately would have a design with inherently lower performance or higher cost; therefore, for residential and smaller commercial systems in which R-22 has traditionally been used, we feel R-134a is the least likely HFC candidate.

This may not be the case in larger commercial systems, in which large screw or centrifugal systems have been traditionally used, and refrigerants like R-11 and R-12 were common. Here, R-134a may offer the best solution for a relatively low-investment, simple redesign to HFCs.

Emerson laboratory and field trials show that the refrigeration capacity and energy efficiency of R-134a are similar to R-12 for medium- and high-temperature applications. At evaporating temperatures below -10 degrees Fahrenheit (-23 degrees Celsius), R-134a loses its attractiveness for several reasons:

- It experiences significant loss of capacity and efficiency compared to R-12.
- Pressure ratios become very high, compromising compressor reliability.
- Low side pressures are sub-atmospheric (i.e., vacuum), resulting in system reliability concerns.

With the exception of ozone-depletion potential, Emerson believes that R-134a possesses the same deficiencies as R-12 and represents a step backward for most commercial refrigeration and air conditioning

applications. These deficiencies include larger-displacement compressors and larger-diameter tubing compared to that required for use with high-pressure refrigerants.

For customers planning to use R-134a, Emerson has developed product lines for applications above -10 degrees Fahrenheit (-23 degrees Celsius) evaporator temperatures. The expectation is that this refrigerant will not be used widely, except in applications in which the benefits of high-pressure refrigerants cannot be achieved practically, primarily fractional-horsepower and auto air conditioning.

R-404A

HFC refrigerant R-404A has been chosen by equipment manufacturers as the long-term replacement for R-502. R-404A is an excellent low- and medium-temperature refrigerant, due to high energy efficiency and zero-ozone-depletion potential. R-404A is a near-azeotropic blend of HFC refrigerants R-125, R-143a and R-134a. It is commercially available from numerous sources and is becoming the most popular refrigerant of its class.

R-507

This refrigerant is an azeotropic mixture of R-143a and R-125, with characteristics also very similar to R-502. Emerson compressors developed for R-404A (except for a few hermetic reciprocating models) are also approved for R-507. Both HFCs R-404A and R-507 operate at slightly higher pressures and slightly lower discharge temperatures than R-502.

R-407C

R-407C is a blend of R-32, R-125 and R-134a. Of the higher-temperature HFC options, R-407C was designed to have operating characteristics similar to R-22. The major concerns surrounding R-407C are in its relatively high glide (approximately 10 degrees Fahrenheit) and the efficiency degradation when compared to R-22; however, the use of this refrigerant provides the simplest conversion of the HFC alternatives. We believe that in systems where glide is acceptable, R-407C will become a popular option for manufacturers who want to move quickly to an HFC alternative. In the long run, however, the lower-efficiency performance of this refrigerant may make it a less attractive alternative when compared to R-410A for medium- and high-temperature applications.

Care should be taken when applying R-407C in any applications in which glide can impact system performance by fractionation in flooded-evaporator or multi-evaporator designs. Also, R-407C should not be viewed as a drop-in for R-22 systems or applications. Like all HFCs, R-407C requires the use of POE lubricants, and other system design modifications may be required for R-407C to operate acceptably in R-22 systems.

R-410A

R-410A is one of the most important HFC refrigerants helping the industry meet the 2010 deadline.

Ample research has shown that R-410A is the best replacement for R-22 refrigerants in high-temperature systems – and manufacturers agree. Most major residential air conditioning manufacturers already offer R-410A product lines. With new residential energy-efficiency regulations going into effect in 2006, significantly more air conditioning manufacturers will have implemented the transition to more energy-efficient units, using R-410A.

R-410A has quickly become the refrigerant of choice for use in residential air conditioning applications, because the refrigerant delivers higher efficiency and better TEWI than other choices. The refrigerant also has many benefits that make it an ideal refrigerant for use in commercial refrigeration applications.

There are several distinct operational differences between R-22 and R-410A refrigerants. R-410A operates at 50 percent higher pressure than R-22; however, the higher pressure allows the system to actually run at a lower temperature. Because of these differences, anyone handling these units should receive training on the technical aspects of the new R-410A systems, where they can learn proper joint brazing and critical maintenance tips for this new refrigerant.

R-410A is a near-azeotrope composition of 50 percent R-32 and 50 percent R-125. To date, optimized system testing has shown that R-410A delivers higher system efficiency than R-22. R-410A evaporates with a 35 percent higher heat-transfer coefficient and 28 percent lower pressure drop compared to R-22.

Additional system performance enhancements have been gained by sizing for equal pressure drop and reducing the number of coil circuits needed to increase the mass flux. The higher density and pressure also permit the use of smaller-diameter tubing, while maintaining reasonable pressure drops.

Because systems that use R-410A have been specially designed to use less tubing and fewer coils, R-410A has emerged as a very cost-effective refrigerant. Fewer materials, along with reduced refrigerant charge and better cyclic performance, also contribute to the affordability of R-410A.

R-410A is considered a very high-pressure refrigerant. Very high-pressure refrigerants operate at pressures significantly higher than those normally seen with refrigerants such as R-22 and R-502. They cannot be used as retrofit refrigerants with existing equipment, but only in new equipment (including compressors) specifically designed for them. Existing R-22 compressors cannot meet UL and industry design standards with these higher pressures.

For refrigeration application, R-410A is potentially the most efficient refrigerant at medium-temperature conditions (zero to 30 degrees Fahrenheit). Additional advantages include reduced line sizes and lower pressure drops; however, the system would require design for higher pressures. Potential changes in UL

requirements may reduce the impact. Testing at lower temperatures has shown promising results. Research is ongoing at Emerson to understand the benefits of this refrigerant in commercial refrigeration.

