

# Refrigerants for residential and commercial air conditioning applications

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**EMERSON**<sup>™</sup>  
Climate Technologies

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## Executive summary

The air conditioning 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 cut chlorine in the atmosphere and are starting to repair the ozone layer.

Today, there is more attention on climate change and reducing greenhouse gases. Carbon dioxide is by far the most significant greenhouse gas, produced mainly by burning fossil fuels for electrical generation and transportation. Since air conditioning equipment consumes energy, energy-efficient designs are important to reducing carbon dioxide production.

New refrigerant choices must be safe to consumers and service personnel, environmentally friendly and provide excellent performance benefits. Hydrofluorocarbons (HFCs), like R-410A, are considered global warming gases, but due to low emissions in air conditioning systems, the indirect global warming impact, which relates to the amount of carbon dioxide produced to power the system, is much more important than the direct global warming potential of the refrigerant itself. Many of the HFCs that have been evaluated are non-ozone-depleting, nonflammable, recyclable and energy-efficient refrigerants of low toxicity that are safe and cost-effective.

Emerson Climate Technologies and other industry partners identified a specific HFC, R-410A, as an excellent long-term solution for residential and light commercial air-conditioning due to its combination of high-efficiency performance in air conditioning systems and direct GWP value close to R-22. System manufacturers have had good success with R-410A because of its energy efficient properties and ease of use in their systems, and components are now widely available for designing efficient R-410A systems.

The topic of potential future transitions to only natural refrigerants, such as propane and carbon dioxide, is mostly driven by anti-HFC regulations in Europe. Research data reveals that HFCs provide equal or superior environmental characteristics to these proposed natural refrigerants at lower cost.

The global sustainability of HFCs like R-410A requires a focus by the HVAC industry on the real environmental issues of refrigerant containment and energy efficiency. By committing to the design of more energy-efficient systems using these refrigerants, the industry will significantly improve the environmental impact of air conditioning products.

Emerson Climate Technologies has committed itself to providing solutions that improve human comfort, safeguard food and protect the environment. Emerson is confident in our ever-developing solutions that provide efficient residential and commercial air conditioning, without compromising our global environment. At Emerson responsible environmental stewardship is an integral part of sound business policy and practice. The following paper discusses the factors that Emerson thinks 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).**

## Refrigerants and environmental drivers

Scientific data supports the hypothesis that chlorine from refrigerants is involved in the depletion of the Earth's ozone layer. The air conditioning industry has supported global efforts to protect the environment by introducing non-chlorine-containing refrigerants. The Montreal Protocol, established in 1987 and later revised, provides guidelines for individual country legislation, setting timetables for the phase-out of chlorine-containing refrigerants. Today, 196 nations have become party to the Montreal Protocol.

The effort started with an emphasis on cutting chlorofluorocarbon (CFC) refrigerants. Work in the late 1980s and early 1990s centered on eliminating CFCs which were used in foam blowing, cleaning and refrigeration applications and centrifugal chillers for air conditioning. By the end of 1995, developed countries stopped producing CFCs, and they are no longer used in new equipment today. These actions have significantly reduced atmospheric chlorine and are starting to repair the ozone layer.

The Montreal Protocol was revised to call for a production phase-out of HCFC refrigerant applications by 2020. The EPA has established U.S. regulations to control the future use of HCFCs and is monitoring the U.S. compliance with the Montreal Protocol. The United States Clean Air Act established regulations for implementing this phase-out. Already factory

charging of new R22 is not permitted, and in 2020 chemical manufacturers will no longer be able to produce R-22.

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

In March 2011 AHRI started a new AREP to identify potential low GWP refrigerant candidates. The objective of the study is to test and present system performance in a consistent and standard manner. Many different types of AC and refrigeration systems were tested in 2012. Over 40 different candidate refrigerants were studied. AHRI posted twenty-six final test reports for many different types of systems, including chillers, commercial ice machines, residential heat pumps, bottle coolers, and transport refrigeration. The alternative refrigerants are not ranked, however. The goal of the program was simply to identify potential refrigerant replacements for high GWP refrigerants (such as R404A, R134a, and R410A) and present performance of these replacements in a consistent and standard manner.

