



**NATURAL
REFRIGERANTS
FOR A SUSTAINABLE
FUTURE**

AN IIAR GREEN PAPER



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EXECUTIVE SUMMARY

Natural refrigerants were the first refrigerants to be utilized for food and beverage production and storage in the 19th century due to their availability as naturally occurring substances. Synthetic refrigerants were not commonplace until 1930. Today, natural refrigerants remain the most commonly used in large refrigeration systems to process and preserve food and beverages due to their low cost and high efficiency.

Natural refrigerants have been essential to the food processing, storage and delivery infrastructure of our economy. More recently, natural refrigerant technologies have enabled refrigeration systems to be used for air conditioning in publicly accessed buildings, increasing output efficiencies for power generation facilities and emissions controls for various industries.

From an operational perspective, natural refrigerants are generally accepted as the most efficient and cost-effective industrial refrigerants available, an important benefit to consumers because lower operating costs contribute to lower food prices. Beyond the economic advantages, ammonia (NH₃), carbon dioxide (CO₂), hydrocarbons (HCs), air and water (H₂O) are natural refrigerants and are environmentally benign in the atmosphere. Natural refrigerants have substantial benefits in terms of Ozone Depletion Potential (ODP) and Global Warming Potential (GWP).

Ammonia is perhaps most well recognized as a household cleaner. However, ammonia makes another important contribution to daily life as an industrial refrigerant. It is responsible for the year-round availability, volume and variety of food and beverages served daily on breakfast, lunch and dinner tables around the world. Ammonia refrigeration is among the most significant developments of modern times and a primary contributor to the modern lifestyle.

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CO₂ has been a common refrigerant since the 1860s; however, it fell out of favor due to emerging synthetic refrigerants in the 1930s. CO₂ has substantial benefits in terms of no toxicity and no flammability with its re-growth as a popular industrial refrigerant. Advances in equipment technology have overcome many of the challenges which caused early systems to lose favor in industrial applications.

With heightened attention given to climate change and the extraordinary international efforts made over the past decade to reduce the use of refrigerants harmful to the environment as well as innovations in the design of system components, natural refrigerants are well positioned to be dominant in the 21st Century. Policies that encourage the expanded use of natural refrigerants are harmonious with current and emerging environmental protection and energy-efficiency goals.

Natural refrigerants advantages are well-known, as they do not destroy atmospheric ozone and do not contribute to climate change. In fact, natural refrigerants are some of the most common compounds found in nature. The use of natural refrigerants is consistent with international agreements on reducing climate change. Because of natural refrigerants' proven applicability as safe and efficient refrigerants for over 150 years, they are immediately available for wider usage and new applications. From a purely economic perspective, and without unnecessary regulatory burdens, natural refrigerants should find broader applications as refrigerants than they currently enjoy.

I. INTRODUCTION TO INDUSTRIAL REFRIGERATION

Mechanical refrigeration was developed in the 19th century based on the principle of vapor compression.¹ The first practical refrigerating machine using vapor compression was developed in 1834 and by the late 1800s refrigeration systems were being used in breweries and cold storage warehouses.² The basic design of the vapor compression refrigeration system, using one of many available refrigerants in a closed cycle of evaporation, compression, condensation, and expansion, has changed very little since the 1870s. Present day systems are more efficient, include engineered safety features, are available in smaller sizes, and require comparatively smaller capital outlays.

During the 1930s, air conditioning markets began to develop, first for industrial applications and then for human comfort.³ The use of smaller units for domestic refrigerators increased substantially between 1920 and 1930. By the 1930s, halocarbons such as chlorofluorocarbons (CFCs) had been developed to replace the use of poisonous refrigerants such as sulfur dioxide and methyl chloride. Halocarbons were believed to be the perfect refrigerants because they had no odor, were nontoxic, were comparable in power requirements and price with the other refrigerants and were suitable for the equipment available at that time.