R-417A

R-417A was developed to be a “drop-in” refrigerant for new and service replacements of R-22, while utilizing traditional HCFC lubricants, such as mineral oil and alkyl benzene (AB). This refrigerant is branded as ISCEON® 59 and Nu-22™ refrigerants and is a blend of R-125 (46.6 percent), R-134a (50 percent) and R-600 butane (3.4 percent). The hydrocarbon in the mixture was added to enhance oil return. ASHRAE designates the refrigerant as A1/A1 rated, meaning that it is nontoxic and nonflammable (see Figure 9). The refrigerant manufacturer claims equivalent capacity and improved efficiency versus R-22. It further claims that existing R-22 lubricants can be maintained, but recommends a consultation with the system and compressor manufacturer for current recommendations.

The manufacturer’s claims regarding R-417A performance are not supported by independent test reports. Independent testing of R-417A has shown between nine and 10 percent reductions in system capacity versus R-22 when used as a drop-in refrigerant. This same testing shows efficiency losses of three to five percent versus R-22. Independent testing of R-417A has also shown significant delays in return of oil that has been pumped into a system versus R-22.

Two additional challenges are presented with R-417A. The refrigerant has a worse GWP rating than both R-407C and R-22. As a blend, R-417A has the same fractionation and glide issues as R-407C. This means that a system leak may affect the composition significantly and, therefore, the properties of this refrigerant.

Emerson Climate Technologies does not expect R-417A to be a significant HFC alternative to R-22. Refrigerant R-417A has neither been fully tested nor qualified by Emerson Climate Technologies and at this time is not approved for use in our compressors or components.

Figure 9 Safety Group per ASHRAE 34

High flammability	A3	B3
Low flammability	A2 R-406A	B2 R-717
No flame propagation	A1 R-11, R-134a, R-410A	B1 R-123
	Lower toxicity	Higher toxicity

R-152a

R-152a is chemically very similar to R-134a, but it is very different environmentally. R-152a has a much lower GWP (120 versus 1,300) than R-134a but is considered ASHRAE A2 – flammable.

R-152a is being considered as an option to replace R-134a in automobile air conditioning; however, due to its flammability, R-152a is not a serious alternative for commercial refrigeration systems.

R-422 refrigerants

R-422A, R-422B and R-422D are other HFC refrigerants that were developed for replacement of R-22. All R-422 series refrigerants have the same blend of refrigerants. The last letter simply signifies slightly different percentages of the refrigerant mixes. R-422 refrigerants are branded as One Shot™ or ISCEON 9 series and are a blend of R-125 (approximately 85 percent), R-134a (approximately 11.6 percent) and R-600a (approximately 3.4 percent). The hydrocarbon in the mixture was added to enhance oil return. The refrigerant manufacturers claim equivalent capacity and improved efficiency versus R-22. They further claim that existing R-22 lubricants can be maintained, but recommend a consultation with the system and compressor manufacturer for current application considerations.

Independent testing of R-422A has shown that its capacity is 10 to 15 percent lower than R-22 and R-404A, especially in low-temperature conditions. Mass flow of R-422A is even higher than R-404A and approximately 55 percent higher than R-22. Pressures of R-422A are similar to those of R-404A and 20 percent higher than R-22.

Refrigerant changeover guidelines are available from Emerson that describe the retrofit procedures when transitioning from R-22 to R-422 series refrigerants.

Future low-GWP fluorocarbon refrigerants

Several refrigerant manufacturers are developing refrigerants for automotive air conditioning applications that will meet 2011 European Union environmental standards for reducing the use of GWP substances. The most likely candidate to replace R-134a in automotive air conditioning applications is HFO-1234yf, a single-component refrigerant with a much lower GWP than R-134a. These future low-GWP refrigerants are being developed as non-carbon dioxide alternatives.

Possible fluorocarbon refrigerants under development are two-blend azeotropes that have material compatibility similar to R-134a. They will likely obtain ASHRAE A1 nonflammable designation and have a GWP much lower than the European maximum of 150, with zero-ozone-depletion potential. These refrigerants will likely be promoted as direct replacements for R-134a, with only minor changes to systems required. Manufacturers position these refrigerants as more practical and cost-effective than CO₂.

The potential downside of future fluorocarbon refrigerants is that they are composed of some new molecules and contain fluorine, which is not considered a “natural refrigerant.” They will be higher-cost refrigerants than R-134a and also require approximately five percent more refrigerant charge. It may take some time to bring these new refrigerants to market, due to the time required to complete toxicity testing and build new production lines.

Halogen-free refrigerants

Ammonia

Ammonia (NH₃) is widely used as a refrigerant in very large industrial refrigeration plants. As a halogen-free refrigerant, ammonia has the benefit of zero-ozone-depletion potential and no direct GWP; however, its high toxicity generally limits its application to industrial refrigeration applications. In very large ammonia systems, the efficiency is comparable to similar systems with R-22 refrigerant.

Although ammonia is widely available and is a low-cost substance, there are significant challenges to applying ammonia as a refrigerant in commercial refrigeration systems. Ammonia systems have higher discharge pressures than R-22. Oil management becomes a major issue in ammonia systems, since the oils used are typically not soluble in ammonia. The very low-mass flow of ammonia compared to R-22 is an advantage for large ammonia plants, but becomes a challenge in smaller commercial systems. Additionally, ammonia is highly corrosive on copper materials, so refrigerant lines must be steel, and the copper in the compressor-motor windings must be insulated from the gas.

The major drawback of using ammonia in commercial refrigeration applications is its high toxicity and flammability level. This alone requires unique safety measures that are well beyond the scope of most commercial installations.

Due to its system chemistry challenges, ammonia was not a serious R-22 alternative candidate in the AREP program.

Carbon dioxide

Increasing environmental concerns about the potential direct emissions from HFC-based refrigeration systems have led to legislation and taxation schemes in parts of Europe that favor the usage of carbon dioxide (CO₂) as a refrigerant. CO₂ is given the designation R-744. CO₂ is environmentally benign versus other refrigerants, is nonflammable, has low toxicity, is widely available and is a low-first-cost substance. These are the reasons it was one of the original refrigerants, used nearly 100 years ago. Although thermodynamic performance of a simple CO₂ cycle is very poor – 30 to 50 percent worse than HFCs – “poor” refrigerants such as CO₂ tend to have very good heat-transfer characteristics and respond well to cycle modifications.