### The greenhouse effect

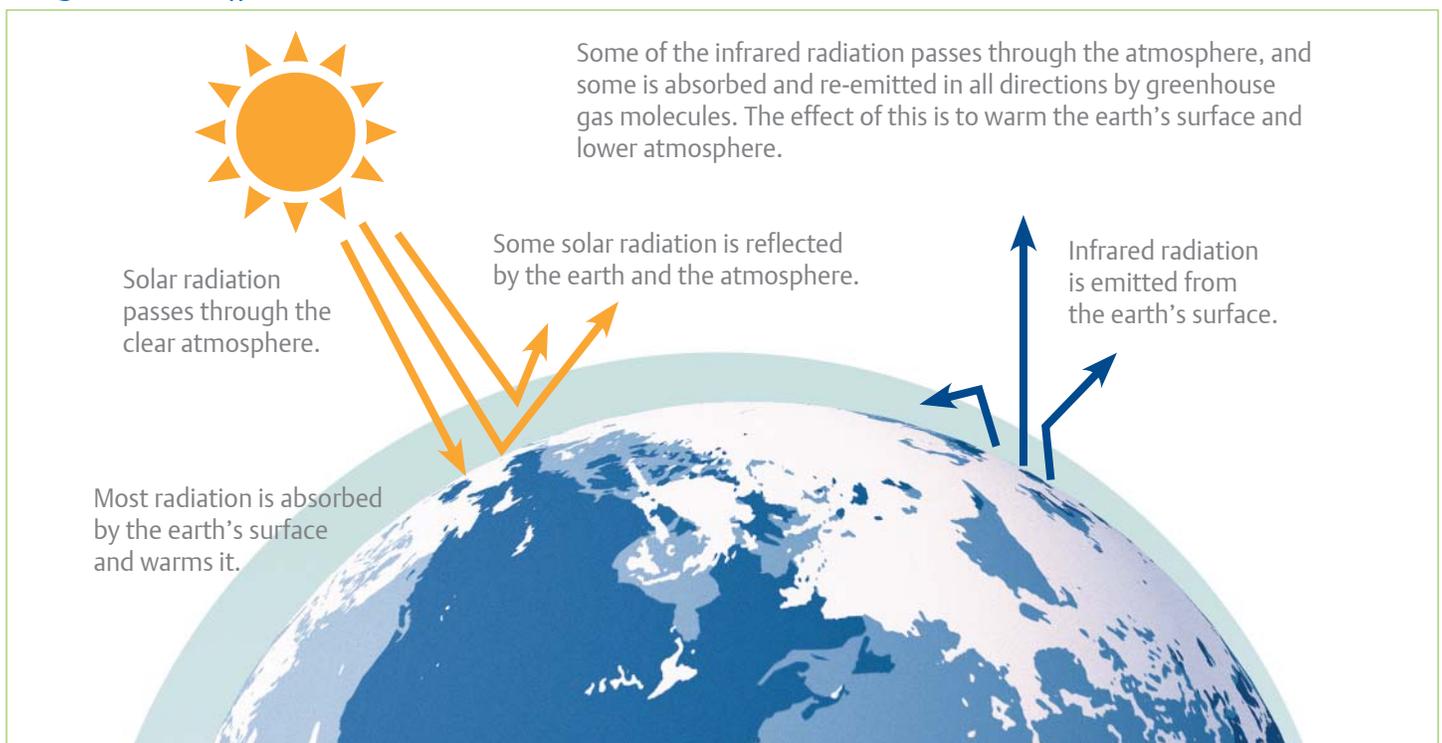


Figure 1

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 more attention on global warming. Although the Kyoto Protocol does not apply to the United States, our industry has worked to lower the impact of refrigerants on climate change with higher-efficiency refrigerants and system designs.

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 more ultraviolet light to reach the surface, negatively affecting the quality of human, plant, animal and marine life.

Scientific data verifies that the earth's ozone layer has been depleted. 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.

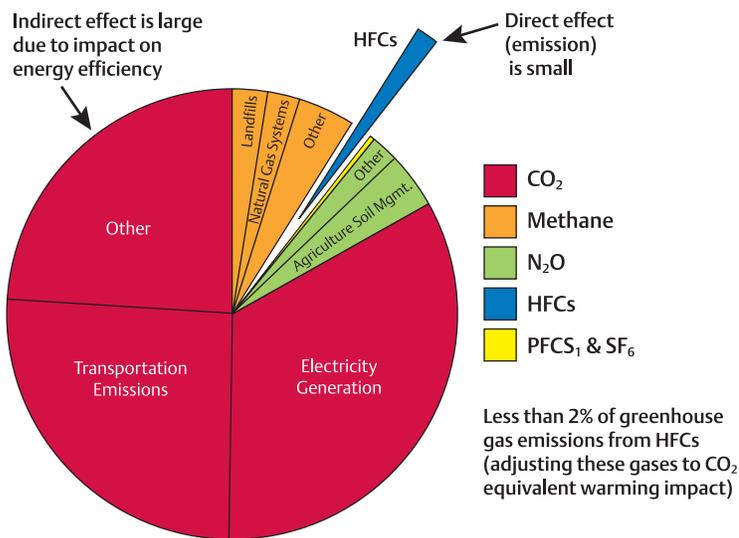
Research has shown that even the chlorine found in HCFC-22 refrigerants can be harmful to the ozone layer. The need to protect the earth's ozone has resulted in new government regulations and HFC refrigerants. Since HFCs are chlorine free, they will not damage the ozone layer.

## Climate change

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 century. There is evidence that suggests that much of the warming during the last 50 years is because of greenhouse gases, many of which are the by-product of human activities. Greenhouse gases include water vapor, carbon dioxide, methane and nitrous oxide, and some refrigerants. When these gases build up in the atmosphere, they trap heat. The natural greenhouse effect is needed for life on earth, but scientists believe that too much greenhouse effect will lead to climate change. **Figure 1** shows the mechanism of this global warming process.

