Abstract

Today's world is putting new demands on refrigeration systems. Environmental concerns are driving regulatory changes, creating uncertainty around the use of synthetic refrigerants. Public awareness of the environmental impact of refrigeration is also higher. New technology offers new capabilities and options for refrigeration system design, presenting opportunities to use ammonia in applications and markets where it has not been used in the past.

This technical paper describes how ammonia can become a significant refrigerant in new markets, including the commercial arena. The paper will
• Summarize regulatory factors affecting refrigerant selection, including the total equivalent warming index (TEWI);
• Summarize technology now available that makes ammonia refrigeration feasible in new applications;
• Present potential new applications and markets for ammonia refrigeration, including a case study of a recent ammonia/CO$_2$ cascade system installed at a retail grocery market; and
• Suggest steps the industry can take to support these new applications.

Ammonia can become a more widely used refrigerant and serve markets in applications where it has not been traditionally used. This will take a change in thinking about how to use the refrigerant and how to design safe and effective systems. In taking this step, the commercial sector has some lessons for the industrial sector on making refrigeration systems user friendly and cost effective.
Introduction

The world is placing new demands on the refrigeration industry. Environmental concerns are driving regulatory changes, creating uncertainty about the use of synthetic refrigerants. Public awareness of the environmental impact of refrigeration is also higher than previously. This has created an interest in using ammonia for new applications and markets.

To date ammonia has not been a significant refrigerant for nonindustrial applications in retail and other commercial installations. However, there are new reasons to consider ammonia as a viable option outside the industrial sector. The total equivalent warming index (TEWI), accounts for leaks as well as system efficiency to compare performance, and is shaping regulations to phase out synthetic refrigerants. Manufacturers and retailers are sensitive to consumer opinions regarding the environmental effect of their operations. These dynamics, in turn, affect decisions about the refrigerants we use. This paper summarizes regulatory and other factors affecting current refrigerant selection.

Recent development of new technology offers new capabilities and options for refrigeration system design. Most notably, significant developments have occurred in the design, fabrication, and application of heat exchangers and controls for ammonia refrigeration. These developments enable manufacturers to offer low-charge and small-capacity ammonia systems for commercial and retail applications. Additional developments in product and system design will enhance operability and reduce the cost of these natural refrigerant systems compared with conventional, synthetic refrigerant systems that are common in nonindustrial applications. This paper summarizes opportunities for ammonia technology to gain wider acceptance in the refrigeration market place.

The ammonia refrigeration industry has a unique opportunity to offer new solutions that meet changing expectations of the systems we build and operate. Ammonia can
become a more widely used refrigerant and serve markets in applications where it has not been traditionally used. This requires a change in thinking about how we use the refrigerant and design our systems. The industrial sector can learn some lessons from the commercial sector about how to make refrigeration systems user friendly and reliable, while addressing ammonia-related safety concerns. One area where this is happening is retail grocery markets. Many grocery retailers are considering ammonia as an option for their supermarket refrigeration. In fact, ammonia refrigeration systems are now serving stores here in the United States. This paper presents a case study of a recent ammonia/CO\(_2\) cascade system installed at a retail grocery market.

For ammonia to become a more widely used refrigerant, our industry must look beyond where it has been traditionally used. This requires changing how we use the refrigerant and how we design systems. Technology is part of the answer, but our industry must also collectively build on our experience and bring that knowledge to a broader market. Organizations like IIAR have an opportunity and an obligation to support the commercial sector of the refrigeration industry in addressing its need for natural refrigerant alternatives. Code and standard development is one area of need. Another is education and training. Before ammonia will be accepted as a viable refrigerant for widespread use, people must understand how to use it safely and effectively. The infrastructure and institutions to develop and support trained and qualified designers, installers, and operators are major concerns that cannot be overlooked. This paper summarizes some areas where industry organizations can play a role in bringing ammonia refrigeration to nonindustrial or light-industrial facilities.

**Current factors driving change in refrigeration**

The refrigeration industry is highly experienced, knowledgeable, and safe. We’ve been doing mechanical refrigeration for nearly 150 years. But we are at a turning
point for two reasons: 1) technology has evolved significantly, opening up new opportunities for ammonia that did not exist before; and 2) the regulatory landscape, public attitudes, and corporate decisions around sustainability are heavily influencing refrigerant selection.