Many CO₂ systems are designed for transcritical operation. These systems tend to have lower energy efficiency, compared to conventional systems, and the system design is very different from conventional systems. Transcritical operation means that the CO₂ does not condense at the high pressure, and instead of using a traditional condenser, a gas cooler is used. The pressures created by CO₂ present significant challenges in its usage. High side pressures are about 2,500 pounds per square inch (psi), and excursions can go to 4,000 psi. This is a technical and cost challenge not only for the compressor, but also for the heat exchangers.

Typical cycle efficiency is 40 percent of the ideal refrigeration cycle Carnot¹⁵, where the Coefficient of Performance (COP) is 2.5, versus 68 percent (COP 4.2) for an R-134a system at high-temperature conditions. Microchannel heat exchangers, gas/suction heat

exchangers or CO₂ expanders improve system performance, with some added cost and complexity.

The cost impact of CO₂ in transcritical systems is substantial. Due to the higher pressure, modifications are required on the compressor shell, valves, rings, terminal and seals, as well as the pressure relief valve and microchannel heat exchanger. Performance

Figure 10

Key Characteristics

	R-404A	R-134a	R-410A	R-407C	Propane
Glide	0.50 °C	0.00	0.11 °C	5.40 °C	0.00
HGWP	0.94	0.28	0.44	0.37	0.02
Pressure at 54.5 °C (kPa)	2,544	1,476	3,406	2,262	1,887
Compressor Energy Efficiency Ratio (EER) (% R-22)	98–109%	101%	92–101%	95–101%	98–100%
Capacity (% R-22)	92–108%	65%	149–155%	98–105%	85%
Heat transfer	Same	Lower	Higher	Lower	Same
Pressure drop	Same	Higher	Lower	Same	Lower
Tubing size	Same	Larger	Smaller	Same	Same
System performance (% R-22)	95–105%	97–98%	98–105%	95–100%	100–103%
System cost	Same	Slight increase	Slight decrease	Same	Large increase*
Redesign required	Moderate	Significant	Significant	Moderate	Significant*

*To address safety issues of flammable refrigerant

¹⁵Carnot is a theoretical measurement of the ideal refrigeration cycle.

implications require CSHX, a discharge-pressure regulator valve and a low side accumulator to control excess charge. An additional oil separator is required, due to oil circulation and return problems. The bottom line is a 20 to 30 percent higher final cost for performance levels equal to those of an HFC.

The comparably high pressure level and thermodynamic properties of CO₂ as a refrigerant have driven system designers to consider subcritical CO₂ systems. These systems operate much like conventional cascade refrigeration systems. In a subcritical system, CO₂ is used as a direct expanding medium in the low-temperature stage, and different options exist for the medium-temperature stage. This way compressors in the low-temperature stage are only exposed to pressure levels similar to high-pressure air conditioning applications, such as with R-410A. Subcritical operation might prove to be the best application of CO₂ as a refrigerant for some commercial refrigeration applications.

In summary, CO₂ has many technical and cost challenges. The low efficiency and cycle complexity are the fundamental limitations; however, CO₂ may prove to be commercially viable in transport and low-temperature cascade systems, as well as in some heat-pump applications. Whether transcritical or subcritical CO₂ systems are considered, CO₂ technology cannot be seen as a drop-in replacement for any of the other refrigerants mentioned in this paper. Any application of CO₂ requires a thorough assessment of system efficiency, TEWI, life-cycle cost, technical feasibility, reliability and safety.¹⁶

Hydrocarbons

The push for halogen-free refrigerants has led manufacturers to investigate hydrocarbons as a replacement for R-22. Propane (R-290) is considered as a replacement, because it is a halogen-free substance with no ozone-depletion potential and low direct GWP. Propane is widely available and is a low-cost substance. The operating pressures of a refrigeration system with propane are similar to R-22. Propane has been applied in systems with low charge – less than 150 grams (approximately 10 ounces) – and often outside the U.S.

The disadvantage of propane and all hydrocarbons is that they are highly flammable. System costs increase significantly, due to the required safety measures. Special considerations must be taken for excess pressures and electrical connections, as well as ventilation to prevent flammable gas mixtures. Commercial operators typically do not want to risk the safety-code issues and litigation risks associated with using propane in a refrigeration system.

Propane has the benefits of zero direct GWP and high system performance; however, its flammability has disqualified it as an R-22 replacement. The safety issues of a flammable refrigerant require significant system adders and redesign, which may include secondary loop configurations that reduce efficiency.

A “safe” hydrocarbon system would have to be determined leak proof through special testing, would contain a secondary loop system that would suffer from heat-transfer and pumping losses, and would have to be explosion proof, with special electrical hardware and technician training.

Emerson policy continues to be one of not developing or selling products for use with flammable or toxic refrigerants for the following reasons:

- We believe there are alternative refrigerants that are not flammable or toxic and provide equal or better environmental characteristics (based on TEWI) at equal or lower cost.
- Adequate safety standards do not exist for systems containing over 50 grams of a hydrocarbon refrigerant, which covers almost all Emerson compressor applications.

Key characteristics of these refrigerants are summarized in Figure 10.

¹⁶ASERCOM statement, Carbon Dioxide (CO₂) in Refrigeration and Air-Conditioning Systems (RAC), June 2006.

Lubricants

When a lubricant is evaluated for use in a compressor, the following characteristics must be considered, in addition to basic considerations, such as product safety and environmental impacts:

Lubricity – The ability of the lubricant to minimize friction and wear between the rotating or sliding surfaces under all operating conditions, including adverse conditions, such as high load, flooded start and floodback. With regard to lubricity, the chlorine in CFCs and HCFCs significantly enhances boundary-layer lubrication in bearings used with mineral oil. Since HFCs do not contain chlorine, POE oil must be formulated to provide the necessary anti-wear capabilities without the presence of chlorine in refrigerants.

Miscibility – The ability of oil to mix with the refrigerant in all areas of the system, so that it can return to the compressor without stagnating in the connecting lines, heat exchangers or receiver. Mineral oils are not miscible with pure HFCs; thus, any mineral oil that leaves the compressor in a pure HFC system may get trapped in the connecting lines or evaporator. Since oil acts as an insulator in heat exchangers, oil trapped in the evaporator can significantly reduce system capacity and efficiency, as well as jeopardize compressor reliability.