Over the seven-decade period from the 1930s through the 1990s, nearly all state and local building codes, air-conditioning equipment standards, design standards for air-conditioning systems, and installation guidelines were developed for equipment and systems utilizing one of the many halocarbon refrigerants. In the United States, most engineering standards applicable to air conditioning systems and equipment were developed by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). In addition, major equipment suppliers developed products to comply with these codes that permitted only halocarbon refrigerants. Architects, consulting engineers, and contractors applied these halocarbon systems in their air-conditioning project designs and installations.

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During the same seven decades, the amount of halocarbon refrigerants lost to the atmosphere through leaks due to system design and maintenance is estimated to have exceeded many times the amount actually required by refrigeration plants, thereby increasing the demand for halocarbons and securing the refrigerants' commercial success. Consequently, halocarbons became the refrigerant of choice for residential and commercial air conditioning applications, while ammonia remained the refrigerant of choice for the industrial refrigeration industry. This growth in the use of halocarbons, promoted as safe refrigerants under trade names such as "Freon", took place before their damaging impact on the environment was known.

Early refrigerants included ammonia (NH_3), sulfuric ether, carbon dioxide (CO_2), sulfur dioxide, methyl chloride, and some hydrocarbons.⁴ Natural refrigerants have been the most successful in terms of longevity in the field of industrial refrigeration. Of these, ammonia is arguably the most utilized. Carbon dioxide has seen a significant resurgence in interest over the past decade, in part due to its environmentally friendly characteristics, its success in the area of commercial refrigeration, and its immunity to the more rigorous codes and regulations associated with ammonia. Hydrocarbons are appearing with regularity in smaller commercial systems and are emerging for larger systems in industrial refrigeration. Surprisingly, both water and air can also be used as refrigerants but only with some significant changes to either the traditional refrigeration cycle and/or the nature of the equipment used.

Today, the most prominent natural refrigerants and the ones with the highest likelihood of commercial success in industrial refrigeration are ammonia and carbon dioxide. Ammonia and carbon dioxide are key intermediaries in natural environmental cycles, and under normal conditions, are essential for many biological processes. Most of the ammonia in the environment comes from the natural breakdown of manure and dead plants and animals, while CO_2 is required for photosynthesis and comes from decomposition and respiration. Ammonia can be found in water, soil, and air, and is a source of much-needed nitrogen for plants

and animals.⁵ Both compounds are emitted by human beings and other animals. In fact, ammonia and carbon dioxide are among the most abundant gases in the environment. And, while it is important to note that all of the other aforementioned natural refrigerant candidates may find success in industrial refrigeration longer term, the focus of this green paper will be on ammonia and carbon dioxide.

AMMONIA

Ammonia was first synthesized in 1823 by reacting air and hydrogen, and the first commercial production of synthetic ammonia began in 1913.⁶ Currently, there are an estimated two billion metric tons of ammonia present in the world. Of this amount, approximately five percent is man-made. Roughly 18 million metric tons of ammonia are produced annually in North America alone, and of this amount, less than two percent is used for refrigeration.⁷ Ammonia is a common, naturally occurring compound in the environment and can be naturally broken down into harmless hydrogen and nitrogen molecules (the atmosphere consists of nearly 80% nitrogen).⁸

Ammonia was first used as a refrigerant in the 1850s in France and was applied in the United States in the 1860s for artificial ice production.⁹ The first patents for ammonia refrigeration machines were filed in the 1870s.¹⁰ By the 1900s, ammonia refrigeration machines were being commercially installed in block ice, food processing, and chemical production facilities.¹¹ From 1875 onwards, ammonia refrigeration was being applied to ice rinks, first as a brine chiller and later as a direct refrigerant.¹²

Today, ammonia refrigeration is used significantly in the food processing and preservation (cold storage) industries and to a certain extent in the chemical industries.¹³ Ammonia refrigeration is the backbone of the food industry for freezing and storage of both frozen and chilled foods.¹⁴ It is the workhorse for the post-harvest cooling of fruits and vegetables, the cooling of meat, poultry, and fish, refrigeration in the beverage industry, particularly for beer and wine, refrigeration

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of milk and cheese, and the freezing of ice cream.¹⁵ Practically all fruits, vegetables, produce and meats, as well as many beverages and juices, pass through at least one facility that uses an ammonia refrigeration system before reaching our homes.