Carbon dioxide (CO<sub>2</sub>) is one of the major greenhouse gases. The natural decomposition of organic materials is the primary generator of CO<sub>2</sub>. Burning fossil fuels also adds CO<sub>2</sub> to the atmosphere. Fossil fuels are used in power plants around the world to produce electricity for vital social needs. According to the U.S. Energy Information Administration, nearly 30 billion metric tons of energy-related carbon dioxide were produced in 2007. In comparison, 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 air conditioning equipment saves energy and cuts energy-related carbon dioxide emissions. See **Figure 2**.

### Effect of HFCs on global warming



Source: Environmental Protection Agency, U.S. Greenhouse Gas Emissions & Sinks: 1990-2002

Figure 2

## 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 been accepted; however, some European countries are using 2,000 as a maximum GWP (reference IPCC-AR42007 GWP for R410A = 2,088).

The air conditioning industry developed TEWI to measure the impact of various activities on global warming. TEWI is widely accepted as the best measure of the net impact on global warming, because it accounts for greenhouse gases from direct emissions of operating fluids together with the sizable energy-related CO<sub>2</sub>, as seen in **Figure 3**. This global warming calculation includes the effects of system efficiency and the source of the electricity (coal, nuclear, hydroelectric) and the direct effect of the refrigerant when it escapes into the atmosphere. The number varies according to the leakage rate and type of power used. Higher energy efficiency of some refrigerants can lower the indirect effect and offset a somewhat higher GWP.

Life Cycle Climate Performance (LCCP) is also widely accepted as a good measure for a refrigerant's net impact on global warming. LCCP is like TEWI, but also takes into account leaks

### Global warming impact

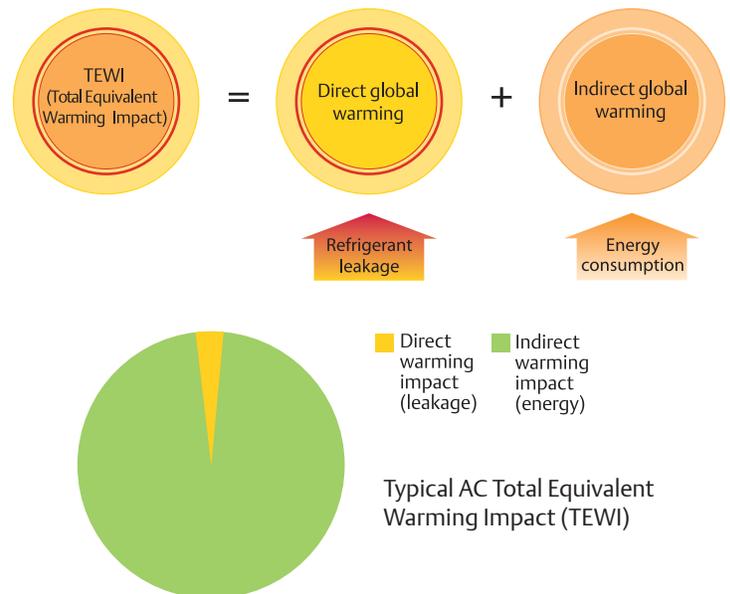


Figure 3

during production and the embodied energy of all material used for the manufacture of the refrigerant.

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 also key to cutting the direct global warming effect. The best way to do this is with low-charge system designs, the quick repair of all leaks and the recovery of refrigerant during service operations. Improved design, maintenance and service practices have minimized the potential for leaks.

Indirect global warming is a function of the efficiency of any piece of equipment. In an air conditioning system, the compressor efficiency, system design, and thermodynamic and heat-transfer properties of the refrigerant affect the energy efficiency of the equipment. Indirect global warming takes into account the energy efficiency, and 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 be important in driving the trend to more efficient refrigerants, as energy consumption is the main contributor to global warming for most applications. In dealing with the changing refrigerant environment, Emerson has adhered to a strategy that permits us to serve our markets with products that provide performance, reliability and minimum risk, while moving as rapidly as possible to chlorine-free alternatives.

## TEWI, LCCP and refrigerants

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

### GWP of HFCs

Refrigerant	GWP (AR4 2007)
R-32	675
R-134a	1430
R-407A	2107
R-407C	1774
R-404A	3922
R-410A	2088
R-507	3985
R-422D	2729
R-427A	2138
HCFC-22	1810

Figure 4

misleading in understanding the effect of various refrigerant alternatives. TEWI helps to assess the climate-change impact fairly, as it takes into account the direct (refrigerant emissions) and indirect (system power consumption/efficiency) effects in evaluating global warming. Many of today's HFC refrigerants appear to be good options when comparing the total global warming impact to that of halogen-free refrigerants.

TEWI/LCCP highlights the need to control leaks to reduce global warming from the refrigerant. As shown in **Figure 4**, indirect global warming — that which can be best dealt with by using 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.

The Kyoto Protocol was established in 1997 in response to global warming concerns. Developed countries are challenged with cutting 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 CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>.

As Emerson considers the refrigerants available to manufacturers and the potential global warming impact of each, Emerson believes one good option for air conditioning applications is to stay with HFC options such as R-410A until an economically viable alternative becomes available. The efficiency performance and cost advantages of HFC refrigerants outweigh the disadvantages associated with higher pressures and direct GWP.