Viscosity – A measure of the resistance of a fluid to deformation under shear stress. It is commonly perceived as “thickness,” or resistance to pouring. Viscosity describes a fluid’s internal resistance to flow and may be thought of as a measure of fluid friction.

Oil return and heat transfer – These characteristics of conventional hydrocarbon lubricants (mineral oil/alkyl benzene) with the HFC refrigerants continue to be investigated, due to ease of handling and lower cost.

Stability and compatibility – Stability and compatibility with commonly used refrigeration components and the refrigerant itself are important. Emerson has performed extensive sealed-tube material compatibility tests and has found that selected POE oils have acceptable compatibility with materials commonly used in refrigeration systems.

Most manufacturers of hermetic and semi-hermetic compressors have determined that POEs are the best choice of lubricants for use with the new generation of chlorine-free HFC refrigerants. In addition to providing

superior lubrication with the new refrigerants, POE oil has other advantages that increase its attractiveness for use in refrigeration.

What is polyol ester?

Polyol ester (POE) oils are a family of synthetic lubricants used primarily for jet engine lubrication. There are many types and grades of POE oils, and it is important to understand that all POE oils are not the same. Areas of difference include lubricity, miscibility with refrigerant, viscosity, additive packages, pour point and moisture content. Unlike natural mineral oils, POE oil is completely wax free. In addition, POE oil has better thermal stability than refrigeration mineral oils.

POE oil is made from more expensive base stock materials than traditional refrigeration mineral oils and therefore costs more; however, some of the characteristics of POE oil help offset the higher cost. For instance, POE oil is backwards compatible with mineral oil, which means that a compressor containing POE oil can be installed in a refrigeration system that contains mineral oil. Furthermore, the POE oils we recommend are compatible with all refrigerants, so that a compressor containing POE oil can be installed in a system that contains CFCs, HCFCs or the new HFCs; thus, for the higher initial cost of POE oil, we obtain significant flexibility in the face of the changes brought on by the CFC issue.

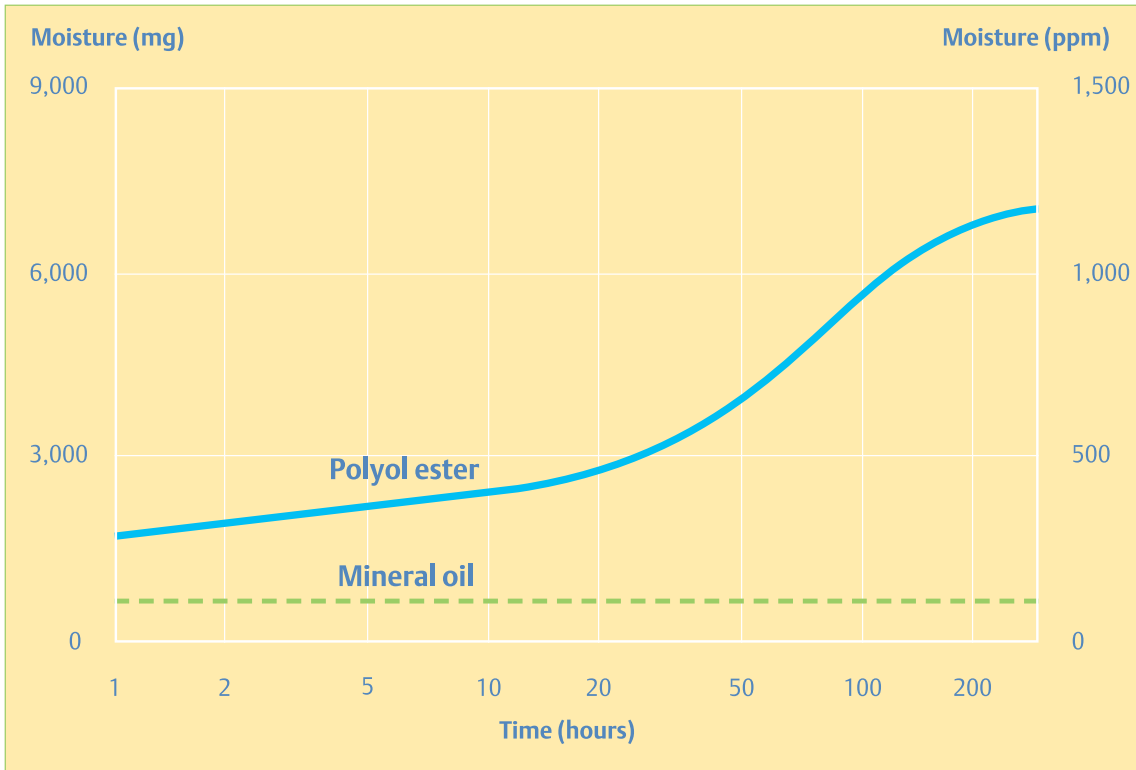
A second positive aspect of POE oil is that it can be designed to meet lubricity requirements equivalent to those of mineral oils used with CFCs and HCFCs. Standard laboratory lubricant bench tests (Falex, pin on v-block and four-ball wear tests) and accelerated compressor-life tests are used to verify these results. Contributing to the superiority of POE oil is the fact that the viscosity of POE oil has less variation with temperature than mineral oil.

A third positive aspect of POE oil is that its miscibility with refrigerant can be matched so easily to that of mineral oil in R-12, R-502 or R-22; thus, POE oil should have oil-return characteristics similar to mineral oil with conventional chlorine-containing refrigerants.

Finally, from an environmental perspective, POE oil is highly biodegradable and should provide low eco-toxicity.

Figure 11

Hygroscopicity Comparison



POE oil can be used with all refrigerants.