These factors are leading to major changes in the industry. In the industrial sector, packaged ammonia systems are used outside the central machine room more frequently. In the commercial sector, ammonia is now considered in nonindustrial occupancies, which we haven’t seen before. In considering how to provide suitable systems for these operating environments understanding what is driving the use of new ammonia refrigeration technology into new market sectors is helpful.

**Reasons to consider ammonia now**

Clearly, a trend toward natural refrigerants is developing. The question is, why is this happening now? Environmental regulations are having an increasingly significant impact, as a review of the history of the regulation of refrigerant use shows.

In the early 1980s, chlorine-based refrigerants (like R22 and R502) were found to damage the ozone layer. The Montreal Protocol of the 1980s resulted in the effective phase-out of refrigerants that damage the ozone layer. As a result of the reduction of these refrigerants in the atmosphere the ozone layer is actually recovering (Rajendran 2015).

Now the focus has shifted to climate change and the effect of newer refrigerants on global warming. The European Union has adopted the “F-Gas Regulation,” which restricts and phases down certain fluorinated hydrocarbons, or HFC refrigerants (Jahn 2014). In the United States, regulations have now been adopted to stop the use of F-gases for commercial (including supermarket) applications under the Significant New Alternatives Policy (SNAP). The U.S. Environmental Protection Agency (EPA)
is widely expected to implement similar restrictions to industrial applications in the near future (EPA 2015).

**TEWI’s effect on refrigerant choice**

Much of the regulatory pressure on synthetic refrigerants is based on concerns about the environmental impacts of climate change. The basis for the phase-down of HFC refrigerants is concern about their global warming potential (GWP). The performance of a refrigeration system is now evaluated on more than just the power needed to run the equipment. Overall impact on greenhouse gas emissions is a key factor that environmental agencies use to regulate refrigerant use. Many refrigerants, especially HFCs, are greenhouse gases when released to the atmosphere. Their GWP is measured as warming potential relative to CO$_2$, which has a baseline GWP of 1. Many commonly used HFCs have a GWP of 1,000 to 4,000 (IOR 2014; see Figure 1). The relative GWP of a chemical is important when refrigerant leaks are considered in determining the overall impact of a system on the environment. This is where the concept of total equivalent warming impact (TEWI) comes into play.

Regulatory agencies are directing the use of refrigerants to new alternatives with lower GWP. The goal is to cut emissions of greenhouse gases by reducing the impact of refrigerant leaks, while maintaining, or improving, overall system performance. The two sources of greenhouse gas emissions from refrigeration systems are 1) direct refrigerant leaks to the atmosphere and 2) indirect emissions resulting from power consumption related to the use of the refrigerant.

The TEWI concept provides a method to evaluate relative performance of refrigeration systems through direct and indirect emissions. Detailed methods of calculating the TEWI for a particular system are established and available (AIRAH 2012). Rajan Rajendran provides a good summary of related topics in his 2015 IIAR Tech Paper #3. TEWI quantifies the global warming impact of a refrigeration system by defining performance in terms of annual CO$_2$ emissions (see Figure 2). When the
direct effect of refrigerant leaks is added to the indirect effect of power consumption, the overall performance of different systems can be readily compared. Until recently the environmental impact of refrigerant leaks was not clearly quantified on an individual system level. Now that accepted evaluation practices are established, showing the benefits of an ammonia refrigeration system relative to a synthetic refrigerant system is much easier (Jahn 2011). This is a good thing for the ammonia refrigeration industry.

As noted in the introduction, supermarkets are an area of opportunity for ammonia refrigeration. There are nearly 38,000 supermarkets in the United States alone, each with a refrigeration system (Progressive Grocer Magazine 2014). The typical direct expansion (DX) supermarket refrigeration system has about 2,500 lb (1,134 kg) of refrigerant and leaks up to 15% of its charge each year (AIRAH 2012; Table 1).

