



# **WORLD GUIDE TO LOW-CHARGE AMMONIA**

**AMMONIA**21

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# World Guide to Low-Charge Ammonia

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# WELCOME MESSAGE

## Welcome message from shecco

The use of low-charge ammonia has emerged as one of the key trends in the industrial refrigeration industry in the last few years. Moreover, the technological developments have opened up opportunities for ammonia beyond its traditional market.

With this report we aim to identify the underlying trends for low-charge ammonia technology in different parts of the world. The report is released in three parts, with this first part highlighting some of the key characteristics of ammonia as a refrigerant and outlining a brief history of its use.

The term “low-charge ammonia” is not well defined yet although there are some efforts to bring more clarity into this. A clear definition and distinction from traditional ammonia systems is essential to strengthen the position of low-charge systems especially in light of growing legislative pressure on fluorinated refrigerants. Low-charge ammonia has the potential to not only replace traditional ammonia systems but also HFCs in applications where it was not possible to use ammonia before.

We have asked key experts in the field to share their views on this important topic, which is presented in this report.

The second part of the Guide will focus on the variety of applications where low-charge ammonia technology has been used with concrete examples from around the world. In addition, it will outline standards and legislation that are key drivers for the reduction of ammonia charge in systems, but also for the use of HFC-free technology as such.

The third and final part of the report will zoom in on the key trends for low-charge ammonia technology, its advantages, drivers and major challenges in today's market. It will compare developments in different world regions, with focus on North America, Europe, Japan and Australia. Moreover, gathering data through analysis of survey, interviews with key experts it will outline the future opportunities and perspectives for low-charge NH<sub>3</sub> systems.



## Founder & Publisher

Marc Chasserot

Marc.chasserot@shecco.com

## Contributing writers

Klara Zolcer Skačanová

Ilana Koegelenberg

Zita Laumen

Marie Battesti

Charlotte McLaughlin

## Specific parts of the report were peer-reviewed by:

Stefan Jensen

Andy Pearson

Terry Chap



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# ***ABOUT THIS GUIDE***





# ***Introduction***

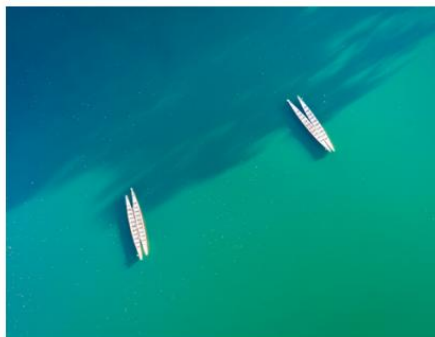
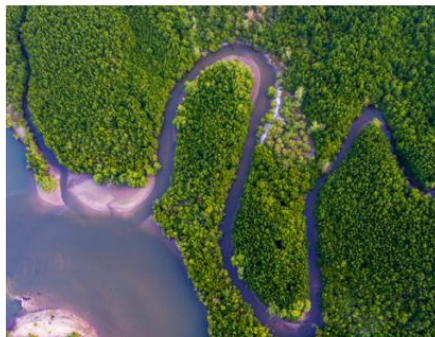
The use of ammonia as a refrigerant goes back 150 years - it is the only refrigerant that has been uninterruptedly used throughout all these years. This is especially thanks to its excellent thermodynamic properties ensuring good energy efficiency performance as well as ammonia's abundance and ease of use.

Ammonia's major drawback - toxicity - has been addressed through design to prevent any leaks. Nevertheless as a result of several major incidents the industry has focused the development efforts on reducing ammonia charge in systems as the most effective measure to improve safety of ammonia-based technologies. In the recent years the development of low-charge ammonia systems has taken a centre stage, disturbing the traditional ammonia refrigeration industry in a positive way.

Today a growing number of manufacturers offer systems that use as little as 20g/kW ammonia charge without compromising the system efficiency, but actually further improving it.

This report zooms in on the recent market and technology developments, identifies key trends, challenges and future progress across different geographical regions.

# A SHORT OVERVIEW



## **CHAPTER 1:** **Ammonia as a Refrigerant**

This chapter provides a short introduction into ammonia as a refrigerant. It takes a look at the characteristics of this molecule, its behaviour as a refrigerant, its role and history in the refrigeration industry.

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## **CHAPTER 2:** **What is 'low-charge ammonia'?**

This chapter seeks to identify what is meant by 'low-charge ammonia', using industry feedback and know-how, and looks at issues of defining a technology that is relatively new in the industrial refrigeration sector. It also provides overview of key types of the technology.

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## **CHAPTER 3:** **Applications of low-charge ammonia**

This chapter delves into the applications for low-charge ammonia technology from its beginnings in traditional ammonia refrigeration, such as in cold storage, food processing and logistic facilities, to its forays into HVAC and the pharmaceutical industry.

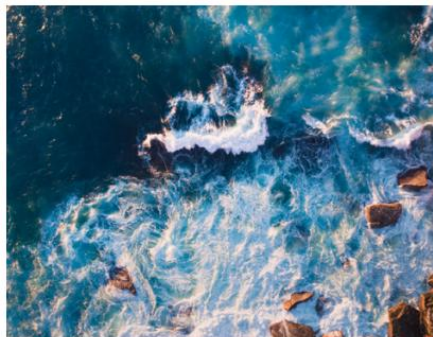
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#### **CHAPTER 4:** **Regulations and standards**

The use of ammonia as a refrigerant is regulated in most of the world due to its risk to human health. This chapter looks at how regulations and standards on high charges of ammonia could offer opportunities for lower-charged technology.

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#### **CHAPTER 5:** **Low-charge ammonia today**

In this chapter, the current market for low-charge ammonia systems and applications is looked at in detail. It identifies the key trends and challenges in different world regions.

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#### **CHAPTER 6:** **Future of low-charge ammonia**

Based on interviews, research, surveys and the market today this chapter anticipates the market potential for low-charge technology in the world, its future uses and the next steps that will need to be taken to make this technology successful.

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# **AMMONIA AS A REFRIGERANT**





# An overview

Together with carbon dioxide (CO<sub>2</sub>, R744) and hydrocarbons such as propane (R290), isobutane (R600a) and propylene (R1270), ammonia (NH<sub>3</sub>, R717) is one of the most commonly used natural refrigerants.

As a general classification, “natural refrigerants” are substances that exist naturally in the environment, whilst “non-natural refrigerants” or “synthetic refrigerants” are man-made chemicals, not naturally occurring in the environment.

Although the term “natural” is sometimes disputed, as these refrigerants must undergo industrial purification and manufacturing processes to be used, these substances do not contribute to ozone depletion, global warming and ecological safety, unlike man-made chemicals.

Important international agreements such as the Kigali Amendment to the Montreal Protocol (signed in 2016 and entered into force in 2019) and the European Union’s F-Gas Regulation (entered into force in 2015) are progressively phasing down the use of hydrofluorocarbons (HFCs), paving the way for a wider uptake of natural refrigerants, including ammonia, for heating, air conditioning and refrigeration applications.