Because POE oil can be used with all refrigerants and is backwards compatible with mineral oils commonly used with CFCs and HCFCs, it offers the greatest level of flexibility in dealing with the uncertainties imposed by the CFC issue. For example:

- Initially using POE oil in a new HCFC system will allow the easy transition to HFCs, without the expensive, repetitive flushing procedure needed to remove the mineral oil from the system.
- During system service, if POE oil is used to replace any mineral oil removed from a system, it begins the process to flush the system of mineral oil, so that conversion to an HFC can be performed with fewer steps later.
- POE oil can also be used with the intermediate HCFC mixtures if they are used to replace CFCs. A mixture of at least 50 percent POE oil in mineral oil provides excellent lubrication and will begin the flushing procedure if a switch to HFCs occurs in the future.

It is imperative that any system that contains POE oil be clearly marked to identify the composition of the oil and refrigerant contained in the system, to avoid cross-charging with the wrong lubricant or refrigerant.

Handling POE lubricants

POE has one negative aspect, in that it is substantially more hygroscopic than mineral oil. Consequently, exposing POE to air will result in the oil absorbing moisture more quickly than would mineral oil. The hygroscopic nature of POE oils means that moisture in the system can rise to levels that are unacceptable in refrigeration systems.

POE also holds moisture more tightly than mineral oil, so removing it with a vacuum is more difficult. The Emerson specification for maximum moisture content of POE oil to be added to refrigeration systems is 50 ppm. If the moisture content of the oil in a refrigeration system rises above 100 ppm, corrosion of various metallic materials and copper plating may occur. In addition, acids and alcohols can be formed through a process called hydrolysis, which will have a negative impact on long-term compressor and system durability and performance.

Figure 11 shows how the moisture level of POE oils can increase when exposed to air. Obviously, it is imperative that containers of POE be kept sealed, except when the oil is actually being dispensed. POE oil must be stored properly in its original container, because many plastics used to package oils are permeable to moisture. One of the requirements for Emerson to qualify a POE lubricant is proper packaging, to prevent moisture contamination during normal shelf storage. For this reason, Emerson approves only POE oils that are presently packaged in metal cans.

It is also important that compressors and systems be kept closed, except when work is actually being performed on the equipment. Leaving equipment open during work breaks, overnight or when performing other work will quickly result in unacceptable levels of moisture in POE lubricants.

It is equally important that undesirable contaminants picked up as a result of POE oil's increased solvency be filtered out. Both can be achieved by proper installation and service techniques, as well as use of the correct filters and driers.

The impending phaseout of chlorine-based refrigerants mandates that the refrigeration industry move to lubricants that will work satisfactorily with the new HFC refrigerants. These lubricants must have as good or better levels of reliability and performance as previously experienced with traditional mineral oils used with chlorine-containing refrigerants. It appears that selected POE lubricants meet this requirement. Because of its compatibility with all commonly used

refrigerants, POE offers a large measure of flexibility in dealing with the many refrigerant options being introduced into the market. This flexibility should help reduce confusion over exactly which lubricants and refrigerants are compatible.

Emerson has qualified the following POE oils (which are compatible with each other): Copeland® brand Ultra 22CC,[™] Mobil EAL[™] Arctic 22CC and ICI EMKARATE[™] RL32CF lubricants. Specifications for POE oils approved by Emerson are provided in Application Engineering Bulletin AR-17-1248, which is available at **EmersonClimate.com**.

Alkyl benzene (AB) refrigeration oils

Another lower-cost option for use with the intermediate-term service refrigerants, such as HCFCs, R-401A, R-401B, R-402A and R-408A, is a mixture of AB and mineral oil. In this case, at least half of the mineral oil should be removed from the compressor and replaced with an AB approved by Emerson, such as Emerson's Ultra 200[™] or Zerol 200 TD lubricant. This option cannot be used with the chlorine-free refrigerants that must use POE oils. Specifications of AB oils approved by Emerson are provided in Application Engineering Bulletin AR-17-1248.

When making the decision of whether to use POE or AB with an intermediate-term service refrigerant, remember that AB does not begin the flushing process to remove mineral oil from the system. If the system is converted to an HFC later on, the entire flushing process will have to be performed with a POE lubricant.

System design considerations

Emerson has worked with many refrigerant companies to ensure that new refrigerants are compatible with new Emerson components used in the refrigeration industry. Older components may not be compatible with the new refrigerants and oils, especially those components that have been operating in the field for more than a decade. Before retrofitting any system, check the manufacturer's recommendations.

Regardless of which HFC refrigerant an OEM is considering, care must be taken in the design and handling of systems utilizing these new refrigerants. While they provide an ozone-friendly solution to the industry, HFCs do present new challenges:

- POE oils are an important requirement to ensure the reliability of the compressor when used with HFCs; however, when using POE oils, care must be taken to keep the oil dry, because of its hygroscopic characteristics. Proper precautions must be taken in both the manufacturing of the system and its ultimate installation in the field, to prevent excess moisture from entering the system. The use of a properly selected filter drier is strongly recommended. (See the section on Lubricants, pp. 22-24, for more information on POE oils.)
- R-410A and R-407C are blends and, therefore, exhibit glide characteristics (particularly R-407C). The impact of glide must be considered both in the system design and in servicing the system. Manufacturers must understand and convey to the field the impact of leaks on non-azeotropic mixtures. Systems containing a non-azeotropic refrigerant must be liquid charged to ensure that the proper component mixtures are added.
- R-410A refrigerant has higher operating pressures and is significantly different from R-22; therefore, R-410A systems require special considerations to maximize performance and benefits of the refrigerant. Precautions must be taken to ensure that the heat exchangers and components being used are designed to handle these higher pressures. The fact that R-410A has a much lower critical temperature (162.5 degrees Fahrenheit, compared to 204.8 degrees Fahrenheit for R-22) must be considered when using this refrigerant in units designed for high ambient applications.

Compressors

As system manufacturers consider new equipment designs to operate with HFC refrigerants, they are impacted by many other changes occurring throughout the industry, including a number of approved and proposed energy-efficiency regulations. New ASHRAE standards mandate increases in efficiency levels across a variety of commercial equipment. Several states are enacting energy-efficiency laws, with the California Energy Commission (CEC) leading the way. There are also efficiency standards emerging throughout Asia and Europe.

Because the timing of these new efficiency standards coincides with the R-22 phaseout schedule, many system manufacturers are developing HFC models for the higher-efficiency systems in their product lines. This strategy is reinforced by the fact that these new refrigerants cost more than R-22 initially, and the POE oil required in these designs also adds to system cost.