If we evaluate the TEWI for a typical supermarket refrigeration system, we can see how selection of the refrigerant and system design can dramatically affect performance. Two of the most common HFCs for medium- and low-temperature refrigeration are R404a and R507. When released to the atmosphere, these refrigerants have a GWP 3,950 times that of CO$_2$. These refrigerants can perform well and are relatively efficient in the refrigeration cycle. However, when the warming effect of leakage is taken into account, the scales tip strongly toward refrigerants with a lower GWP.

If we compare a standard centralized DX multicompressor system with the common HFC refrigerant R404a with a cascade CO$_2$ system the difference is dramatic. In the DX system, the direct emissions are more than 50% of the warming effect of the system (this is due to the fact that each pound of R404a leaked has the effect of 3,950 lb [1,792 kg] of CO$_2$ in the atmosphere). By eliminating the 2,500 lb (1,134 kg) of R404a from the system and going to a low-GWP refrigerant on the high side of the cascade, the direct emissions can be reduced to less than 10% of the annual warming effect (Emerson Climate Technologies 2016). When the cascade system utilizes
ammonia as the high-side refrigerant, the direct emissions become negligible because ammonia has a GWP of zero and $\text{CO}_2$ has a GWP of just 1.

The indirect emissions due to energy consumption are comparable for DX and cascade systems. Energy efficiency comparisons largely depend on the ratio between low- and medium-temperature loads. For typical supermarket applications, a well-designed cascade system will result in performance within 2%, or less, of a typical DX system with synthetic refrigerant (Emerson Climate Technologies 2016). The difference can be further reduced by going with ammonia refrigerant on the high side of the system given its relative performance in a mechanical refrigeration system (Ciesielski 2015).

**Regulatory and consumer impact on refrigerant choice**

The regulatory pressure on synthetic refrigerants has a significant impact on the refrigeration industry. As widely used HFC refrigerants like R404a and R507a are phased out, chemical companies are developing new synthetics. Recently developed HFC refrigerants like R407a, c, and f have lower GWP but are less efficient and have operational challenges related to being refrigerant mixtures.

A new class of refrigerants based on hydrofluoroolefin (HFO) compounds is being developed. These synthetics have very low GWP but are Class 2 flammables because of their ignition potential. Nonflammable mixtures of these compounds are entering the market; however, such mixtures have higher GWP and other disadvantages.

Great uncertainty centers on whether new synthetic refrigerants can effectively replace the HFCs that are being phased out. This uncertainty around synthetic refrigerants is driving renewed attention to natural refrigerants like R717 (ammonia) and R744 (CO$_2$). Hydrocarbons like R290 (propane) are great refrigerants and are gaining acceptance in very small systems, despite their flammability. These natural refrigerants are not at risk of phase-out, which makes them an attractive alternative
to synthetics. Combine this with favorable coefficient of performance (COP) ratings typical when compared with synthetics, and a strong case exists for ammonia, CO$_2$, and hydrocarbons based on TEWI.

The attention that regulators are focusing on TEWI is forcing new decisions in refrigeration selection. For companies using refrigeration, public opinion can also affect decisions. Consumers are aware of and pay attention to decisions on refrigerant use more than ever before. New environmental attitudes are shaping customer attitudes.

Large retailers like Whole Foods and Target and producers like Pepsi, Nestle, and others have already announced programs to move away from HFCs ahead of expected phase-outs. Refrigeration end users are realizing that their customers are aware of their technology decisions and are seriously considering natural refrigerants as a result. They are doing so not only for operational reasons, but also as a public relations strategy to show that they are taking a proactive approach to the environment.

**New technology driving growth**

The ammonia refrigeration industry is mature with a highly developed knowledge base built over 150 years of practical experience worldwide. As with any mature industry, change can be a slow process. The pace of innovation has increased in recent years with the development of new technologies that are changing how ammonia refrigeration systems are designed and built. The recent trend toward small-charge and distributed packaged equipment is bringing ammonia systems outside of the traditional central machinery room environment. New technologies have enabled the evolution, which, in turn, is driving greater innovation. Two significant areas of development, summarized in the following sections, include low-charge technology
and ammonia/CO₂ cascade systems. These developments, and others, are allowing system designers to bring ammonia refrigeration to new markets and applications.