Emerson Climate Technologies supports TEWI/LCCP and expects that this measurement tool will become the representative criterion in selecting future refrigerants. Using the right refrigerant in energy-efficient air conditioning equipment can lower greenhouse gas emissions.

## Regulations & Timing

The Montreal Protocol was revised to call for a production phase-out 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 cutout HCFC refrigerants. As shown in **Figure 6**, allowable HCFC production levels drop with time, with the next significant cut planned in 2020.

The Montreal Protocol supports 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 the agency and industry believe is right.

The EPA is monitoring the U.S. compliance with the Montreal Protocol and has developed a schedule to monitor progress toward the total phase-out of HCFCs. The United States Clean Air Act established regulations for implementing this phase-out. 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 using R-22. In 2020 use of existing refrigerant, including recovered and recycled refrigerant will be allowed beyond 2020 to service existing systems, but chemical manufacturers will no longer be able to produce R-22. Canada has a National Action Plan (NAP) for the Environmental Control of ODS which aims to reduce HCFC consumption by 2015.

High GWP HFCs are coming under pressure globally to be phased-down. In the US, Congress tried to pass legislation to curb the use of HFCs. The American Clean Energy & Security Act of 2009 (Waxman-Markey Bill) passed the House Energy and Commerce Committee the week of May 18, 2009. This bill would require a reduction in HFC use long term. But the Senate bill failed to get traction and the future of this legislative action at the federal level is uncertain. Many states continue to work on climate change legislation; California leads the way. In addition, the EPA has the authority to regulate HFCs as greenhouse gases.

The US is also actively developing a separate international agreement on HFCs, proposing a Montreal Protocol amendment to phase-down HFCs. Figure 5 shows the North American

Proposal to amend the Montreal Protocol for phase-down of the consumption of HFCs' GWP.

In the European Union, the F-Gas Regulation took effect as of July 2007. It requires leak inspections, leak-detection systems, recovery, and training and certification. Manufacturers must comply with the requirements on labeling and leak checks. The European Commission is currently reviewing the effectiveness of the F-Gas Regulations. See EPEEGlobal.org for further details.

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

### Air conditioning efficiency standards

At the same time that the air conditioning industry is dealing with refrigerant transitions and the 2010 phase-out of R-22, another major trend is occurring. Increased energy-efficiency standards are already in place for residential systems, and new energy standards for commercial systems went into effect in 2010.

The Energy Policy Act of 2005 established federal energy-efficiency standards for commercial air conditioning systems that are 10 percent above current American Society of Heating, Refrigerating & Air Conditioning Engineers (ASHRAE) 90.1 minimums. These standards became effective January 1, 2010, coinciding with the phase-out of HCFC R-22 for new systems. Higher state or regional standards may emerge, pushing minimum efficiency levels even higher. Most commercial system manufacturers have redesigned systems for both R-410A and higher efficiency.

### NAP to phase-down HFCs

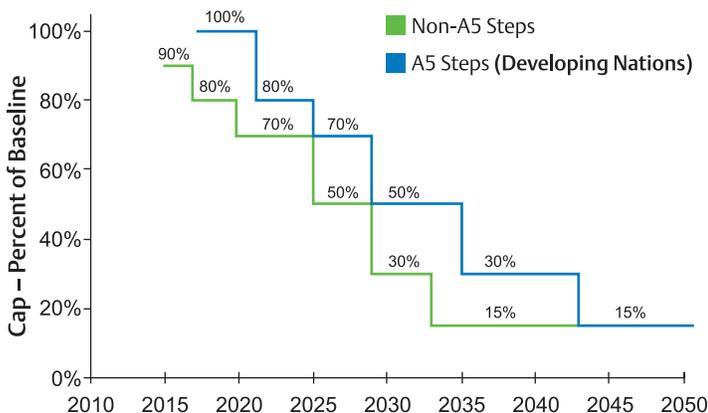


Figure 5

### HCFC phaseout timeline

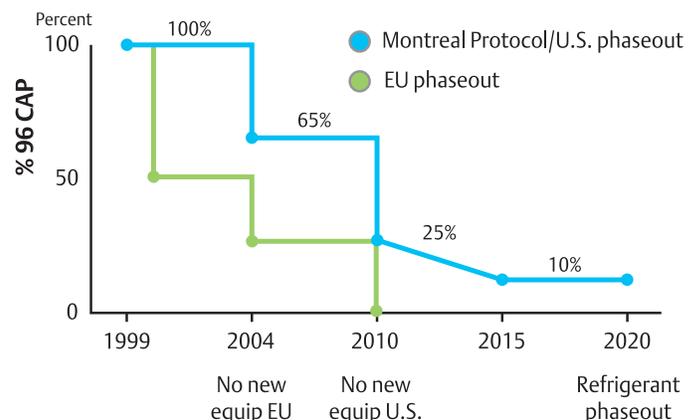


Figure 6

Due to its ozone depletion potential, government regulations currently restrict the use of R-22 refrigerant in new HVAC systems. End-users can still get replacement parts for R-22 equipment and in some cases can replace the entire outdoor unit on split systems. However, most industry analysts expect there to be shortages of R-22 refrigerant to use in these repair situations within the next three to five years due to the Montreal Protocol's mandated reduced production of HCFCs. Consumers should consider the likely R-22 refrigerant shortage when making a buying decision. Staying with R-22 equipment will eventually become more costly than moving to R-410A, as the industry begins to experience shortages of R-22 refrigerant.