# AMMONIA AS A REFRIGERANT: KEY CHARACTERISTICS

Ammonia is a colourless gas at atmospheric pressure. It is part of many natural processes, so it occurs in abundance worldwide. 5% out of more than 2 billion metric tons of ammonia in the world is man-made, and less than 2% is used for refrigeration.

The refrigerant itself consists of one atom of nitrogen and three hydrogen atoms; hence the chemical formula  $\text{NH}_3$ .

Ammonia's refrigeration code is R717. Besides water (R718) and air (R729), ammonia is the only refrigerant with zero ozone depleting (ODP) and global warming potential (GWP).

Being lighter than air, and becoming a vapour upon release, any ammonia leakage first tends to form a cloud that stays near the ground for a short time and then gets dispersed into the sky.

Ammonia is classified as a B2L refrigerant due to its low flammability threshold (2L) and higher toxicity (B) with a pungent odour.

Flammability is not a major concern when dealing with ammonia as a refrigerant.  $\text{NH}_3$  ignites at temperatures hardly encountered in conventional HVAC&R applications (above  $650^\circ\text{C}$ ) and it needs a support flame to burn. In any case, due to its slight flammability, ammonia has to be kept away from ignition sources such as hot surfaces or sparks, for example from electric switches. In facilities that use

ammonia as a refrigerant it is recommended to install ventilation and special detectors in all areas where  $\text{NH}_3$  could leak.

The use of ammonia has rather been limited by its toxicity to use in large industrial or food preservation systems (in places not directly accessible by the general public) or low-charge systems. In these contexts, ammonia is usually the primary refrigerant in secondary systems, while increasingly being used in packaged systems.

Even though small amounts of ammonia are also found in cigarette smoke and even in the air we breathe, inhalation of high quantities of  $\text{NH}_3$  can lead to serious health complications.

A number of technological solutions are implemented in the design of an ammonia system to prevent any leakage and minimize risks. These include for example the use of welded joints, hermetic or semi-hermetic compressors, use of shell and plate heat exchangers as condensers and chillers, installations of the system on a rooftop, amongst others. In addition, to ensure safe maintenance of ammonia systems technical personnel need to have adequate training and follow basic safety procedures. Other safety measures include frequent checks of the system, protecting the system from external damage, as well as a well-adjusted alarm system. If all the right measures are taken, the refrigerant is safe to use.

|                                               |               |
|-----------------------------------------------|---------------|
| Refrigerant number                            | R717          |
| Chemical formula                              | $\text{NH}_3$ |
| Global warming potential (GWP) over 100 years | 0             |
| Ozone depleting potential (ODP)               | 0             |
| Normal boiling point ( $^\circ\text{C}$ )     | -33,3         |
| Critical temperature ( $^\circ\text{C}$ )     | 133           |
| Ignition temperature ( $^\circ\text{C}$ )     | 651           |
| Critical pressure (kPa)                       | 11,41         |
| Odour threshold (ppm)                         | 5-50          |
| Safety group                                  | B2L           |
| Molecular weight (g/mol)                      | 17,031        |

Table 1: Ammonia's main characteristics.

Source: IIR (2018)



Investigations of incidents involving ammonia-based systems have indeed consistently shown a pattern of human errors, with poor maintenance and ignorance of basic safety protocols as the main causes of incidents.

To address the higher toxicity of ammonia considerable efforts have been made to develop ammonia systems with reduced refrigerant charge as the most effective way to improve safety while increasing system efficiency.

## ECONOMICAL SOLUTION

The abundance of  $\text{NH}_3$  translates into low purchasing price. Due to its excellent thermodynamic properties ammonia also has relatively low running costs. It requires less energy than most competitors, because the refrigerant has a great ability to absorb a large amount of heat when it evaporates. This makes ammonia an economical choice as a refrigerant.

Compared with other commonly used refrigerants for various applications, ammonia presents a higher thermodynamic efficiency too, as measured in Coefficient of Performance (COP) in Table 2.

| Refrigerant    | For positive temperature cold rooms (+40°C/+2°C) | For secondary fluids operation (+40°C/-5°C) | For low temperature cold rooms (+40°C/-25°C) | Blast freezers/ individual quick freezing (+40°C/-40°C) |
|----------------|--------------------------------------------------|---------------------------------------------|----------------------------------------------|---------------------------------------------------------|
| <b>Ammonia</b> | <b>6,20</b>                                      | <b>4,965</b>                                | <b>2,91</b>                                  | <b>2,06</b>                                             |
| HFC-410A       | 5,43                                             | 4,80                                        | 2,50                                         | 1,75                                                    |
| HFC-134a       | 5,88                                             | 4,67                                        | 2,70                                         | 1,88                                                    |
| HFC-404A       | 5,18                                             | 4,07                                        | 2,26                                         | 1,52                                                    |
| HCFC-22        | 5,93                                             | 4,74                                        | 2,79                                         | 1,98                                                    |

Table 2: Comparison of COP\* of ammonia with other refrigerants. Source: Paranjpey (2018)

\* Coefficient of performance (COP) is a number determining a ratio of useful heating or cooling provided to work required. Higher COP means lower operating costs.

## SHORT HISTORY OF AMMONIA AS A REFRIGERANT

Even though nowadays the market is invaded by dozens of different types of man-made chemical refrigerants (HFCs, HFOs), natural refrigerants were the only substances commonly used until 1920s.

More specifically, the use of ammonia as a refrigerant goes back in history by approximately 150 years, making  $\text{NH}_3$  the only refrigerant in use since day one.

As early as 1755, Dr William Cullen's experiments at Glasgow University identified aqua-ammonia solution as the most effective fluid for evaporative cooling and paved the way for the development of mechanical refrigeration. Cullen's phrase was that the ammonia solution he used was the "most efficacious at sinking the thermometer".

Although such pioneering studies on refrigeration and cooling were completed in the 18th / early 19th centuries, the development of  $\text{NH}_3$  as an industrial gas for refrigeration purposes took off only around the mid 19th century.

American David Boyle made the first commercial development of an ammonia compressor for refrigeration in 1872. German Carl von Linde in the early 1870s developed a similar machine but boasting more advanced mechanical design features. In 1876, Linde turned his attention from dimethyl ether to ammonia and developed a new style of a compressor and cooling system. Linde saw ammonia as being a safer alternative to dimethyl ether.

Many compressor manufacturers followed the lead of Boyle and Linde in the 1880s, so that by the end of that decade ammonia was established as the most common refrigerant for industrial refrigeration on land.

In the United States, Charles A. Zilker contributed to advancing the development of the Carré's and Boyle's machines in the 1880s. Further improvements such as high-speed engine and electric motor drivers for ammonia compressors followed.

Given the growth of agricultural production in non-European countries and the development of global trade routes, the diffusion of ammonia went on and in the 1920s  $\text{NH}_3$  had become the main option in industrial applications and on board ships.

As of 1930s chlorofluorocarbon (CFC) synthetic fluids, non-toxic and non-flammable, were introduced as «safe» replacements to methyl chloride and sulphur dioxide in domestic systems. CFCs were not in competition with  $\text{NH}_3$  at that time. It was only with the development of hydrochlorofluorocarbons (HCFCs) in 1950s that ammonia started to be squeezed out of the market by HCFC-22 and later by CFC-502. The first low pressure receiver (LPR) systems were developed with these refrigerants in 1970s. Nevertheless  $\text{NH}_3$  was never completely put out the market.