More recently, air conditioning provided by ammonia refrigeration systems has found limited applications on college campuses and office parks, small scale buildings such as convenience stores, and larger office buildings.¹⁶ These applications have been achieved by using water chillers, ice thermal storage units, and district cooling systems. In Europe, where regulatory regimes have encouraged new applications, ammonia refrigeration systems have been used safely for air conditioning in hospitals, public buildings, airports, and hotels. Ammonia refrigeration has also been used to provide air conditioning for the International Space Station and Biosphere II.¹⁷ Installation at power generation facilities represents an emerging application of ammonia refrigeration. Unfortunately, a broader application of ammonia as a refrigerant is hindered by restrictive regulations at all levels in the United States.

CARBON DIOXIDE

The history of CO₂ use as a refrigerant closely parallels the use of ammonia although certainly not to the same extent. Alexander Twining first proposed the use of CO₂ in a steam compression cycle in 1850; however, it was Thaddeus Lowe who first built an ice production refrigeration system using CO₂ in 1866.¹⁸ Significant progress was made in the adoption of CO₂ as a refrigerant in the late 1800s and into the early 1900s in developing machines utilizing CO₂ as a refrigerant primarily for ice making machines and marine applications. In the early 1900s only about 25% of ships used CO₂ as a refrigerant but this number is estimated to have grown to 80% by the 1930s. CO₂ was also introduced for use in comfort cooling in the early 1900s.

Additionally, CFCs were discovered in the early 1900s and were perceived to be a better alternative. Equipment challenges (sealing issues, capacity loss, and

difficulties in warm climates) and improved alternatives for CO₂ likely contributed to the decline of use of CO₂ as a refrigerant. The last large-scale CO₂ system was built in 1935 for Commonwealth Edison and was replaced 15 years later by machines using CFC refrigeration. By the early 1950s, nearly all CO₂ refrigeration systems had been eliminated.

In the late 1980s there was a revival of interest in CO₂ as a refrigerant primarily in response to the discovery of the adverse effects of CFC's on the ozone layer. This revival was spearheaded by Professor Gustav Lorentzen who believed that the most significant opportunities for CO₂ refrigeration were in automotive applications and heat pumps.¹⁹ While CO₂ offers substantial benefits in terms of ODP, GWP, no toxicity, and no flammability, it has its limitations. CO₂ based refrigeration systems operate at significantly higher pressures than ammonia and have a much lower critical point temperature which creates challenges for heat rejection. Advances in compressor technology, gas cooler/condenser designs, innovative valves, system configuration and software advances have allowed CO₂ to become almost as mainstream as ammonia. Today, potential applications around the globe in commercial and industrial refrigeration are seeing the early stages of a resurgence.

OTHER NATURAL REFRIGERANTS

There are 3 other categories of refrigerants which fall under the generally accepted definition of natural refrigerants and which may have potential in the long term as a substitute to ammonia and/or carbon dioxide: hydrocarbons, air, and water.

Hydrocarbons

The two most common hydrocarbon refrigerants are propane and isobutane; however, ethane and propylene are also considered acceptable hydrocarbon refrigerants. They are all classified as low toxicity, but they are highly flammable. All four HC refrigerants have no ODP and low GWP. From a performance perspective, the compressor efficiencies are, typically, very similar. If it were not for the

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flammability concerns, hydrocarbons would be suitable candidates for replacement refrigerants for R-22 and R134a. Aside from the need for enhanced safeguards, the equipment necessary to utilize hydrocarbons is very nearly the same as that used for the synthetic refrigerants today.