While most residential and light commercial air conditioning applications in the U.S. have moved to R-410A systems, a small percentage who are dealing with a space constrained area, have opted to repair systems by replacing the outdoor section with available R-22 units and leaving the indoor sections alone. The minimum standard of 13 SEER enacted in 2006 is about 30% more efficient than the old minimum and requires more heat transfer space, which make both the indoor and outdoor units larger than the older, less efficient R-22 systems they were replacing. This has caused some installation/retrofit problems in "space-constrained" applications where the indoor unit and air handler are in, for example, a small utility closet. The larger size of 13 SEER indoor coils and the EPA's current position that an outdoor condensing unit is a component, have helped create a new niche market of R-22 "dry charge" units. Consumers should also be aware that matching a new R-22 condensing unit with an old indoor coil may not yield 13 SEER in energy efficiency.

Many system OEMs are petitioning the EPA to close the loophole allowing the manufacture and sale of dry charged R-22 outdoor condensing units. These OEMs have expressed serious concern that continuing to produce R-22 condensing units is not consistent with The Clean Air Act, is bad for the environment, and is bad for the consumer by not providing the mandated minimum energy efficiency levels and further populating the field with units that will likely have significant shortages of R-22 refrigerant for service in the future.

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.

Regardless of regulations, many OEMs 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.

## Refrigerant choices

### Criteria for refrigerant selection

Some of the desirable characteristics for a widely used refrigerant include:

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

The components of a refrigerant mixture 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 are chosen based on the exact characteristics desired in the final product.

AHRI established AREP to evaluate refrigerant alternatives. More than 180 AREP reports were approved and released to the public when the committee finished testing in 1997. This testing led to the widespread use of HFC refrigerants to replace R-22.

### Safety

As the air conditioning and refrigeration industries move away from the few CFC and HCFC refrigerants still in circulation, the safety of new refrigerants must be considered for both consumers and service technicians. Refrigerant safety issues fall into four major areas:

**Pressure** — almost all the new HFC refrigerants operate at a higher pressure than the refrigerants they replaced. 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. Many new refrigerants are zeotropes, which can change composition under some leakage scenarios. So it is important to understand the flammability

of the refrigerant blend, and what it can change into under all conditions.

**Toxicity** — during the transition to HFCs, some countries have explored or applied toxic refrigerant options. These alternatives may offer system performance benefits, but they can also be highly dangerous. It is the view of Emerson that toxic refrigerant options should not be used for residential or commercial air conditioning, especially considering that HFCs can deliver the equivalent or better efficiency and 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.

### **Chlorine-free refrigerants (HFCs)**

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

HFCs, or hydrofluorocarbons, are nonflammable, recyclable, energy-efficient refrigerants of low toxicity that are being used safely worldwide. Based on these factors, Emerson Climate Technologies cited the following key criteria for evaluating and approving HFC refrigerants for use in Emerson 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 non-toxic, with a Threshold Limit Value (TLV) minus Time-Weighted Average (TWA) greater than 400 parts per million (ppm), and nonflammable. If they are not, steps must be taken to ensure that the refrigerants are properly used in equipment and facilities designed to provide adequate safety protection for both consumers and service technicians. Maximum system pressures must be no greater than current acceptable limits for retrofit applications. Emerson approves only refrigerants that meet UL standards. See Emerson Climate Technologies, Inc. Accepted Refrigerants/Lubricants (Form 93-11).

It is desirable that lubricants work with current oil-control technology, meet current or improved durability requirements and be backwards compatible with mineral-oil sys-

tems. 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 one lubricant solution that works with all the alternative refrigerants, including HFC and HCFC retrofit chemicals. One lubricant that works with all the approved chemicals makes the service and long-term refrigerant use easier.

Service procedures for equipment should remain simple. Using refrigerant blends should not require unreasonable service procedures.

The performance of new refrigerants should be 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.

### **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. So HFC mixtures (also called blends, azeotropes, near-azeotropes and zeotropes) are widely used.

Mixtures have 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 of the popular zeotropic mixtures exhibit low glide. This phenomenon is a little different from similar effects seen with single-component refrigerants caused by normal pressure drop in 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 some 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 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.

## Common HFC refrigerants

### R-410A

R-410A was the most important HFC refrigerant for meeting the 2010 deadline. R-410A is a near-azeotrope composition of 50 percent R-32 and 50 percent R-125.

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 excellent refrigerant for use in commercial applications. 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 less coil, 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 operates at 50 percent higher pressure than R-22. Anyone handling these units should receive training on the technical aspects of the new R-410A systems, at which time they can learn proper joint-brazing and critical maintenance tips for this new refrigerant.

R-410A cannot be used as a retrofit refrigerant with existing R22 equipment; it should only be used in new equipment (including compressors) specifically designed for it. Existing R-22 compressors cannot meet UL and industry design standards with the higher working pressures of R410A.