The discovery of the ozone depletion process induced by CFCs in the 1970s led to the Montreal Protocol (1987), an international agreement phasing out CFCs. The detrimental effect on global warming of their chemical "descendants", hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs), became an issue soon

after. International agreements to limit the use of such substances followed, including the Kigali Amendment to the Montreal Protocol (2016).

According to the international agreements the use of high GWP HFCs will gradually phase down by more than 80% over the next 30 years. This provides an impetus and renewed interest in ammonia and other low-GWP alternatives.

It is without doubt that in recent years attention was paid to reducing ammonia charges. It is especially thanks to the introduction of advanced control systems and electronic expansion valves that it was possible to reduce system charge as well as to use direct expansion (DX) technology to reduce system overfeeds to 1:1. In addition, the development of the low pressure receiver contributed greatly to reducing system charge to so called «critically charged». The first concrete prototypes of systems with low and ultra-low charges were realized in the late 1990s, typically as results of niche-level experiments performed at universities and R&D laboratories. In 2008, Mayekawa made the first installation of its  $\text{NH}_3/\text{CO}_2$  refrigeration system in Japan, marking the first commercially available ultra-low-charge ammonia system.

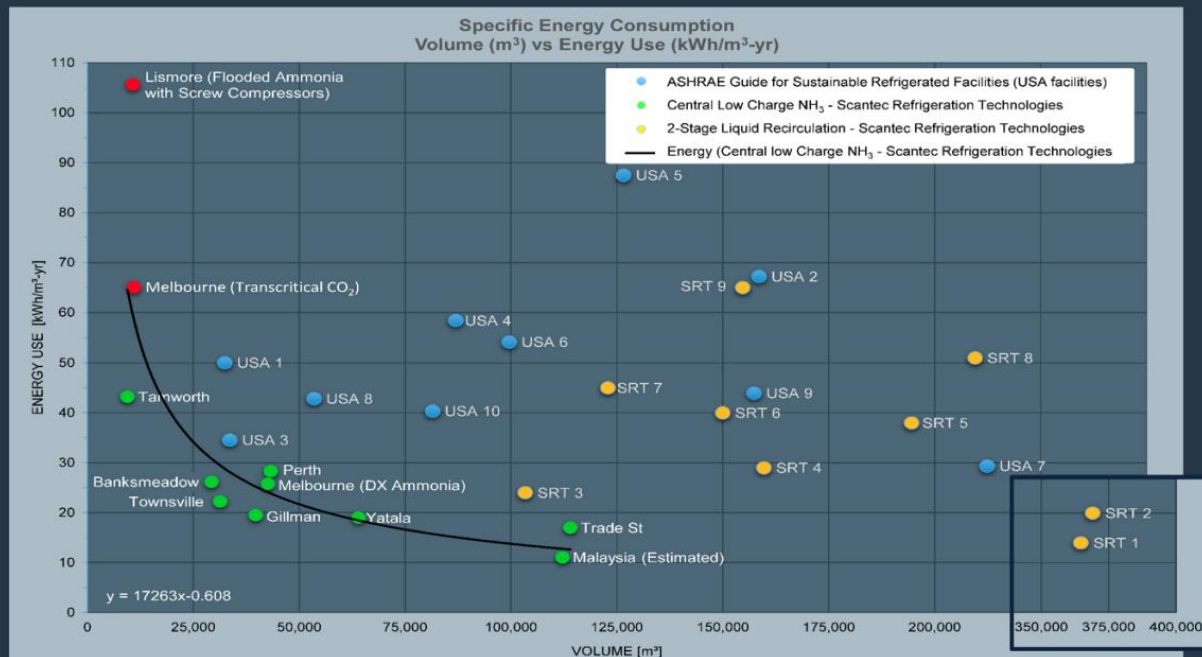
Today, the reduction of ammonia charge by 75% compared to traditional systems can be realized without compromising the system efficiency. Thanks to this, the use of ammonia is expanding to applications that were earlier considered too risky due to the toxicity issue (e.g. supermarkets, air conditioning). The increased focus on safety and development of low-charge ammonia systems is opening new market opportunities, and gaining growing support from end users and governments.



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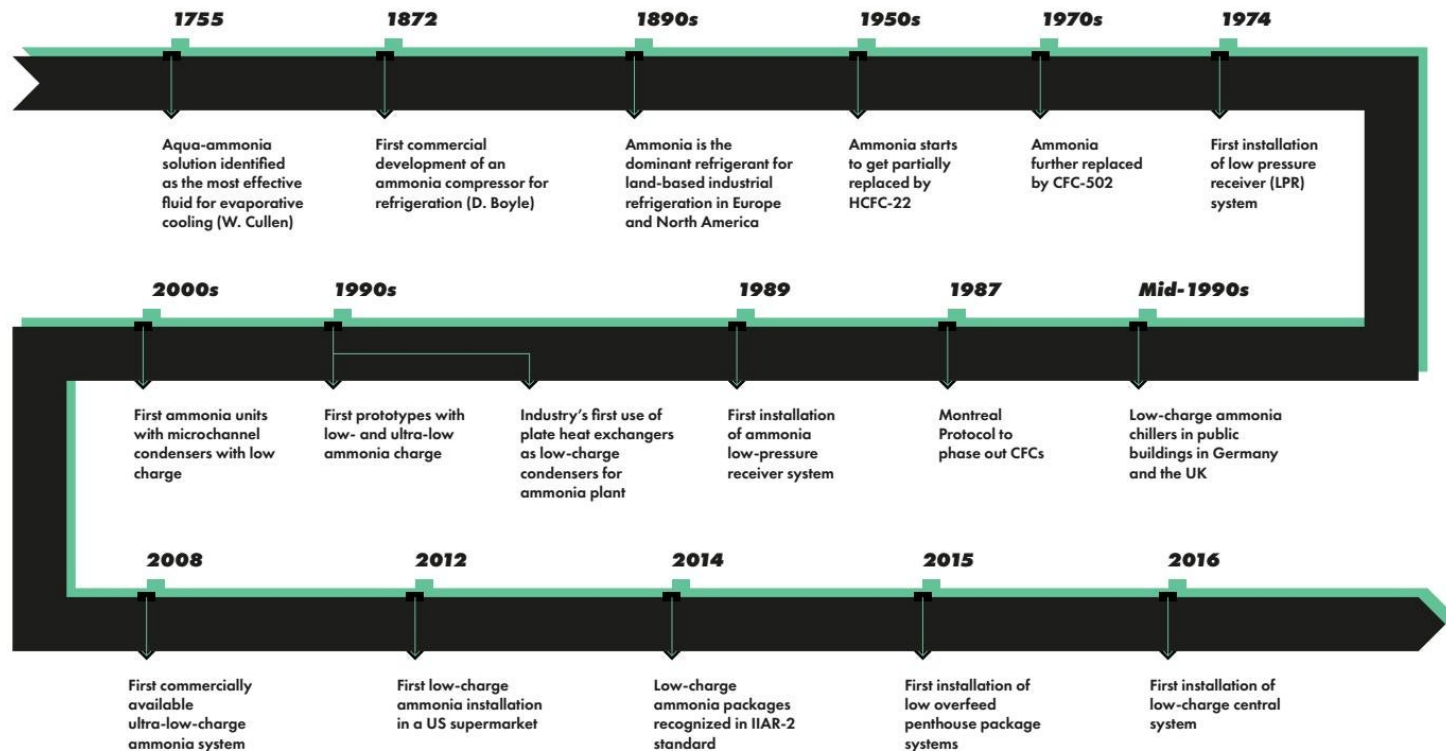
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225 Queensport Road North  
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1. Douglas T.Reindl, Todd B.Jekel, Industrial Refrigeration Consortium, March 2010. Industrial Refrigeration Energy Efficiency Guidebook, University of Wisconsin- Madison
2. ASHRAE 2018, Guide for Sustainable Refrigerated Facilities and Refrigeration Systems