Currently, hydrocarbons are utilized in process cooling and industries more familiar with the safety concerns surrounding flammability of these refrigerants. In 2018, the EPA raised the hydrocarbons charge limit for propane to 150 grams for residential use.²⁰

Air

Air can be utilized as a refrigerant with obvious environmental advantages. Due to the thermodynamic properties of air, efficiency is only achieved at considerably lower temperatures than commonly seen in cold storage and food processing. However, traditional mechanical refrigeration with air is not an option. For air refrigeration, the Brayton cycle (thermodynamics) would have to be utilized, which requires a large input of power due to the thermodynamic properties of air. Power consumption in air cycles is a direct function of temperature. Air as a refrigerant has some clear advantages under certain conditions (e.g., cooling air on jet planes, cooling processes below -60°F, etc.).

Water

Water may also be used as a refrigerant with similar environmental advantages to air, but evaporating temperatures need to be kept above freezing unless temperature suppression additives are included. Analysis from many different sources show the potential for water to be capable of providing one of the highest efficiencies for all refrigerants. Compressors could, in theory, be optimized for water as a refrigerant, but research, development, and manufacturing costs would have to be justified before this becomes a reality.²¹

II. ADVANTAGES OF NATURAL REFRIGERANTS

Ammonia and Carbon Dioxide are environmentally compatible refrigerants

Unlike their synthetic refrigerant counterparts, ammonia and carbon dioxide do not impact atmospheric ozone or contribute to climate change in the same manner. The 1987 Montreal Protocol and its amendments led to the implementation of the gradual reduction of CFCs and HCFCs in developing countries, including the United States, Canada, Japan, and many European countries. Under the Protocol, HCFCs will be gradually phased out by 2030. Certain countries have set earlier target dates for phase-out of HCFCs.²²

The 1997 Kyoto Protocol defined six gases or families of gases for which developing countries would reduce emissions by at least five percent by 2012, as compared to 1990 levels. The components are carbon dioxide (CO₂); methane (CH₄); nitrous oxide (N₂O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulfur hexafluoride (SF₆). CFCs and HCFCs, which are governed by the Montreal Protocol, are not included in the Kyoto Protocol.²³

Under each protocol, each signatory nation establishes its own rules and procedures to meet the phase-out goals.²⁴ This led to the U.S. EPA-established Significant New Alternatives Policy (SNAP) Program, which establishes timelines to phase-out listed substances contributing to climate change. Through the SNAP Program, the EPA has identified ammonia as an acceptable substitute.

The Total Equivalent Warming Impact (TEWI) and the Life Cycle Climate Performance (LCCP) indicators concepts illustrate how important energy efficiency and low GWP of refrigerant emissions are to refrigeration and air conditioning systems. These concepts add the direct and indirect contributions to climate change for selected refrigerants.

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GWP is a measure of how much energy the emissions of one ton of a given gas will absorb over a period of 100 years relative to one ton of CO₂ emissions over the same period. The amount of energy absorbed is a function of both the ability to absorb energy and how long the gas stays in the atmosphere. This energy absorption creates a “blanket” in the atmosphere which prevents the energy from escaping to space and thus contributes to warming of the earth’s surface. CO₂, while itself a greenhouse gas, is naturally occurring in the environment and, when used as a refrigerant, is not considered to be problematic. It is the base by which other greenhouse gases are judged with a GWP rating of 1.0.²⁵

ODP calculation is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11 (Freon). Similar to the GWP, CFC-11 (FREON) is the base by which other refrigerants are judged with an ODP rating of 1.0. A value of 1.0 is considered very high.

The table below summarizes the ODP, GWP, flammability, and toxicity values for selected refrigerants. Flammability and toxicity values are obtained from the National Fire Protection Agency (NFPA 704), commonly referred to as the NFPA Diamond.