However, barriers to wider use of ammonia refrigeration in new markets still exist. To make ammonia refrigeration more widely used in smaller-capacity, nonindustrial locations, the systems we build must be cost competitive, user friendly, and safe. This requires the industry to invest money and effort to develop new products and materials specifically for small-capacity, low-charge ammonia systems. The options available to the system designer are still too limited to make ammonia an easy alternative to synthetic refrigerants. The end of this section suggests some areas of significant opportunity for product development.

Recent developments in ammonia refrigeration technology

A few promising new technologies are gaining wider acceptance in recent years. A concerted effort on the part of researchers, manufacturers, system designers, and end users has brought these to many new installations. Some of the benefits are described below.

Microchannel heat exchangers

One of the most exciting low-charge developments is microchannel heat exchangers. Traditional industrial ammonia systems have relied heavily on round tube heat exchangers for air-side equipment like evaporators and condensers. About 40–50% of the system refrigerant charge could be contained in these components. In comparison, microchannel heat exchangers can operate with as little as 10% of the charge of traditional round tube exchangers (Litch and Hrnjak 1999; Traeger and Hrnjak 2005). Microchannel exchangers are now commonly used in condensers, which is having a significant impact on reducing system charges.
DX ammonia evaporators and distributed systems

Two other low-charge technologies have made significant headway recently. First, DX ammonia evaporators have become more common due to advances in evaporator design, valves, and controls. DX systems can operate effectively while reducing the refrigerant charge by 60% or more compared with a recirculated system (Welch 2013).

Second, several distributed unitary systems are now on the market. The advantage over the traditional industrial system is elimination of the central machinery room and piping mains that contain large quantities of charge.

Ammonia/CO$_2$ cascade systems

As discussed in the case study presented later in this paper, one technology that has recently gained momentum is the ammonia/CO$_2$ cascade system. Figure 3 illustrates the basic schematic of the system (Vestergaard 2007). Ammonia is contained on the high side of the system, which commonly operates with an evaporating temperature of 10 to 20°F (-12 to -7°C). The ammonia evaporates in an ammonia/CO$_2$ heat exchanger. The ammonia absorbs heat from vaporized CO$_2$ to condense it back to liquid.

The safety benefit of this system is that the ammonia side of the system can be contained in a small area outside occupied spaces, while CO$_2$ is circulated to cooling equipment inside the building. The beauty of CO$_2$ is that it can do double duty:

1. As a volatile brine pumped to medium-temperature loads in the 15 to 25°F (-9.5 to -4°C) range and

2. As a DX refrigerant to low-temperature loads in the -60 to 10°F (-51 to -12°C) range utilizing a booster compressor.
The CO₂ system gives you the benefit of a secondary coolant, like glycol, by isolating the ammonia from occupied spaces but the flexibility to operate at low temperatures (down to -60°F [-51°C]) for some portion of the load. The CO₂ in the cascade system operates in the subcritical range at pressures less than 450 psig (31 bar), which allows construction typical to most HFC refrigerant systems.

In addition to eliminating the environmental impact of refrigerant leaks, the ammonia/CO₂ cascade system offers energy efficiency benefits for nonindustrial applications where straight DX refrigeration systems are typical. For systems with a large ratio of the load in the low-temperature range, the cascade system efficiency improves with the reduced compression ratios that multiple stages offer. This gives an energy efficiency advantage to a cascade system over a straight DX system for many applications.

Opportunities for new development—what we need

The aforementioned technologies are being used effectively today. To apply ammonia refrigeration more broadly we need products that are specifically developed for the light industrial and heavy commercial market. To bring ammonia to markets currently dominated by synthetic refrigerants ammonia must become cost competitive. Technology is how we get there. Product development aimed specifically at bringing new ammonia technology to the small system, nonindustrial market is required. The following sections discuss a few areas to consider.

Small-capacity ammonia compressors

Currently, many manufacturers offer ammonia compressors in the 50 TR (176 kW) and larger capacity range. To meet broader market demands and effectively pursue opportunities in new applications, we need to provide small-capacity compressor options in the 2 to 25 TR (7 to 88 kW) range. A wider range of compressor types
(reciprocating, screw, and scroll) also must be available to system designers and builders.