### 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. R-407C was the initial choice of some manufacturers who wanted to move quickly to an HFC alternative. In the long run, however, the lower-efficiency performance of this refrigerant makes it a less attractive alternative, when compared to R-410A, for air conditioning 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 new 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-134a

R-134a was the first non-ozone-depleting fluorocarbon refrigerant to be commercialized. It was developed more than 20 years ago to have characteristics similar to R-12. 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 has the benefit of being a single-component refrigerant and, therefore, does not have any glide. 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. This, combined with the larger 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, Emerson thinks that R-134a is the least likely HFC candidate.

For large commercial air conditioning systems featuring screw technology, R-134a may offer the best solution for a low-investment, simple redesign. For large commercial air conditioning systems featuring scroll compressors, R-410A represents the best refrigerant choice.

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

### R-32

R-32 is an HFC refrigerant that is slightly flammable, with an ASHRAE 34 flammability classification of A2L. It is best known as a component in R-410A. R-32 is not currently being marketed as a stand-alone refrigerant in North America, but is gaining interest in China. The reason for this is because China and other developing countries are required under the Montreal Protocol to phase down HCFCs, and they are looking at refrigerants with GWPs lower than R410A.

Figure 7 shows how refrigerants are classified into safety groups based on flammability and toxicity. A2L is a new classification that applies to most low GWP refrigerant candidates. Except for ammonia, refrigerants classified as Bx are not permitted in appliances.

### Retrofit AC refrigerants

A number of HFC refrigerants with properties similar to R-22 have been introduced in the service market that include R-417a, R-422A/B/C/D, R-434A, R-427A and R-421A. The capacity and efficiency of most of these refrigerants are lower than R-22, while GWP values are significantly higher.

In addition to the performance loss, sufficient air conditioning system testing of these HFC service refrigerants has not been undertaken by the HVAC industry to understand their oil return characteristics and therefore their long-term reliability.

Use of these HFC service refrigerant/oil combinations may have an adverse impact on reliability and will void compressor or system warranties. Emerson Climate Technologies has not approved any of the listed HFC R-22 like service refrigerants for air conditioning applications of Copeland® compressors. The recommended HFC service replacement for R-22 is R-407C with POE lubricant. Refer to application bulletin 93-11 for refrigerants and lubricants approved for

### Refrigerant safety groups (ASHRAE 34 and ISO 817)

	Lower toxicity	Higher toxicity
No flame propagation	A1	B1 (includes R-123)
2L	A2L (includes HFO-1234fy)	B1 (includes ammonia)
Lower flammability	A2	B2
Higher flammability	A3 (includes hydrocarbons)	B3

Figure 7

use in Copeland compressors. Please check with your system manufacturer to understand the warranty implications of field retrofitting refrigerants.

### Future low-GWP refrigerant possibilities

Several refrigerant manufacturers are developing refrigerants that will meet European Union environmental standards for GWP substances. Many of these new low-GWP refrigerants are HFO (hydrofluoro-olefin) refrigerants or two-blend azeotropes with HFO and R-32 or R-134a. Advocates for these HFO refrigerants point to the very low GWP, mild flammability, and toxicity and performance similar to HFC refrigerants. Equipment manufacturers will be evaluating these new refrigerants in terms of safety, reliability, cost, energy efficiency, and environmental impact.

### HFC alternatives

#### Ammonia

Ammonia (NH3) is widely used as a refrigerant in 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 limits its application to industrial refrigeration applications. In large ammonia systems, the efficiency is the same as similar systems with R-22 refrigerant.

### Global A2L regulatory activities

	Standards working group	Focus of standards activity for A2L refrigerants
ISO (Intl)	ISO 5149	Safety and use; general equipment requirements
	IEC 60335-2-40	AC and heat pump application; equipment and use requirements
	IEC 60335-2-89	Commercial refrigeration application; equipment and use requirements
CEN(EU)	EN 378	Safety and use; general equipment requirements
	EN-IEC 60335-2-40	AC and heat pump application; equipment and use requirements
	EN-IEC 60335-2-89	Commercial refrigeration application; equipment and use requirements
ASHRAE (US/Intl)	Standard 15	Safety and use; general equipment requirements
UL (US)	Working group #1	AC and heat pump application; equipment and use requirements (UL 1995)
	Working group #2	Commercial refrigeration application; equipment and use requirements (UL 250, UL 471)
	Working group #3	Refrigerant chemistry and requirements
China	R32 A2L committee	Develop R-32 specific application requirements – AC, heat pump, ref

Figure 8

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 usually not soluble in ammonia. The low mass flow of ammonia compared to R-22 is an advantage for large ammonia plants, but becomes a challenge in smaller commercial systems. Also, 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.

### Carbon dioxide

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 (CO<sub>2</sub>) as a refrigerant. CO<sub>2</sub> is given the designation R-744. CO<sub>2</sub> is environmentally benign compared with 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 CO<sub>2</sub> cycle is poor — 30 to 50 percent worse than HFCs — “poor” refrigerants such as CO<sub>2</sub> tend to have good heat-transfer characteristics and respond well to cycle modifications.