SUMMARY OF MOST COMMONLY USED REFRIGERANTS AND THEIR ENVIRONMENTAL IMPACT

Natural Refrigerants	Designation	ODP	GWP	Flammability	Toxicity
Ammonia	R717	0	0	1	3
Carbon Dioxide	R744	0	1	0	0
Propane	R290	0	3.3	4	2
Isobutane	R600	0	3	4	1
Air	R729	0	0	0	0
Water	R718	0	0	0	0

Synthetic Refrigerants	Designation	ODP	GWP	Flammability	Toxicity
Freon-12	R12	1	10,900	0	0
HCFC-22	R22	0.05	1,810	1	2
1,1,1,2-Tetrafluoroethane	R134a	0	1,430	0	1
Freon 404A	R404a	0	3,922	0	1
Freon 507	R507	0	3,985	0	2

Economic Advantages of Ammonia and Carbon Dioxide

For industrial refrigeration applications, ammonia and carbon dioxide refrigeration systems may cost less to design and install than systems using alternative synthetic refrigerants when compared on an in-kind system basis. Thermodynamically, ammonia and carbon dioxide are more efficient than other refrigerants; as a result, both systems use less power than systems with synthetic refrigerants.

The material cost of ammonia and carbon dioxide refrigerants are significantly less than synthetic refrigerants. In addition, less ammonia or carbon dioxide is generally required to meet the load requirements as compared to synthetic refrigerants. Regulatory programs (i.e., the EPA Refrigerant Management Requirements and the California Air Resources Board Refrigerant Management Program) also imply that leak rates are higher for synthetic refrigerants, thus consuming more synthetic refrigerant and resulting in higher cost.

Utilization of ammonia or carbon dioxide as refrigerants may lead to lower operating costs for food processors and cold storage facility operators. Energy costs are historically one of the most significant operating costs for cold storage operators. Lower energy costs ultimately translate to lower grocery bills for the average household.

III. ADVANTAGES OF AMMONIA AS A REFRIGERANT

Ammonia functions as a refrigerant in various types of systems that consume electricity or other types of energy during operation. Due to its highly favorable thermodynamic properties, ammonia used as a refrigerant requires less primary energy to produce a certain refrigeration effect compared to other commonly used refrigerants.

Ammonia is a simple chemical compound that is stable under normal operating conditions. It will not experience fractionation and glide in the two-phase state like some synthetic refrigerants. If a leak occurs in a system, the original concentration of ammonia will not change because it is not a mixture of other refrigerants. This stability also makes accurate analysis of temperature, pressure and performance easy.

Ammonia is a naturally-occurring compound, made up of one atom of nitrogen and three atoms of hydrogen, with the chemical formula NH_3 and a molecular weight of 17. Refrigerant-grade ammonia is 99.98% pure – free of water and other impurities. It is readily available, inexpensive compared to other refrigerants, and capable of absorbing large amounts of heat through evaporation. The operating pressures of ammonia are comparable with other refrigerants. Ammonia's ability to absorb larger amounts of heat per volume makes it possible to use smaller pipes and smaller components compared to other refrigeration systems while delivering the same amount of refrigeration.²⁶

As a refrigerant, ammonia offers three distinct advantages over other commonly used refrigerants. First, ammonia is an environmentally compatible refrigerant because it has an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of zero.²⁷ Second, because of its superior thermodynamic properties, ammonia as a refrigerant typically requires less energy than other refrigerants. Third, ammonia refrigeration has a proven safety record, in part because of the physical properties of ammonia, not the least of which is ammonia's

well-recognizable and easily-detectable odor, compliance with voluntary industry standards, and an industry of well-trained operators.