# TIMELINE OF LOW-CHARGE AMMONIA DEVELOPMENT



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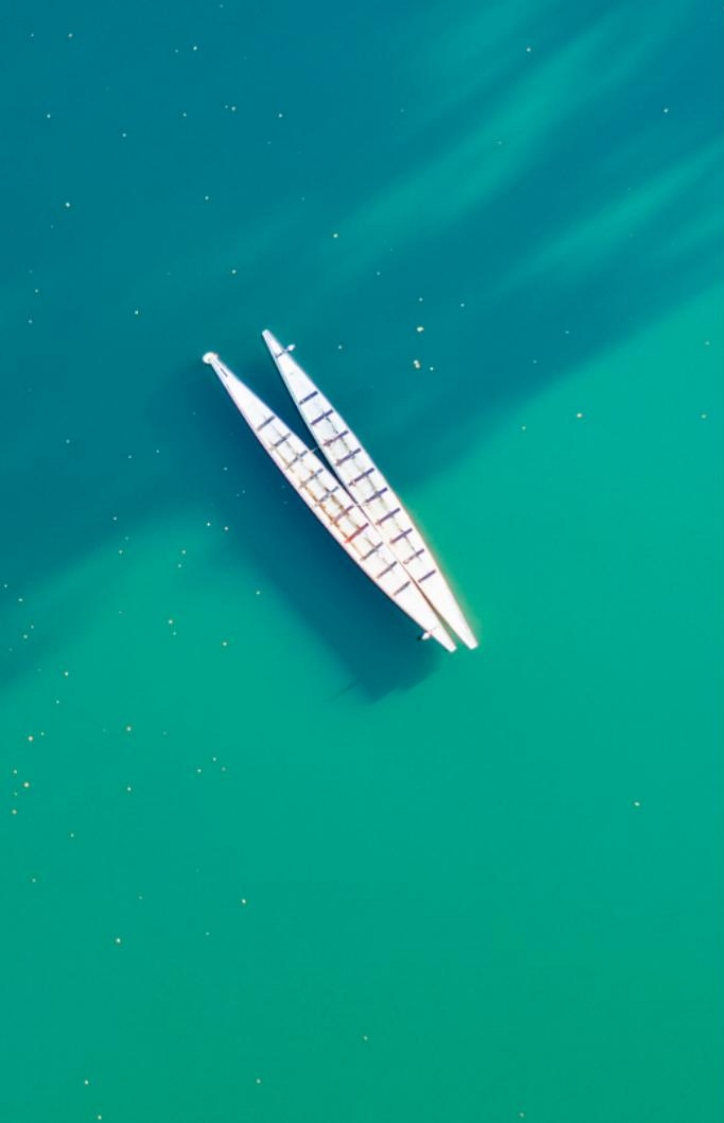


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**WHAT IS  
«LOW-CHARGE  
AMMONIA»?**





An aerial photograph of a sailboat with two sails up, sailing on a vibrant turquoise sea. The boat is positioned diagonally, moving from the bottom left towards the top right. The water's surface is textured with small whitecaps and reflects the sunlight, creating a shimmering effect. The overall tone is bright and clear.

# An overview

Ammonia, which has traditionally been associated with high toxicity that can cause risk to human health if released, has in recent years become safer thanks to efforts to reduce its charge in systems, commonly referred to as «low-charge ammonia» technology.

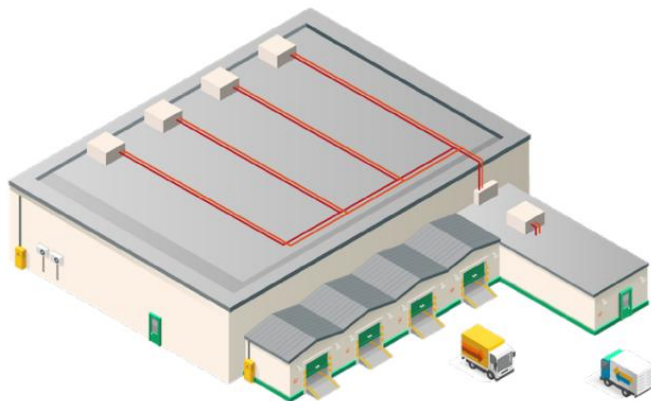
Low-charge ammonia means, essentially, lowering the charge or amount of refrigerant used within a refrigeration circuit.

The U.S.-based industry groups Global Cold Chain Alliance (GCCA), International Association of Refrigerated Warehouses (IARW) and the International Association for Cold Storage Construction (IACSC) classify three types of technology as low-charge:

- Optimized traditional system, which use enhanced controls or evaporators to lower the charge of ammonia;
- Packaged systems, which are normally installed on the roof;
- Hybrid systems, which use  $\text{CO}_2/\text{NH}_3$  in tandem to lower the charge.

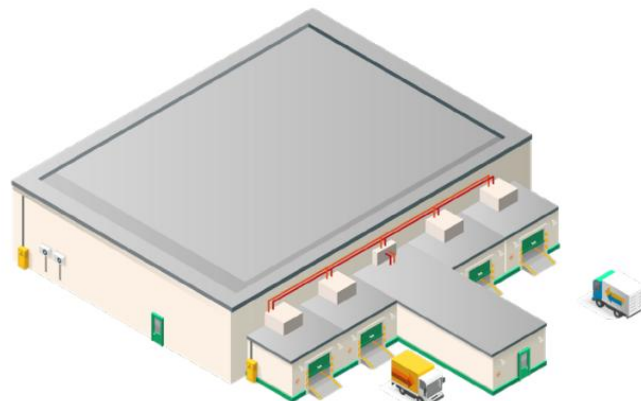
These three types of low-charge ammonia technology have been installed in food processing, food storage, data centres and pharmaceutical facilities, along with supermarkets and commercial building air conditioning.