Many CO<sub>2</sub> systems are designed for transcritical operation. These systems tend to have lower energy efficiency, compared to conventional systems, and the system design is different from conventional systems. Transcritical operation means that the CO<sub>2</sub> does not condense at the high pressure, and rather than using a traditional condenser, a gas cooler is used. The pressures created by CO<sub>2</sub> 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 Carnot, where the Coefficient of Performance (COP) is 2.5, compared with 68 percent (COP 4.2) for an R-134a system at high-temperature conditions. Microchannel heat exchangers, gas/suction heat exchangers or CO<sub>2</sub> expanders improve system performance, with some added cost and complexity.

The cost impact of CO<sub>2</sub> in transcritical systems is substantial. Because of the higher pressure, modifications are required on the compressor shell, valves, rings, terminal and seals, and the pressure relief valve and microchannel heat exchanger. Performance implications require CSHX, a discharge-pressure regulator valve and a low side accumulator to control excess charge. Another oil separator is required because of 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 CO<sub>2</sub> as a refrigerant have driven system designers to consider subcritical CO<sub>2</sub> systems. These systems operate much like conventional cascade refrigeration systems. In a subcritical system, CO<sub>2</sub> 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 be the best application of CO<sub>2</sub> as a refrigerant for some commercial refrigeration applications.

In summary, CO<sub>2</sub> has many technical and cost challenges. The low efficiency and cycle complexity are the main limitations; however, CO<sub>2</sub> may become used in transport and low-temperature cascade systems, and in some heat-pump applications. Whether transcritical or subcritical CO<sub>2</sub> systems are considered, CO<sub>2</sub> technology cannot be seen as a drop-in replacement for any of the other refrigerants mentioned in this paper. Any application of CO<sub>2</sub> requires a thorough assessment of system efficiency, TEWI, life-cycle cost, technical feasibility, reliability and safety.

### 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 small refrigeration systems with low charge — less than 150 grams (10 ounces) — and often outside the U.S.

The disadvantage of propane and all hydrocarbons is that they are highly flammable. System costs are higher because of the required safety measures. Special considerations must be taken for excess pressures and electrical connections, and ventilation to prevent flammable gas mixtures. Commercial operators do not want to risk the safety-code issues and

litigation risks associated with using propane in an air conditioning system.

Emerson Climate Technologies supports initiatives to apply alternate refrigerants and is funding R&D and Engineering programs to study many of them.

## System design considerations

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

### Lubricants

Most manufacturers of hermetic and semi-hermetic compressors have determined that POEs are the best choice of lubricants for use with HFC refrigerants.

POE oil can be used with all refrigerants and is backwards compatible with mineral oils commonly used with CFCs and HCFCs.

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 the manufacturing of the system and its ultimate installation in the field, to prevent excess moisture from entering the system. A properly selected filter drier is strongly recommended.

### Compressors

As system manufacturers consider new equipment designs, they are impacted by many other changes occurring throughout the industry, including several approved and proposed energy-efficiency regulations. ASHRAE standards mandate increases in efficiency levels across a variety of commercial equipment. State and federal energy efficiency standards, along with various incentive programs, drive OEMs to periodically redesign many of their products.

Over the past decade, Emerson has developed and released a series of new Copeland Scroll® models to support the industry's need for chlorine-free systems. There is a wide variety of displacements available for residential and commercial air conditioning applications.

This shows the unique flexibility of Copeland 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 more efficient than other compressor technologies. Most reciprocating designs will require extensive retooling and redesigning to handle the higher pressures.

## Service considerations

### Responsible-use principles

Emerson 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 air conditioning equipment. But other factors also figure into optimized energy efficiency (see **Figure 9**). Prompt maintenance is important to keeping systems running not only longer, but also more efficiently. Preventive maintenance routines can help extend the life of equipment and 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 in a well-designed system. Early leak detection and repair will reduce refrigerant consumption. All refrigerants should be recovered, reclaimed and recycled at the end of the system life.

### Responsible use of refrigerants

- Contain refrigerants in tight or closed systems and containers, lowering atmospheric releases.
- Encourage monitoring after installations to lower direct refrigerant emissions and to maintain energy efficiency.
- Train all personnel in proper refrigerant handling.
- Comply with standards on refrigerant safety, proper installation and maintenance (ASHRAE-15, ISO-5149 and European Standard EN378).
- Design, select, install and operate to increase energy efficiency.
- Recover, recycle and reclaim refrigerants.
- Continue to improve equipment energy efficiency when cost effective.

## Future direction of refrigerants

HFC refrigerants are the current choice for the air conditioning industry for all the reasons covered in this paper. Many of the HFCs being used are non-ozone-depleting, nonflammable,

recyclable and energy-efficient refrigerants of low toxicity that are safe and cost-effective.

As reviewed here, HFCs have good environmental properties and promote energy efficiency. HFCs like R-410A are considered global warming gases, but due to low emissions in air conditioning systems, the indirect global warming impact, which relates to the amount of carbon dioxide produced to power the system, is much more important than the direct global warming potential of the refrigerant itself. Regional energy standards and future energy efficiency standards beyond 2015 will clearly continue to push system manufacturers to high-efficiency designs. It is not clear what the exact timing will be for future, low GWP refrigerant requirements in the US. However, Emerson is committed to providing cost effective, environmentally responsible solutions for its HVACR OEM customers in advance of when they are needed.