The inherent safety of ammonia refrigeration is explained in part by ammonia's characteristic odor. Ammonia's self-alarming quality is due to its well recognizable and easily detectable odor and OSHA's odor threshold is between 5 parts per million (ppm) to 50 ppm. This allows for the safe and immediate repair of system leaks or sources of leaks. Ammonia's safety record as a refrigerant is also explained by other physical characteristics such as its density and limited range of flammability, engineering advances for refrigeration systems, and the solid record of well-trained ammonia refrigeration systems operators. However, ammonia has a high toxicity rating.

While releases of liquid ammonia are rare, ammonia is 1.7 times lighter than air and will vaporize quickly even at ambient temperatures. If a leak occurs in a refrigeration system under pressure, only the pressurized gas and, absent additional heat, a smaller amount of the liquid in that space will be released.²⁸ In the presence of moisture, a visible water vapor cloud will form.²⁹

Ammonia exhibits a narrow range of flammability under extremely limited conditions and requires an ignition source. Ammonia's burning velocity is substantially lower than other flammable refrigerants, and is not high enough to create an explosion. For these reasons, ammonia explosions are rare. Properly designed ammonia refrigeration systems that are well ventilated and free of open flames or ignition sources mitigate against potential explosion.³⁰

Also significant to ammonia's safety record is the fact that individuals who work with ammonia refrigeration systems have specific training available to them through organizations such as the Refrigerating Engineers and Technicians Association (RETA) and IIAR. A wide range of education and hands-on instruction is currently provided by industry associates, contractors, and community colleges. RETA

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maintains a robust credential program for operations technicians including five certificates requiring on-going education.

Additionally, industry codes and standards established by Federal, State, and local authorities provide further operational and system design safeguards. IAR has gone further to address concerns by established specific codes designed to mitigate safety issues with ammonia refrigeration systems. OSHA, ASHRAE, NFPA, and national building codes have recognized the standards established by IAR and consider compliance with them to be mandatory. OSHA has cited IAR standards as an example of industry recognized and generally accepted good engineering practices (RAGAGEP).

IV. ADVANTAGES OF CARBON DIOXIDE AS A REFRIGERANT

Carbon dioxide, on the other hand, typically consumes more power than ammonia in meeting the load requirements of any given facility. However, the combination of new technology developments and the opportunity to make use of high-grade heat from a CO₂ system can make the overall energy consumption the lowest of all refrigerants. Therefore, the indirect climate change effect due to CO₂ emissions from electric power plants can be considered one of the lowest of all refrigerants for both ammonia and carbon dioxide refrigeration systems.³¹

Carbon Dioxide is a naturally occurring compound in nature consisting of one atom of carbon and two atoms of oxygen with the chemical formula CO₂ and a molecular weight of 44. As with ammonia, carbon dioxide is part of our natural ecosystem and readily available. It represents about 0.04% of air by volume. It is the baseline for GWP with a value of 1.0 and has an ODP rating of 0. From a global warming perspective, all refrigerants are judged against CO₂.

Like ammonia, CO₂ is a simple compound that is stable under operating conditions. It will not undergo glide or fractionation while in a two-phase state, making system analysis and maintenance straightforward.

Historically, the industry has viewed the higher operating pressures of CO₂ as a disadvantage; however, the fact that CO₂ refrigeration systems never operate in a vacuum means that impurities such as air and moisture do not have an easy path into the closed system other than through poor installation or maintenance practices. Moisture content in CO₂ can be a severe detriment and it is important to have a very high purity in refrigerant applications. Typical purity of CO₂ is greater than 99.99% with less than 10 ppm water by weight. While it is an excellent heat transfer fluid, it is less effective in its ability to absorb heat than ammonia; however, it redeems itself in its high density. This allows for lower displacement compressors,

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much smaller pipes on the suction side of the system and significantly lower pumping power than ammonia. Also of significance is the fact that it is far less affected by parasitic losses manifested in temperature drops. This can contribute to higher overall system efficiency. Additionally, CO₂ is not flammable and has no toxicity below 400 ppm.