# TYPES OF AMMONIA REFRIGERATION SYSTEMS



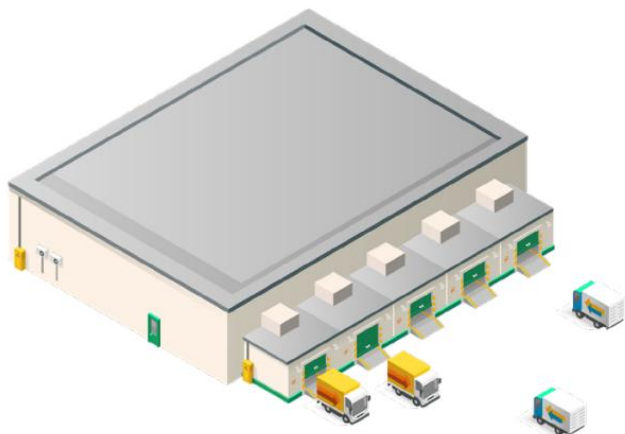
## TRADITIONAL AMMONIA SYSTEM

A traditional ammonia refrigeration system uses over 10,000 lbs (4,536 kg) of ammonia, usually with a glycol loop, in what is called a central system. This central system uses air handling units, cooling coils, etc. located throughout the facility. The main components, such as the compressors, condensers and vessels of the system, are in a central machine room. Ammonia is then piped from the machine room to the evaporators at the load.



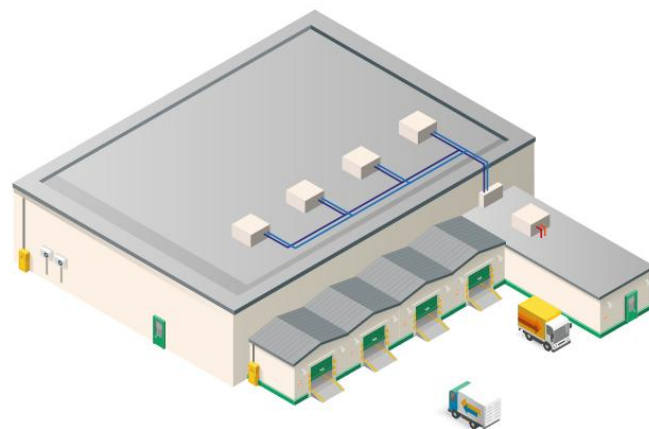
## 1/ LOW-CHARGE AMMONIA: OPTIMIZED SYSTEM

An optimized low-charge ammonia refrigeration system works by using the traditional industrial ammonia refrigeration technology and further optimizing it with low-charge components, such as specifically designed evaporators, controls, heat exchangers, compressors and condensers. A properly designed low-charge optimized system, uses less than 6,053 lbs (2,746 kg) of ammonia and requires therefore fewer vessels, fewer pipes, smaller pipe diameters and no pumps. Nevertheless it still needs a machine room.



## 2/ LOW-CHARGE AMMONIA: PACKAGED SYSTEM

*A packaged ammonia system eliminates the huge quantities of ammonia inventory, and piping, by moving to smaller self-contained systems that are usually placed on the roof/ground outside preventing any danger from leaks. These self-contained systems have about 4.3 lbs/TR (0.55 kg/kW) ammonia charge and usually combine the compressor, evaporator valve system and control systems into one easily installed and movable packaged system.*



## 3: LOW-CHARGE AMMONIA: NH<sub>3</sub>/CO<sub>2</sub> SYSTEM

*An ammonia/CO<sub>2</sub> system can come in various formats (such as cascade, CO<sub>2</sub>/NH<sub>3</sub> with pumped volatile brine and ammonia DX system using liquid CO<sub>2</sub> overfeed) but the main idea is to isolate the ammonia charge, which is usually between 4 and 6 lbs/TR (0.5 - 0.83 kg/kW), to the machine room and use the CO<sub>2</sub> as the secondary coolant that can be pumped into cold rooms in the facility. The system might require additional equipment to pump the CO<sub>2</sub>, along with extra compressors and other components for the CO<sub>2</sub> side.*



## DO WE NEED A DEFINITION?

To further foster innovation in low-charge ammonia and develop the technology for the HVAC (heating and air conditioning) market, along with increasing food and worker safety in the refrigeration industry, experts agree it is necessary to clearly determine what is «low-charge».

*“Those who want to go slow are typically not interested in non-industrial applications and do not like ultra-low-charge because that requires too much new technology. They are used to go through acceptance of ammonia systems by authorities. They do not want a definition because they do not look as good. Those who would like to see ammonia used in applications where it is not typically applied today (HVAC and other chillers) would like ammonia to be treated as any other A2L (or B2L) refrigerant.”* - Professor Pega Hrnjak, the University of Illinois at Urbana-Champaign, U.S.

If the industry continues without a definition many experts warn that «low-charge» will reduce the substance of the term.

*“The reason standards organisations, industry associations, contractors, end-users and everybody else struggle with the definition of low-charge NH<sub>3</sub> systems is that there is no clear definition of such systems. The term ‘Low-Charge NH<sub>3</sub>’ is a marketing term commonly used for any type of ammonia refrigeration system where an effort has been made to reduce the ammonia refrigerant inventory*

*by design.”* - Stefan Jensen, managing director and founder of Australia-based Scantec Refrigeration Technologies (Scantec) that has been developing ‘low-charge’ technology since 2013.

*“I would hate to say a system with 501 lbs [227.5 kg] is not a ‘low-charge system’ although, I’m not seeing that there would be any penalty for not falling into the definition of low-charge. So I’m not sure there’s any real merit in trying to set anything in stone. I think a more qualitative definition is a better approach: ‘A system that takes advantage of available and proven technology to reduce the ammonia inventory in the system such that a minimum amount of refrigerant is used while not introducing significant efficiency or reliability penalties.’”*

- Caleb Nelson, vice president, Azane Inc, the U.K.-based Star Refrigeration’s low-charge ammonia manufacturer for the U.S. market.

Any definition will have to keep in mind how a low-charge system can be safe, reliable and efficient while speaking to the amount of ammonia content that can be contained in a system (per lbs / kg) and the lbs/TR (kg/kW) ratio.

If a definition is agreed on it will lead to accelerated adoption of low-charge, provide quality technical information and allow for less burdensome codes and regulations to be used by the industry when working with ammonia.

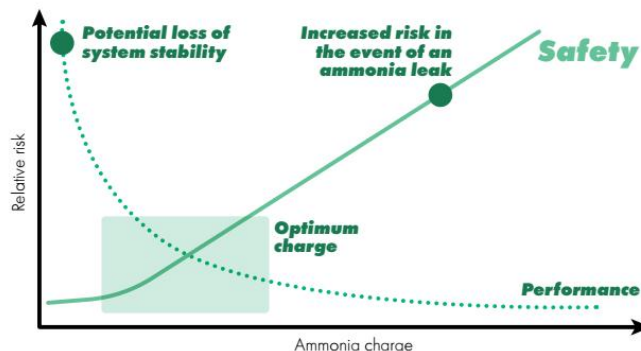


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## OPTIMIZING CHARGE



*It is important when optimizing and reducing the ammonia charge in a system to take into consideration the performance and potential loss of stability within a low-charge ammonia refrigeration system when using the lowest possible charge (less than 5.51 lbs/2.5 kg). Conversely, when using higher charges (such as over 10,000 lbs/4,536 kg) a facility operator increases the risk of ammonia to human health in the event of a leak.*

## OPTIMIZING THE AMMONIA REFRIGERANT CHARGE

Manufacturers of low-charge systems have warned, for example, if the  $\text{NH}_3$  content of a unit becomes too critical the smallest leak could cause a malfunction and failure of the refrigeration system. This tension between safety, charge and performance, nicely summed up in the graphic "Optimizing the ammonia refrigerant charge", is something that has to be grappled with if a definition is to be agreed on.