**Semihemetic ammonia compressors**

Most synthetic refrigerant systems use semihermetic compressors, which minimize leaks and simplifies the construction and maintenance of refrigeration systems. New materials and designs are needed to make what is standard compressor construction in the commercial market a reality for ammonia. Some manufacturers are testing and have developed semihermetic ammonia compressors (Tomooka 2011). End users and systems designers must specify and support the application and development of this technology.

**Miscible oils for ammonia**

Manual draining of oil or expensive automated oil recovery systems are a challenge for commercial application of ammonia. Limited maintenance budgets and scarce availability of qualified service technicians are the reality now and in the future. Reducing the need for regular hands-on intervention to keep the systems operational is an important step to greater acceptance of ammonia refrigeration. Oils that are miscible, like they are for synthetics, could be an important step toward opening new opportunities for application of ammonia in small-capacity systems.

**New piping materials and fabrication methods**

Carbon steel and stainless steel piping materials have traditionally been used in ammonia refrigeration. These are excellent for ammonia and are long proven for refrigeration applications. However, they are costly to install and require highly skilled labor for welding, and quality can vary with ambient conditions during fabrication. Alternatives to all-steel welded pipe systems are needed.
Aluminum certainly is promising, but more research is required on proper application and fabrication techniques. Testing and evaluation of aluminum materials has shown them to be effective for ammonia application (Eurammon 2012), but pipe fittings and joining methods need further development to define what can be effectively used for ammonia applications. Compression-type joints are an option that would provide consistency and reduce some of the variables of field labor.

**Readily available parts**

Replacement components for ammonia systems are a concern as is the case with any technology. The distribution networks for small-system compressors, valves, controls, and other elements must support a market that expects and requires 24-hour delivery. The commercial sector is generally designed around a replace versus rebuild philosophy, with little redundancy and no planned downtime for maintenance. To truly penetrate the larger market systems designers and component manufacturers must consider means to facilitate maintenance, including stocking spare parts for immediate delivery.

**Case study: Addressing challenges in new operating environments**

Ammonia has traditionally been dominant in large food production/storage facilities and some manufacturing applications, primarily because these industrial applications are separated from the public. Ammonia has always had significant operational advantages over synthetic refrigerants in such large industrial systems. However, in the mid-20th century, systems built around synthetic refrigerants became prevalent in most commercial and small-capacity applications. Given the current environment and advances in technology, however, real potential exists to use ammonia where it has not commonly been used before.
Some areas of great potential for ammonia refrigeration include

- Comfort cooling for warehouses, manufacturing facilities, and even public assembly or office buildings;
- Equipment or process cooling for manufacturing or communications and data centers; and
- Commercial refrigeration for retail grocery markets, convenience stores, or commissaries.

Of course, using ammonia in these new applications isn’t as simple as building the same refrigeration systems we’ve always built in industrial environments. Bringing ammonia to these new markets will require a change in how the systems are designed and built to address the challenges of nonindustrial locations.

**Challenges of installing ammonia refrigeration in nonindustrial applications**

The main challenges of installing nonindustrial ammonia applications include

- Applying new technology to mature market sectors traditionally served by synthetic refrigerants,
- Isolating ammonia from the public and employees at the facility,
- Making the system user friendly with minimum hands-on interface by local users, and
- Making the system cost justifiable.

Bringing ammonia to nonindustrial applications means introducing a new, or at least unfamiliar, technology to a sector of the refrigeration industry that is accustomed to systems designed around synthetic refrigerants. We must address the unique engineering challenges of ammonia with good design solutions that fit the particular needs and expectations of the end users (Pearson 2008). Working within local regulations to ensure that the design covers safety concerns is very important. This will take various solutions, like low-charge equipment, indirect systems with secondary coolants, and cascade refrigeration systems.
One of the biggest potential markets for ammonia is in retail grocery and supermarket facilities. In supermarket systems ammonia can be used as the high-side refrigerant with a secondary coolant or refrigerant like CO$_2$ to cool occupied spaces. Although ammonia and CO$_2$ have been used rather widely in Europe and Canada, using it in retail applications in the United States is relatively new. As noted previously, typical U.S. supermarket refrigeration consists of direct expansion with an HFC refrigerant. A significant shift is now underway, spurred by new EPA requirements that will favor new system designs that minimize the amount of high-GWP refrigerants and encourage the use of natural refrigerants. At this time, however, only a handful of supermarkets in the United States use ammonia and CO$_2$.