Carbon dioxide is not a toxic substance. On the other hand, it is odorless and, at certain concentrations, carbon dioxide can cause illness and death. Due to its odorless nature, it is difficult to detect without detection systems. Carbon dioxide is heavier than air and a major leak into a confined space can displace the oxygen leading to asphyxiation of individuals working in that space. Of course, this condition is true for synthetic refrigerants as well.

Detection systems are composed by either a direct CO₂ sensor and / or an oxygen sensor to detect low oxygen levels. IIAR is anticipating the development of a CO₂ guidance document to establish safe practices and standards for these refrigeration systems. The anticipated release of the IIAR CO₂ guidance is early 2020.

V. SAFE USE OF REFRIGERANTS

A well-designed and properly maintained refrigeration system requires its owner and operator to be familiar with the operation of the equipment and the characteristics of the refrigerant. Prevention is key to ensuring a safe work environment associated with any refrigeration system. Workers must be knowledgeable of emergency procedures and applicable standards. In addition, regulations require regular inspection of safety equipment and ongoing training to prepare workers in the event of an emergency.³²

In the event of a leak of any refrigerant, evacuation and ventilation are important mechanisms for minimizing exposure. Under normal circumstances, individuals will seek relief from ammonia before its presence becomes a serious health hazard. Air containing amounts of ammonia or higher than normal levels of carbon dioxide in which a person is willing to remain is generally not dangerous; however, as with any irritating atmosphere, care should be taken to prevent prolonged exposure.

The risks associated with any refrigeration system that must be addressed through appropriate control mechanisms include accidental releases, releases occurring during operations and maintenance, degradation of components, and engineering flaws. Modern plants have state of the art gas detection and ventilation systems. These refrigeration systems provide alarms or are programmed to shut down the system once the presence of a refrigerant reaches a pre-programmed concentration and immediately removes or restricts the supply of the released refrigerant from the designated area. Refrigeration system design and safety features address minimizing the refrigerant charge, suitable ventilation, relief systems, restricting the use of refrigerants in public locations, and promoting indirect cooling systems.

Due to its significantly lower toxicity potential, carbon dioxide systems are not subject to the same level of rigorous standards as ammonia but are still subject to the regulatory requirements known as the General Duty Clause. General safe design, practices, and operation are required for all industrial refrigeration systems.

VI. REGULATORY REGIMES FOR REFRIGERATION SYSTEMS

Industry regulations, codes, and standards have been developed and revised over the years to address risks associated with refrigeration systems, and they incorporate appropriate systems requirements and personnel training. These industry-driven regulations, codes, and standards, which have done the most to achieve acceptable levels of safety associated with refrigeration systems, include the following.

- United States Environmental Protection Agency (USEPA) Risk Management Plan (RMP) regulation
- Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) and General Duty Clause regulations
- United States Department of Transportation (USDOT) regulations
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE): Safety Standard for Refrigeration Systems (ASHRAE-15)
- IIAR Standards

Three regulatory agencies have jurisdiction over activities involving industrial refrigerants. OSHA, USEPA, and USDOT have developed regulatory requirements for the use of highly hazardous substances. In addition, many state and local agencies have gone further to address concerns specific for their geographical area.

OSHA administers most workplace safety requirements and has promulgated standards addressing workplace hazards which are applicable to ammonia refrigeration systems, and the General Duty Clause. OSHA's PSM Program regulates ammonia refrigeration systems with on-site thresholds over 10,000 lbs. The General Duty Clause regulates systems under the PSM threshold or systems with chemicals that may be unlisted but requires employers to "shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees".³³

The USEPA administers most federal environmental requirements, including numerous reporting and risk management requirements applicable to refrigeration systems. The EPA RMP requires ammonia refrigeration systems with thresholds over 10,000 lbs to comply with these requirements. The RMP regulations reflect those of OSHA's PSM Program, with a few exceptions. The EPA also administers reporting and handling of synthetic refrigerants which is an often-overlooked regulatory burden when synthetic refrigerants are being considered.