## TOWARDS A U.S. DEFINITION

Industry groups in the U.S. have been active on proposing a 'low-charge ammonia' definition but have not yet incorporated this into standards or codes.

The U.S.-based International Institute of Ammonia Refrigeration (IIAR) is seeking to meet that demand for

a 'low-charge ammonia' definition with new guidelines designed to help users safely install, operate and maintain ammonia refrigeration systems that use a charge of 500 lbs (226.8 kg) or less (under 100 lbs /45.4 kg).

These guidelines, called Ammonia Refrigeration Management - Low-Charge (ARM-LC), are a scaled-down version of the ARM guidelines the IIAR previously issued for ammonia systems using higher charges of between 500 lbs (226.8 kg) and 10,000 lbs (4,535.9 kg).

Operators and manufacturers of low-charge ammonia systems will shoulder most of the work involved in safe operation and maintenance under ARM-LC, which have ammonia charge capacity ratios of 0.5 lbs/TR (0.065 kg/kW) to 7 lbs/TR (0.91 kg/kW) compared to 20-30 lbs/TR (2.59-3.88 kg/kW) or more in conventional systems. This will be good for end users, who have never worked with ammonia systems before, as they face less of the burden to provide safety guidelines for operating

low-charge ammonia systems and can instead rely on contractors and manufacturers to explain to them the day-to-day operation of a system.

However, this is not a standard or regulation but an IIAR guideline sheet that is recommended for the low-charge ammonia industry. IIAR will await feedback on the ARM-LC published guideline note and may look to incorporate it into the ammonia safety code IIAR-2 (which already has a definition for packaged systems).

If IIAR does incorporate a definition on the charge of low-charge ammonia systems then it will provide certainty in the U.S. where the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the International Fire Code (IFC), the National Fire Protection Association (NFPA), the National Electrical Code (NEC) and the Uniform Mechanical Code (UMC) defer to IIAR standards.

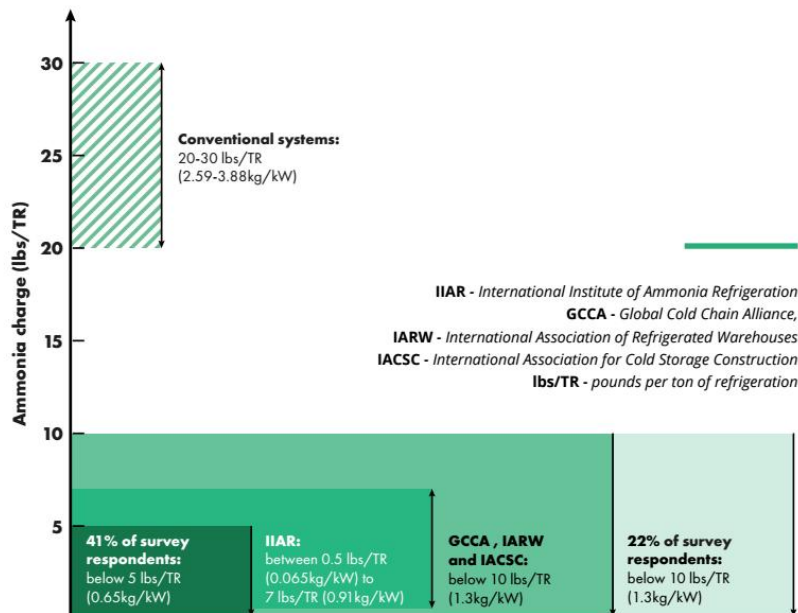
Manufacturers, regardless of the lack of incorporation into codes/standards, are citing IIAR's definition of low-charge ammonia system under the ARM-LC.

Another definition, often cited in the U.S. by manufacturers and operators at international conferences, comes from the GCCA, IARW and IACSC (that all have European branches). It states low-charge is an ammonia system that requires a charge of "no more than 10 pounds of ammonia per ton of refrigeration," or (1.3 kg/kW).

Similarly, this low-charge ammonia definition has not so far been incorporated into any code or standard either and is at the moment a guideline for the industry.



## HOW LOW IS LOW-CHARGE AMMONIA?



In another effort to bring more clarity to defining 'low-charge ammonia', leading expert Professor Pega Hrnjak from the University of Illinois suggested a definition based on three categories, namely:

- Ultra-low-charge: Up to (5.51 lbs) 2.5kg charge
- Very low-charge: Up to (110.23 lbs) 50kg charge
- Low-charge: Up to (220.46 lbs) 100kg charge

*"It is possible to reduce the ammonia charge to 18 grams per kW of cooling capacity."* - Prof. Hrnjak, University of Illinois, U.S.

## WILL THE REST OF THE WORLD JUMP ON BOARD?

If the U.S. can determine a definition then South America will likely jump on board. Currently, IIAR has chapters in Mexico, Costa Rica and Caribbean, Colombia, Ecuador, Peru, Chile and Argentina that incorporate and use its current standards.

Chile, for example, when coming up with its ammonia regulation worked with an IIAR representative from the U.S. and the IIAR Chilean chapter to develop an ammonia standard for the South American country's ministry of health.

The Association of Ammonia Refrigeration (AAR) in India, the Australian Refrigeration Association in Australia and the Chinese Association of Refrigeration in China are also allied associations of IIAR and do use a mix of international and IIAR standards so it could be predicted they might incorporate IIAR standards as well.

## TAKE CHARGE EUROPE!

In Europe IIAR standards are not followed and bodies such as the France-headquartered International Institute of Refrigeration (IIR) do not cite a specific charge limit or propose standards for the industry to follow.

"The minimum charge in a refrigeration system is the minimum charge required for stable operation of the unit over the full range of possible operating conditions," IIR's often quoted 25th Informatory Note on Refrigeration Technologies, advocates.

The body, which does represent mainly the ammonia industry in Europe – Eurammon – has so far not set best practices or proposed industry codes to follow. Instead, it relies on European standardisation bodies such as CEN/CENELEC. Nevertheless there are indications that this industry group will focus on this topic in the near future.

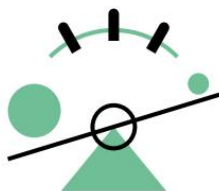
The European standard that defines safety and environmental requirements for refrigerants is EN 378 (Safety and environmental requirements for refrigerating systems and heat pumps) applicable to all types of equipment.