Compressor technologies have also been evaluated for best overall performance relative to the new high-efficiency HFC applications. As existing manufacturers introduce scroll products, adoption in other segments will grow even further.

The Montreal Protocol was revised to call for a complete production phaseout of R-22 by 2020; however, with the first caps on R-22 approaching quickly, OEMs need to begin working on system redesigns now. Design and testing cycles may be extensive, especially in the case of R-410A.

Regardless of regulations, many OEMs have already launched environmentally friendly systems in response to competitive pressures.

Over the past decade, Emerson has developed and released a series of new scroll models to support the industry's need for chlorine-free systems. A range of products is designed to operate with R-404A, R-134a, R-407C or R-410A. There is a wide variety of displacements available for most commercial refrigeration applications.

This demonstrates the unique flexibility of scroll technology, with its inherent ability to adapt to higher-pressure refrigerants like R-410A and more standard-pressure refrigerants like R-407C. Although the design challenge is serious, scrolls are more easily

adapted to higher pressures and are inherently more efficient than other compressor technologies. Most reciprocating designs will require extensive retooling and redesigning to handle the higher pressures.

System protection

Filter driers

Filter driers currently available are compatible with the new refrigerants and lubricants, as far as materials are concerned. The construction of the filter drier must be solid core or compacted bead (spring loaded). The desiccant must be tested to ensure compatibility with the new refrigerants and lubricants. Filter Driers from Emerson Climate Technologies with a maximum of 30 percent activated alumina, is designed for this specific purpose. These are available both as hermetic filter driers and as replaceable core-type products.

Activated alumina is used in filter driers to remove acids from the system. POE oils, in the presence of excessive moisture, may hydrolyze and produce acids; therefore, small amounts of alumina are used in filter driers recommended with POE oils. Molecular sieve filter driers are the best for moisture absorption. With the hygroscopic nature of POE oil lubricants, it is very important that the filter drier have a high moisture-absorbing capability. Oversized filter driers may become the standard.

For more information on the EK Filter Drier, please reference the Appendix (p. 31).

Pressure-control valves

Many new refrigerants have higher pressures; thus, all pressure controls and pressure-operated valves may need to be reset for proper operation. Some of the controls or valves may even need to be replaced. Pilot-operated valves must be checked to be sure they are operating properly. The pilot-operated valve, in many cases, requires a minimum pressure differential to open, and the valve will not operate properly unless this pressure differential is correct. Valves

or controls may also need to be resized. Other system components will also be affected by the new refrigerants and lubricants. Consult your equipment manufacturer for guidelines and more information.

Viewing lens/moisture indicator

Moisture indicators on refrigeration equipment are critical early-warning components in the effort to lessen the long-term effects of water damage and reduce repair and maintenance costs. The proper moisture indicator must sense and report just how much water is in the system's circulating refrigerant. An indicator in a sight glass changes color as the moisture content reaches potentially damaging levels. Be sure to choose an indicator that is sensitive enough to alert operators early on that moisture levels are rising, allowing corrective action to be taken before serious system damage occurs.

Moisture Indicators from Emerson (HMI, AMI and MIA) are able to read moisture levels far below industry standards. These indicators actually begin to change color at two percent relative humidity (RH), which is a "very dry" indication. At three percent RH, the purple caution color begins to appear. Many other indicators do not begin changing colors until about seven to eight percent RH; however, early detection is critical with HFC refrigerants and POE lubricants. POE oil can hold up to 20 times more moisture than the mineral oil used by older refrigerants, which can allow corrosive acids to build up and totally destroy a system.

Liquid-control device

The liquid-control or metering device may be a capillary tube or a thermal expansion valve. The purpose of the liquid-control device is to control the flow of refrigerant to the evaporator. The liquid-control device will not have to be changed when an R-502 system is retrofit with R-402A, R-408A, R-404A or R-507. While the capacity of the liquid-control device is virtually the same, the flow capacity of the liquid-control device in an existing R-12 system may increase up to 30 percent with the new refrigerants.

When an R-12 system is retrofitted with either an HCFC blend or R-134a, the liquid-control device may have to be changed; however, a properly sized R-12 expansion valve may work with the new refrigerant by adjusting the evaporator superheat. The existing capillary tube can, in all probability, be made to work with the new refrigerant by adjusting the refrigerant charge. While most systems can be retrofitted without changing the liquid-control device, it will be necessary to adjust the valve superheat or the system charge. Systems using expansion valves still require a solid column of liquid refrigerant at the expansion-valve inlet.

Service considerations

Responsible-use principles

Emerson actively promotes the idea that responsible use is the key to safety and environmental stewardship. As already discussed, HFC refrigerants are the key to energy-efficient refrigeration equipment. But other factors also figure into optimized energy efficiency (see Figure 12). Prompt maintenance is important to keeping systems running not only longer, but also more efficiently. Preventative maintenance routines can help extend the life of equipment, as well as increase energy efficiency.