Any application of ammonia in commercial, or nonindustrial, locations requires that we find ways to make it safe, relatively easy to use, and cost justified. The following case study of an ammonia/CO$_2$ cascade system installed at a retail grocery store examines these challenges and some solutions.

**Whole Foods Market project overview: Challenges and solutions**

Whole Foods Market has defined its place in the grocery sector as a high-quality retailer with a philosophy of environmental sustainability that is closely tied to the company’s public image. This case study exemplifies how the company has been a leader in a trend toward sustainable design in the commercial sector. The project was one of several new Whole Foods locations that have advanced the use of natural refrigerants into commercial settings in the United States. Previous facilities utilized trans-critical CO$_2$ systems and subcritical CO$_2$ in a cascade system with a synthetic refrigerant on the high side (Coffin et al. 2015). This project took the use of natural refrigerant to the next level by utilizing ammonia in the cascade system as the condensing medium for the CO$_2$. 
Challenge 1: Application of new technology

From the perspective of Whole Foods Market, a cascade ammonia/CO$_2$ system is an attractive technology choice for two primary reasons. First, by using natural refrigerants the system can operate with zero ozone depletion and very low TEWI. Second, by eliminating synthetics entirely the company has eliminated the uncertainty that its refrigerant choice will be phased out in the future.

So how does the system work? As noted previously, this is an ammonia/CO$_2$ cascade system. In this case, the manufacturer built a two-module package. The ammonia module is mounted outdoors on the roof, and the CO$_2$ module is mounted indoors on a mezzanine. Figure 3 shows a simplified system schematic diagram (Vestergaard 2007). The ammonia module removes heat from the CO$_2$ and condenses any vapor back to a liquid. The CO$_2$ module is the low-temperature side of the system and circulates CO$_2$ to refrigerated cases inside the retail areas. The CO$_2$ is pumped as a volatile brine to and from medium-temperature loads (fresh or perishable product cases) and as a DX refrigerant to low-temperature loads (frozen product cases).

The ammonia/CO$_2$ cascade system is a good fit for the retail grocery application. But applying ammonia in a new environment means that designing the system for safety is a key factor.

Challenge 2: Isolation of ammonia

For those of us who work with ammonia refrigeration regularly, awareness of hazards and proper handling of the refrigerant are standard practice. However, we must recognize that most of the public and many contractors and technicians who work in commercial refrigeration do not know the requirements for proper design, installation, and operation of ammonia equipment. With the Whole Foods project, we addressed the limited knowledge of the people on site in a few ways.
A fundamental part of the design required that the ammonia be isolated from any areas where unqualified, unauthorized personnel may be. The cascade system fulfills this requirement by isolating the high side of the system from the low side via the condensing heat exchanger. The system is designed in two unitary modules, which keeps the entire ammonia charge away from occupied spaces. The package system is designed to minimize field ammonia piping to keep the refrigerant charge small and limit potential for off-site consequences. Building air intakes are located away from the ammonia module and upstream from the prevailing winds to minimize potential for indoor exposure through the ventilation.

The high-side ammonia module is located on the rooftop where access is closely monitored and controlled (see Figure 4). To further reduce potential for unauthorized access, the components of the system are fully enclosed within the equipment package. Qualified service technicians can access the system by removing the external access panels. Note that the ammonia module is not a machinery room; it is equipment located outdoors. IIAR-2 2014, Chapter 14, defines requirements for ammonia package systems.

An added level of safety is provided through leak detection inside the package. Should a leak occur, a local horn-strobe and a remote signal provide an early warning and alert of the condition and potential hazard.

Challenge 3: Usability and limited routine maintenance

Industrial refrigeration systems were traditionally designed as a central plant to be operated by full-time, on-site employees who are highly trained and knowledgeable about refrigeration and the specifics of the systems at their facility. This is not generally the case for commercial refrigeration systems. Grocery store refrigeration is expected to operate automatically with little or no equipment interface by the local staff. Off-site contractors maintain the system and respond to upset conditions in response to emergency service calls. The availability of qualified service contractors
and replacement parts is a key consideration in pursuing ammonia refrigeration in commercial applications.