## HOW WOULD YOU DEFINE A LOW-CHARGE AMMONIA SYSTEM?



65%

FAVOR A DEFINITION  
BASED ON SPECIFIC  
AMMONIA CHARGE



35%

FAVORING ONE BASED  
ON TOTAL QUANTITY OF  
AMMONIA ONLY

As part of the industry-wide survey, carried out in 2018, the experts were asked 'How should low-charge ammonia be defined?'. Most of the respondents were in favour of a definition stating a specific ammonia charge (65%), with the majority (41% vs. 22%) of those opting for low-charge as 'A closed loop system requiring a specific ammonia charge below 5 lbs/TR (0.65 kg/kW) over 10 lbs/TR (1.3 kg/kW). Few (35%) favored a definition based on total quantity of ammonia.

*"The most important law we have to consider regarding the use of refrigerants and measures needs to be taken against any risks comes from EN 378. It is a [harmonized] European standard so all the countries have to follow."* - Wolfgang Dietrich, responsible for product management (chillers) at GEA.

*"There are no standards about what is low-charge."* - Alexander Cohr Pachai, Technology and product manager (CO<sub>2</sub> systems), Johnson Controls Denmark and chair of the IIR Working Group on Refrigeration Safety.

*"We should find a common 'definition' where the limit could be to still speak as 'low-charge'. Currently I saw 'low-charge' arguments at [1.15 lbs/TR] 150 g/kW cooling capacity and I know the ambitious level is [0.39 lbs/TR] 50 g/kW cooling capacity. You see there is a wide range in interpretation."* - Wolfgang Dietrich, responsible for product management (chillers) at GEA.

So far none of the EU standard bodies, industry or national groups have attempted to set out a definition for what is low-charge ammonia. Nevertheless the low-charge ammonia industry hopes they will look at this topic in the future.

## QUALIFYING THE DEFINITION

Regardless of whether definitions for low-charge go ahead, manufacturers and researchers believe it will also be necessary to define what is low-charge and what is ultra-low-charge so as to differentiate between the most ambitious technology and the least for end users.

There is also some concern that chillers and heat pumps, which can be packaged and non-packaged, should have separate definitions. In addition, some argue there should be different requirements for air-cooled or water-cooled chillers.

*"It depends from the technology used (factory-made chiller/local built chiller), the type of a chiller (water-cooled; air-cooled, evaporative condenser) and the temperature level of the application (low; AC or heat pump)."* - Wolfgang Dietrich, responsible for product management (chillers) at GEA.

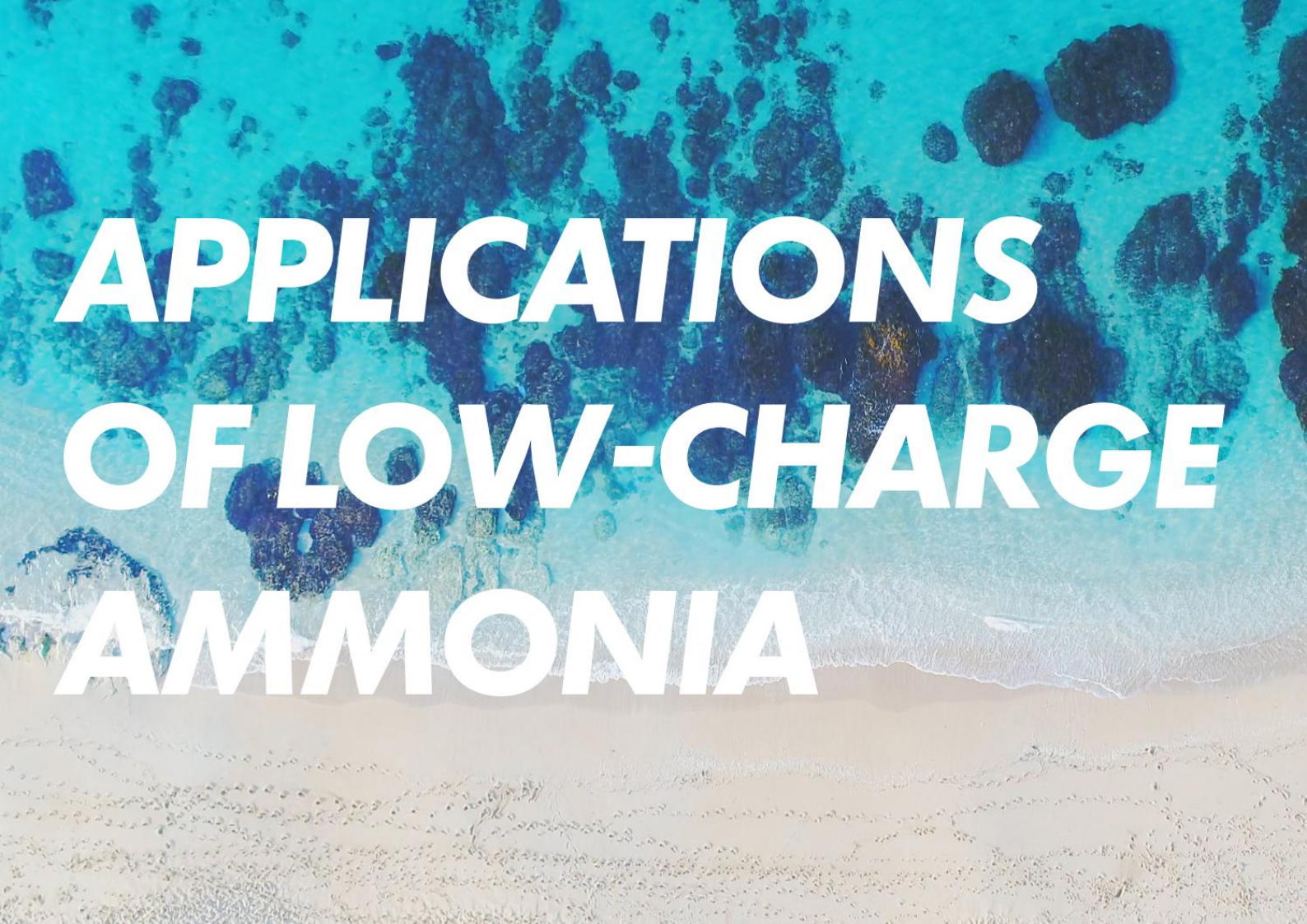
Though there is still much disagreement among manufacturers, industry bodies and researchers about what should be considered as low-charge ammonia technology it seems clear it will be down to the specific charge of ammonia in the system (lbs/TR or kg/kW).

Regardless of the inherent difficulties with proposing a low-charge ammonia definition, a clear understanding will need to be agreed so low-charge ammonia manufacturers and contractors can sell their units in confidence and end users are well informed about what they are buying.

#GoNatRefs







# **APPLICATIONS OF LOW-CHARGE AMMONIA**



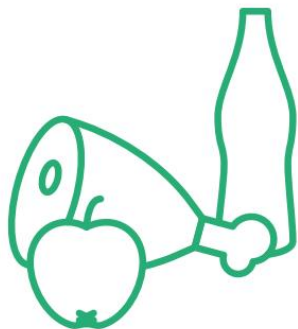
# ***An overview***

Low-charge ammonia technology has been deployed in a variety of applications across the world for many years. From food processing and data centres to pharmaceutical facilities, supermarkets, and even commercial air conditioning applications.