The USDOT administers most requirements applicable to the transportation of all goods, including refrigerants. Requirements include carrying Safety Data Sheets (SDSs), bill of lading requirements, signage on transportation vehicles, and how a substance or product is transported. Driver requirements for training, security, recordkeeping, and hours of service are included.

While these regulations are addressing safety issues associated with refrigeration systems, the industry in general has taken great strides to "self-regulate" with written standards and best practice. The IIAR Standards accomplish this goal. IIAR has developed 9 American National Standards Institute (ANSI)-approved standards associated with the safe design and operation of natural refrigeration systems, and these standards have been accepted internationally. In addition, several guidebooks have been published, the Ammonia Refrigeration Management – Low Charge (ARM-LC) Guidebook provides guidance on systems containing less than 500 lbs of ammonia and the CO₂ Handbook focuses on the safe design and operation of CO₂ refrigeration systems.

ASHRAE-15 has updated Addendum A in 2018 to refer specifically to IIAR 2 regarding the safe design of ammonia refrigeration systems. Other regulatory and standards organizations are following suit in viewing IIAR as the authoritative source for safe design, operation, and maintenance of natural refrigeration systems.

VII. A NEW VISION FOR NATURAL REFRIGERANTS

Ammonia and carbon dioxide offer many advantages as refrigerants. Neither refrigerant has ill effects on atmospheric ozone, and CO₂ has minimal impact on climate change while ammonia has none. Because both refrigerants have favorable thermodynamic properties, both refrigeration systems have the potential to be more efficient than most traditional and newer refrigerants. Finally, ammonia refrigeration has a strong safety record, one that is comparable to other refrigeration systems in use today. Carbon dioxide systems are relatively new to the field of industrial and commercial refrigeration but all indications are that they will be as safe or safer than any other type of system.

Certainly, the growing environmental concerns relating to halocarbon refrigerants has sparked a renewed interest in natural refrigerants. Ammonia has found its greatest application as a refrigerant in industrial settings, primarily in the food processing and food distribution sectors. It is also used in the petrochemical and pharmaceutical sectors. As a result of significant advances in products and system design, carbon dioxide now offers a second viable choice for industrial applications.

Ammonia air conditioning applications are found in government office buildings, museums, airports, colleges and hospitals. With regulations properly tailored to ammonia refrigeration systems, the application of ammonia refrigeration systems will become more widespread. When coupled with carbon dioxide in what is known as a cascade refrigeration system, ammonia offers excellent performance on the high-pressure side of the system while carbon dioxide offers superior performance on the low side of the system.

To realize natural refrigerants' full potential, regulations may require a more tailored application to ammonia refrigeration systems, ammonia/carbon dioxide cascade systems, and carbon dioxide transcritical systems. In particular, application of the PSM and RMP regimes must be refined and tailored to avoid the burdens

and barriers imposed on existing and new refrigeration systems. Local regulations can also achieve their health and safety goals with more informed applications that do not restrict the broader use of natural refrigeration systems. The IIR has recognized both the current and future potential of all of these systems and has taken steps to develop recognized and accepted standards which can be applied throughout the world.

Technologies are advancing towards low-charge ammonia and CO₂ refrigeration systems. With an increased interest in natural refrigeration systems and the phase-out of some synthetic refrigerants, it is clear that natural refrigeration will remain prominent for the foreseeable future. Refer to the IIR's State of the Industry Report summarizing the current state of industry and more detail on the future of the industry and organization, which is published annually.

ENDNOTES

- ¹ Ammonia as a Refrigerant (International Institute of Refrigeration, 1999), 13.
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- ³ S. M. Miner, an Appraisal of Ammonia as an Alternative Refrigerant in Light of the CFC and GWP Situation (International Institute of Ammonia Refrigeration, Technical Paper T167, 1992), 1.
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