A key goal for the project was to make the system as user friendly as possible. Unlike many large central refrigeration systems, the facility has no on-site service staff, much less a qualified refrigeration operator. The system needed to be operable without local user intervention. Providing near-total automation and working closely with the local service contractor to ensure it had the proper knowledge of the system and was properly trained addressed this issue.

Operating sequences were carefully developed to provide for stable function over the full range of operating conditions. Should a system-upset condition occur, the system incorporates safety shutdown sequences for various scenarios with automatic reset and restart upon system recovery.

Supplemental sensors are provided to monitor system conditions and include trend logging and alarming. With the facility communication capabilities this provides good information that can be accessed remotely to check current status, troubleshoot, and make system adjustments from off site.

Because of the limited access to qualified service technicians, one design priority was to minimize the potential for on-site maintenance staff being exposed to ammonia. Eliminating the need to perform some traditional maintenance functions addresses this issue. An automatic oil recovery and return system is provided in lieu of the standard oil pot in most industrial systems (see Figure 5). Automating a function like oil recovery limits the number of times the system has to be opened, thus minimizing the potential for exposure to ammonia because an inexperienced technician does not need to open system valves.

The clear lesson here is the need to engineer a high level of usability to compensate for the lack of on-site expertise at nonindustrial facilities. To bring ammonia
technology to new markets, system design must adapt to a different operating environment and account for the different capabilities of the end user.

**Challenge 4: Cost justification**

A significant challenge for ammonia refrigeration in nonindustrial applications is the first cost relative to traditionally built commercial systems. Most ammonia refrigeration systems are built with industrial-grade components and materials with an expected useable life in the range of 30 years or more. However, commercial systems are seldom expected to last more than 15–20 years. Furthermore, many commercial refrigeration components are built to be replaced, rather than rebuilt as is typical for industrial components.

The cost justification for the ammonia/CO₂ cascade refrigeration in commercial applications is usually based on the overall life cycle cost, not the installed cost. This requires the end user and designer to have a broader view of the project costs than just the initial construction budget.

For Whole Foods, system efficiency gains and lower refrigerant cost for ammonia and CO₂ over synthetic refrigerants lower the life cycle costs. Good system design with low approach temperatures on the heat exchangers and variable speed motor control on condensers and compressors achieve energy savings. Heat reclaim also provides hot water and reduces the facility’s overall energy consumption.

Water savings further reduce operating costs. The system is provided with hybrid condensers using adiabatic cooling pads on the air intake. The benefit is improved performance over a conventional air-cooled condenser, but with very low water consumption and no chemical water treatment.

Utilizing packaged equipment addressed safety issues by placing the ammonia module on the rooftop, but a secondary benefit was keeping initial costs down.
Putting the equipment outside on the roof avoided the expense of a full machinery room.

One challenge for the application of \text{CO}_2 \text{ systems} compared with standard DX HFC systems is the cost of controls. Traditionally, DX systems use mechanical thermal expansion valves (TXVs). A typical supermarket may have 100–200 TXVs. When switching to \text{CO}_2, these valves generally have to be replaced with electronic expansion valves (EEVs). The cost of the valves is comparable to that of TXVs, but the cost of the controls for the EEVs is very high. Few manufacturers serve the application, and they utilize proprietary controllers. Controls are one element that is keeping the cost of \text{CO}_2 \text{ systems} relatively high.

In comparing the costs of natural refrigerants to synthetics, one area to consider as an industry is the definition of a “baseline” system. Many of the higher costs associated with natural refrigerant systems can be attributed to improvements that could be considered current industry standard. The comparison of EEVs and TXVs is a case in point. EEVs are known to improve system efficiency and reduce start-up time. This technology has a payback regardless of the refrigerant. However, applying the cost only to the natural refrigerant option creates a hurdle to acceptance.