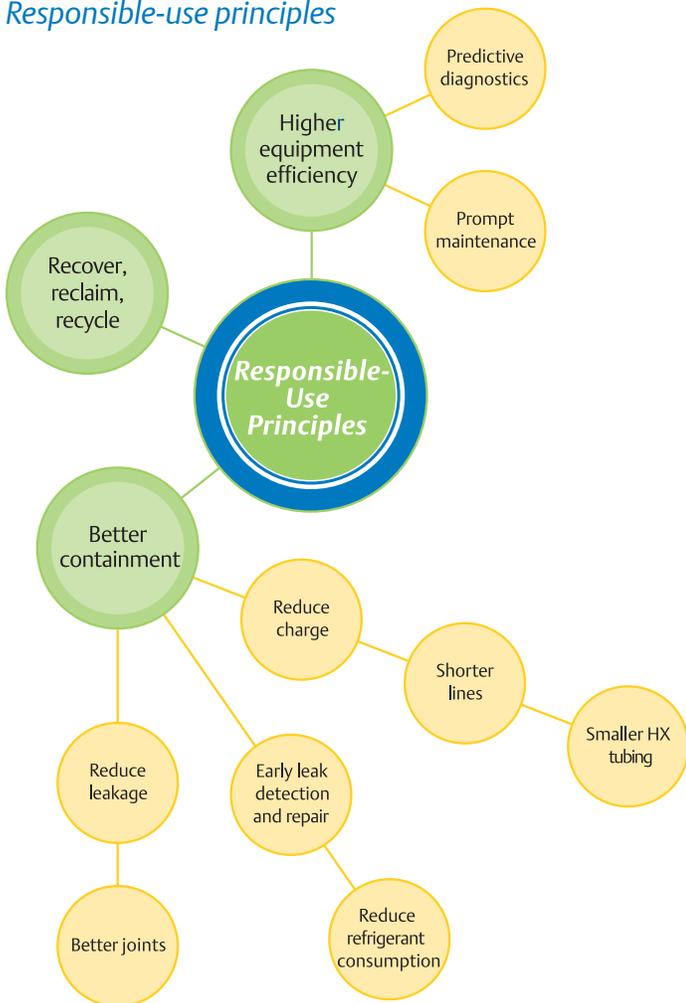
Emerson Climate Technologies supports TEWI/LCCP and expects that this measurement tool will become the representative criterion in selecting future refrigerants. Using the right refrigerant in energy-efficient air conditioning equipment can lower greenhouse gas emissions.

Emerson is actively participating in the new AHRI Alternative Refrigerants Evaluation Program (AREP), an international testing program to identify potential low GWP refrigerant candidates. Over 40 different candidate refrigerants will be studied through 2012 across a variety of applications.

It is important for the industry to stay engaged with international and US working groups (UL, for example) which will continue to develop A2L refrigerant-use rules. Government regulations will affect system architecture, refrigerant choice and life cycle cost. Developed countries must be aware of the choices that are being made in China and the rest of the world regarding refrigerant choices.

No HFC refrigerant can cause direct global warming if it is properly contained. In the HVACR industry and in others, Emerson expects to see more 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 regulating authorities to improve compressor performance, efficiency and reliability, while reducing the overall environmental impact of HVAC system operation.

*Responsible-use principles*



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

**Figure 9**

## 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 (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 (hydrocarbons, ammonia). 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 (HCFC R-22).

**HFC refrigerant:** A hydrofluorocarbon, containing hydrogen, fluorine and carbon molecules (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 one number, usually expressed in terms of CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 materials are available from Emerson on 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

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

(HCFC) R-22 to (HFC) R-407C 95-14

## References

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<http://www.eia.doe.gov/oiaf/ieo/emissions.html>

[http://ozone.unep.org/teap/Reports/TEAP\\_Reports/teap-2010-progress-report-volume1-May2010.pdf](http://ozone.unep.org/teap/Reports/TEAP_Reports/teap-2010-progress-report-volume1-May2010.pdf)

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

The 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.

TLV 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/m<sup>3</sup>).

The Alliance for Responsible Atmospheric Policy,  
<http://www.arap.org/print/docs/responsible-use.html>

ASERCOM statement, Carbon Dioxide (CO<sub>2</sub>) in Refrigeration and Air-Conditioning Systems (RAC), June 2006.

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## About Emerson

Emerson (NYSE: EMR), based in St. Louis, Missouri (USA), is a global leader in bringing technology and engineering together to provide innovative solutions for customers in industrial, commercial, and consumer markets around the world. The company is comprised of five business segments: Process Management, Industrial Automation, Network Power, Climate Technologies, and Commercial & Residential Solutions. Sales in fiscal 2013 were \$24.7 billion. For more information, visit [www.Emerson.com](http://www.Emerson.com).

## About Emerson Climate Technologies

Emerson Climate Technologies, a business segment of Emerson, is the world's leading provider of heating, 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](http://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 100 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](http://EmersonClimate.com).

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