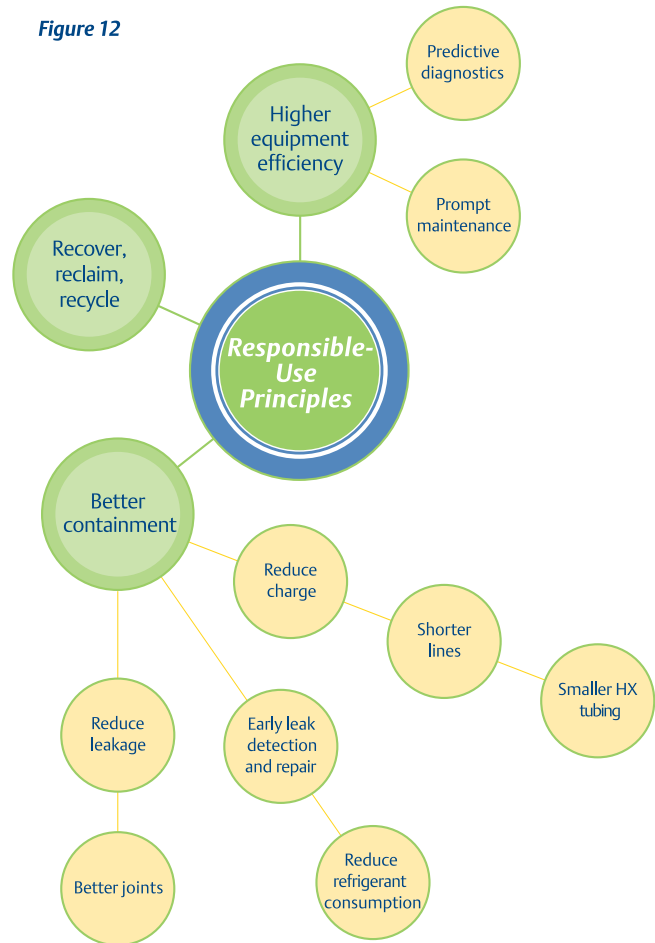
Containment is one way to promote the responsible use of refrigerant. Equipment manufacturers are working to design systems that require less charge and have fewer leaks. There can be no direct impact on the environment from any refrigerant that is contained in a well-designed system. Early leak detection and repair will reduce refrigerant consumption. And finally, all refrigerants should be recovered, reclaimed and recycled at the end of the system life.

Emerson Climate Technologies developed its ProAct® Refrigerant Management service in order to help equipment owners maintain compliance with the EPA's Clean Air Act. The service organizes refrigerant-related inventory information quickly and easily, minimizing refrigerant loss due to leaks or reduction of inventory. By providing all the proper documentation, Emerson Climate Technologies helps operators close the loop between the technicians who complete the work and the owners who have the responsibility for compliance. The service provides electronic access to all refrigerant data for management, analysis and reporting purposes, alleviating many of the hassles and omissions associated with paper tracking.

Responsible use of refrigerants¹⁷:

- Contain refrigerants in tight or closed systems and containers, minimizing atmospheric releases.
- Encourage monitoring after installations to minimize direct refrigerant emissions and to maintain energy efficiency.
- Train all personnel in proper refrigerant handling.

Figure 12



Endorsed by: U.S. EPA, MITI, UNEP, ARI, ACCA, AHAM, The Alliance and 25 others

- Comply with standards on refrigerant safety, proper installation and maintenance (e.g., ASHRAE-15, ISO-5149 and European Standard EN378).
- Design, select, install and operate to optimize energy efficiency.
- Recover, recycle and reclaim refrigerants.
- Continue to improve equipment energy efficiency when cost effective.

¹⁷arap.org/responsible.html

Future direction

The next generation of refrigerants has been established. As reviewed here, HFCs have low-ozone-depletion advantages over R-22; however, they still have some GWP.

It is important to recognize that this is an evolutionary process. Today's HFCs are the next steps, but they are not the last steps in the process. As technologies develop and new applications and system designs continue to emerge, other refrigerants may be developed and applied in the future.

No HFC refrigerant can cause direct global warming if it is properly contained. Within the HVACR industry and in others, we expect to see increased emphasis on refrigerant recovery and leak prevention in the coming years. As the concern over potential climate change grows, Emerson Climate Technologies will continue to work closely with refrigerant and system manufacturers, industry organizations and approved regulations to improve compressor performance, efficiency and reliability, while reducing environmental impact.

Glossary of terms

Azeotrope: A blend, when used in refrigeration cycles, that does not change volumetric composition or saturation temperature appreciably as it evaporates (boils) or condenses at constant pressure.

Blend: A refrigerant consisting of a mixture of two or more different chemical compounds, often used individually as refrigerants for other applications.

CFC refrigerant: A chlorofluorocarbon, containing chlorine, fluorine and carbon molecules (e.g., CFC R-12).

Fractionation: A change in composition of a blend by preferential evaporation of the more volatile component(s) or condensation of the less volatile component(s).

Glide: The difference between the starting and ending temperatures of a phase-change process by a refrigerant (at constant pressure) within a component of a refrigerating system, exclusive of any subcooling or superheating. This term is usually used in describing the condensation or evaporation process.

GWP: Global Warming Potential. This is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale that compares the gas in question to that of the same mass of carbon dioxide, whose GWP is 1.0.

Halogen-free refrigerant: A refrigerant that does not contain halogen compounds, such as chlorine and fluorine (e.g., hydrocarbons, ammonia, etc.). This is also commonly referred to as a “natural refrigerant,” since it is found in nature.

HCFC refrigerant: A hydrochlorofluorocarbon, containing hydrogen, chlorine, fluorine and carbon molecules (e.g., HCFC R-22).

HFC refrigerant: A hydrofluorocarbon, containing hydrogen, fluorine and carbon molecules (e.g., HFC R-134a).

HGWP: Halocarbon Global Warming Potential. This is similar to GWP, but uses CFC-11 as the reference gas, where CFC-11 is equal to one (GWP for R-11 - 4,000).

Near-azeotrope: A zeotropic blend with a small temperature and composition glide over the application range and no significant effect on system performance, operation and safety.

Pure compound: A single compound, which does not change composition when changing phase.

Total Equivalent Warming Impact (TEWI): TEWI integrates the global warming impacts of equipment’s energy consumption and refrigerant emissions into a single number, usually expressed in terms of CO₂ mass equivalents. The calculated TEWI is based on estimates for (1) the quantity of energy consumed by the equipment over its lifetime; (2) the mass of CO₂ produced per unit of energy consumed; (3) the quantity of refrigerant released from the equipment over its lifetime; and (4) the GWP of that refrigerant, expressed in terms of CO₂ mass equivalent per unit mass of refrigerant.

Zeotrope: A blend, when used in refrigeration cycles, that changes volumetric composition and saturation temperatures to varying extents as it evaporates (boils) or condenses at constant pressure.