This example shows how implementation of new technology in an established market is often delayed until external factors drive it. Our industry is in the early stages of bringing natural refrigerants to the nonindustrial market. Part of what currently drives initial costs up are the limited options available to the designer for equipment and components to build small-capacity ammonia and \text{CO}_2 \text{ systems}. As more products become available and more projects are built, the costs will come down. In the meantime, tax credits and utility-funded incentive programs help to offset costs for environmentally friendly upgrades. The concept of life cycle climate performance (LCCP) is important in this evaluation (see Rajendran 2015). The EPA and the U.S. Green Building Council define criteria and provide resources to evaluate refrigeration system performance based on life cycle factors.
The right base of knowledge and skills

The F-gas regulations in Europe and the SNAP program in the United States are effecting change in the refrigeration industry. Ammonia refrigeration stands to benefit from these changes, but industry organizations must step up to the challenge. For ammonia to become a more widely used refrigerant, the industry must look beyond where its traditional uses. This takes a change in how we use the refrigerant and how we design systems. Technology is part of the answer, but the industry must also collectively build on its experience and bring that knowledge to a broader market. The infrastructure and institutions to develop and support trained and qualified designers, installers, and operators is a major concern that cannot be overlooked. This will take the concerted effort of industry groups, including end users, systems designers, manufacturers, contractors, and governmental agencies.

Organizations like IIAR have an opportunity and an obligation to support the commercial sector of the refrigeration industry in addressing its need for natural refrigerant alternatives. Code and standard development is one area of need. Another is education and training. Before ammonia will be accepted as a viable refrigerant for widespread use, people must understand how to use it safely and effectively.

IIAR is in a unique position to support the industry through the development of standards that will affect ammonia refrigeration throughout the world. The recent publication of IIAR-2 2014 is bridging the gap between industrial and nonindustrial ammonia applications. The goal is to make IIAR-2 a singular reference standard for the industry, minimize the need to interpret varied or competing regulations, and influence regulations so that they keep pace with the evolution of the technology.

The updated IIAR-2 addresses the design of ammonia systems in industrial and nonindustrial occupancies and defines requirements that multiple documents from ASHRAE and various other code organizations previously covered. The new standard also provides requirements for equipment located outside of a machinery
room in Chapter 7, and Chapter 14 expands on this by covering requirements for preassembled package equipment and systems.

To implement successful ammonia systems, we must develop the people who are installing, operating, and maintaining them by training and providing new technical information. The ability to bring new knowledge and technical resources to these people is one of the major challenges to opening new markets for our industry.

The Refrigerating Engineers and Technicians Association (RETA) and the Refrigeration Service Engineers Society (RSES) are key to effective training and certification for system operators and service technicians. RETA primarily focuses on industrial refrigeration, and RSES serves the broader heating, ventilating, air-conditioning, and refrigeration (HVACR) industry, including commercial applications.

The ammonia refrigeration industry can benefit from leveraging the technical expertise of an accredited standards development group like IIAR and training-oriented groups like RETA and RSES. This can be done formally through executive-level partnering, but also less formally through individual members. RETA and RSES have local chapters that are wonderful communities for the exchange of ideas that will grow the industry.

**Conclusions**

The ammonia refrigeration industry is evolving. Changes are occurring not only in the technology, but also in the environment, regulations, and public attitudes that shape decisions about the refrigeration systems we install. Government regulations are putting new burdens on the use of synthetic refrigerants, and a more holistic approach is being applied to evaluate the effectiveness of refrigeration systems. All this, combined with recent developments in equipment technology, is encouraging the use of ammonia in nonindustrial applications where it was previously considered unsuitable.
The ammonia refrigeration industry is poised to expand significantly in the near future. The growth will come from applying ammonia technologies in sectors that were previously dominated by synthetic refrigerants. However, to take advantage of the opportunity, the ammonia refrigeration industry must take some lessons from the commercial refrigeration sector in designing, building, and operating the systems. Developing the technology, equipment, knowledge, and skills base necessary will take a concerted effort on the part of end users, system designers, manufacturers, contractors, and government.

References


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Figure 1. GWP of various refrigerants.
Figure 2. Total equivalent warming index.
Figure 3. Cascade system diagram.
Source: Vestergaard (2007).
Figure 4. Rooftop ammonia module for cascade system.
Figure 5. Automatic oil recovery.