Appendix

For more information, the following suggested reading materials are available from Emerson via our online product information (OPI) website,

EmersonClimate.com:

- Introduction to Refrigerant Mixtures, form number 92-81
- Emerson Climate Technologies, Inc. Accepted Refrigerants/Lubricants, form number 93-11
- R-134a, Application Engineering Bulletin AE-1295
- Application Guidelines for ZP**K*E Scroll Compressors for R-410A, Application Engineering Bulletin AE-1301
- Refrigerant Changeover Guidelines
 - (CFC) R-12 to (HCFC) R-401A 93-02
 - (CFC) R-12 to (HCFC) R-401B 93-03
 - (CFC) R-12 to (HFC) R-134a 93-04
 - (CFC) R-502 to (HCFC) R-402A/408A 93-05
 - (CFC) R-502 to (HFC) R-404A/R-507 94-15
 - (HCFC) R-22 to (HFC) R-407C 95-14
 - (HCFC) R-22 to (HFC) R-404A/R-507 2005CC-54

Access the EK Filter Drier and HMI white papers at **EmersonClimate.com**.

Contributors

Warren Beeton

Warren is a 1966 graduate of Cornell University, with a master's degree in mechanical engineering. He has 35 years of experience in the air conditioning and refrigeration industry, including positions in marketing product management and engineering product development. He has worked on the development of a wide range of products, including centrifugal chillers and compressors, unitary air conditioners and heat pumps, residential gas furnaces and reciprocating and scroll compressors.

Warren joined Emerson Climate Technologies, Inc. in 1995, as vice president of engineering for Emerson Climate Technologies, Inc. – Air Conditioning division. In 1999 he was appointed vice president of engineering for Emerson Climate Technologies, Inc. – Refrigeration division.

Warren is active on several ASHRAE and ARI committees. He is also a member of the Board of the Alliance for A Responsible Atmospheric Policy.



Dave Bell

Dave is an Educational Services technical specialist with Emerson Climate Technologies. During his 32 years in the industry, he has worked very closely with OEMs, including helping them to accurately design Emerson components into systems.

Dave earned an associate's degree in tool design technology from ITT Technical Institute in 1973. He is an established member of the Refrigeration Service Engineers Society (RSES) and has served as a North American Technician Excellence, Inc. (NATE) exam facilitator. He has been published in *RSES Journal*.



Brian Buynacek

Brian is a graduate of Cornell University and the University of Dayton, with an M.B.A. and degrees in mechanical engineering. He has 15 years of industrial marketing experience, including positions in marketing product management, key account management, and application and manufacturing engineering. Brian is a registered professional engineer in the state of Ohio.

As a senior consultant with Emerson Design Services Network,SM Brian has driven more than 50 key marketing and engineering projects in the past five years.



John Gephart

John is a graduate of the University of Toledo, with a degree in mechanical engineering. He has 33 years of experience in the air conditioning and refrigeration industry, and he is a registered professional engineer in the state of Ohio.

John has worked at Emerson Climate Technologies, Inc. since 1972. He has been a member of ASHRAE for 25 years, serving on ASHRAE technical committee TC 8.1 Compressors from 1982 to 1992; in addition, he was secretary from 1986 to 1990.

John is well published in trade journals, such as *RSES Journal* and *Store Equipment & Design*, on topics such as refrigeration system troubleshooting and refrigerant retrofitting.



Norbert Kämmer

Dr. Ing. Norbert Kämmer is vice president of engineering for Emerson Climate Technologies Europe. Prior to joining Emerson in 1993, Norbert spent nine years in engineering, design and development for a centrifugal-pump manufacturer in Germany.

Norbert studied mechanical engineering at the University of Hannover in Germany. He also has a master of science degree in mechanical engineering from Purdue University and a Ph.D. in centrifugal compressors from the University of Hannover in Germany.



Rajan Rajendran

Rajan is director of applications engineering for Emerson Climate Technologies, Inc. Refrigeration. He has a Ph.D. in mechanical engineering from Iowa State University and an M.B.A. in finance from Wright State University. Rajan has over 17 years of experience in the research, development and application of compressor products in refrigeration. He also serves on committees with ARI and ASHRAE.



Rob Schemmel

Rob is manager of service engineering for Emerson Climate Technologies, Inc. In this role, he has been instrumental in transitioning refrigeration applications to newer refrigerants. Rob has an associate's degree in HVAC/refrigeration and has worked at Emerson Climate Technologies, Inc. for 33 years.



Eric Winandy

Eric Winandy is manager of applications engineering for Emerson Climate Technologies Europe. Eric has more than 15 years of experience in air conditioning and refrigeration research and applications. He has authored and co-authored papers and articles on compressors and applications topics, and he is an active member of the technical committee of the Association of European Refrigeration Compressor and Controls Manufacturers (ASERCOM) and the International Institute of Refrigeration (IIR).

Eric has a degree in mechanical engineering – aerospace from the University of Liège, Belgium, and a Ph.D. in thermodynamics from the University of Concepción, Chile.



About Emerson

Emerson (NYSE: EMR), based in St. Louis, is a global leader in bringing technology and engineering together to provide innovative solutions to customers through its network power, process management, industrial automation, climate technologies, and appliance and tools businesses. For more information, visit **Emerson.com**.

About Emerson Climate Technologies

Emerson Climate Technologies, a business of Emerson, is the world's leading provider of heating, ventilation, air conditioning and refrigeration solutions for residential, industrial and commercial applications. The group combines best-in-class technology with proven engineering, design, distribution, educational and monitoring services to provide customized, integrated climate-control solutions for customers worldwide. The innovative solutions of Emerson Climate Technologies, which include industry-leading brands, such as Copeland Scroll and White-Rodgers, improve human comfort, safeguard food and protect the environment. For more information, visit **EmersonClimate.com**.

About Emerson Climate Technologies, Inc.

Emerson Climate Technologies, Inc., part of Emerson Climate Technologies, is the world's leading compressor manufacturer, offering more than 10,000 compressor models in a full range of technologies, including scroll, reciprocating and screw compressor designs. A pioneer in the HVACR industry, the company led the introduction of scroll technology to the marketplace. Today, more than 50 million Copeland Scroll® compressors are installed in residential and commercial air conditioning and commercial refrigeration systems around the world. Emerson Climate Technologies, Inc. is headquartered in Sidney, Ohio. For more information, visit **EmersonClimate.com**.