The following pages showcase examples of installations using different types of low-charge ammonia systems across the world, categorized by type of application.



# FOOD CHAIN



## FOOD & DRINK PROCESSING

### Meat processing

Belgian retailer Colruyt Fine Food's meat processing facility, located in Buizingen, near the Belgian capital Brussels, uses a CO<sub>2</sub> subcritical system with an ammonia refrigeration and heat pump system. The facility was opened in September 2016. The Belgian employers' organisation Agoria awarded the "Factory of the Future" award to the Fine Food meat processing facility for its use of green technology.

lowa-based meat processor Western Liberty opened a cold storage facility in Illinois in 2015. It is equipped with an ammonia system using 7,500lbs [3,402kg] of refrigerant to cool the 253,360ft<sup>2</sup> [23,538m<sup>2</sup>] facility. The ammonia charge supports a capacity of 928TR [3,267kW] with a ratio of approximately 8.1 lbs/TR [1.04kg/kW]. Liberty Cold Storage is keeping the stick-built, central-engine-room format traditionally used by industrial operators, but employs a direct expansion (DX) evaporator for both medium- and low-temperature applications.

### Fish processing (on-shore and off-shore)

Seafood processor Neptune Foods is one of a growing number of industrial refrigeration end users installing low-charge ammonia packaged units, in a major break from traditional refrigeration technology. Neptune Foods operates a seafood storage facility in an old Chicken of the Sea cannery right on the waterfront at San Pedro Bay (U.S.). The fish is stored in a 30,000ft<sup>2</sup> [2,700m<sup>2</sup>] freezer at minus 4°F [minus 20°C] before being shipped to market overseas. Neptune Foods operates two low-charge ammonia freezer units that reside outside the building next to the freezer room. Each unit requires only 20 lbs [9kg] of ammonia to generate 40TR [141kW]. In total, the system's 0.5lbs/TR [0.06kg/kW] makes it one of the lowest-charge industrial refrigeration systems in the world.

An HCFC-22 freezing system in Greenlandic vessel, "The Polar Princess", was retrofitted with 12 vertical plate freezers using an ammonia/CO<sub>2</sub> cascade freezing system. back in June 2015. It is capable of freezing 200 tons of fish a day. The ammonia/CO<sub>2</sub> freezing system consists of three ammonia screw compressors and five CO<sub>2</sub> reciprocating compressors. On the low temperature side, CO<sub>2</sub> helps to maintain freezing at a constant temperature.

### Fruits and vegetable processing

An ammonia/CO<sub>2</sub> fluid solution was commissioned in 2007 for a sophisticated high-rise fruit distribution centre near the port of Rotterdam, in the Netherlands. The building is 66ft [20m] high and can store 12,500 pallets, spread over 15 individually controlled temperature compartments. The unique design for the NH<sub>3</sub>/CO<sub>2</sub> pump-system was implemented with all 100 evaporators providing a 852TR [3,000kW] refrigeration capacity.

### Other food and drink processing

Shepherd's Processed Eggs, Spanish Fork, Utah, which processes about one million eggs per day for fresh, hard-boiled and pasteurized liquid-egg products, installed a low-charge ammonia DX system at its 10,000ft<sup>2</sup> [900m<sup>2</sup>] facility. This was in contrast to its other facilities, which run condensing units using HCFC and HFC refrigerants. The plant consists of a freezer room with two blast freezers at -15°F, -25°F [-26°C, -32°C] saturation suction and two large egg-cooler rooms at 38°F [3°C]. The total ammonia charge is only 400lbs or 3lbs/TR [182kg or 0.43kg/kW], compared to what would have been a pumped ammonia charge of 5,000lbs [2,273kg]. The first cost of the system was USD125,000 less than a pumped ammonia system, and USD180,000 less than an HFC-507 system, with lower operating and maintenance costs.



Slovakian dairy company Milsy a.s. has installed a cooling system that runs on the rarely-used refrigerant R723, a mixture of 60% ammonia (R717) and 40% dimethyl ether (RE170), which has a GWP of eight. The system provides a cooling power of 141kW [40.1TR] and a heating power of 187kW [53.2TR]. The dairy, which produces 100,000 liters [26,417 gallons] of milk per day, uses the system to cool down production and storage areas to 4°C [39.2°F]; waste heat is used for 2m<sup>3</sup> [70.63ft<sup>3</sup>] of domestic hot water, the cloak room, a 420 m<sup>2</sup> [4,520ft<sup>2</sup>] dining room and defrosting. The energy efficiency of the R723 system is 40% better than the considered HFC solution according to the system manufacturer.

Turner Dairy, a member of Prairie Farms, operates a milk and juice processing plant in Memphis, Tennessee (U.S.). The dairy installed four low-charge ammonia packaged units – two 35°F [1.7°C] penthouse coolers and two process cooling chillers – to replace an outdated ammonia refrigeration system. The total charge of the four units is 960lbs or 2.1lbs/TR [435kg or 0.27kg/kW], which is 1/10th the charge of what the system would have had in a conventional expansion system. The chillers use secondary glycol to do process cooling (for ingredient tanks and pasteurizers), eliminating ammonia from the process area. The penthouse units also confine ammonia to the roof. Cooling to the new warehouse and existing plant is done via ducted air supplied to separate rooms.

An ammonia/CO<sub>2</sub> refrigeration system was installed at a candy manufacturing facility in Irvine, California (U.S.). A study funded by Southern California Edison (SCE) on the energy performance of the system shows the system consumes 32% less energy than baseline R507A equipment running in the same facility.



## WINERIES & BREWERIES

### Winery

The Sirromet Winery in Australia replaced its existing R22 chiller with two screw compressors using ammonia refrigerant. The plant chills the Alcoof LF secondary heat exchange fluid, which is reticulated in a closed loop throughout the winery. By using an evaporative condenser, lower condensing pressures are achieved in comparison to an air-cooled system. This results in a lower compressor compression ratio with reduced energy costs for every kW of refrigeration. Based on Sirromet's average medium load run-time, the theoretical estimated cost-saving of electricity for the new ammonia chiller is up to 32% per annum.

### Brewery

Refrigeration is the biggest energy load in a brewery. Craft brewery Stone & Wood, New South Wales, Australia, installed a centralized ammonia plant in 2017. The 298TR [1,050kW] welded-plate heat exchanger package provides glycol chilling. It is fitted with an oversized surge drum and heat exchanger frame, allowing future for an upgrade of 597TR [2.1MW] including a second screw compressor and condenser. The 298TR [1,050kW] ammonia screw compressor is fitted inside a 20ft shipping container with sound attenuation, ammonia detection, ventilation system, lighting, and full access doors on three sides. The total ammonia charge is 1,320lbs [600kg], leading to a specific charge of 4.43lbs/TR [0.57kg/kW].

## FOOD STORAGE & DISTRIBUTION

### Cold storage



An Australian transport depot installed a low-charge, two-stage, central-style ammonia system at its plant in Brisbane. The refrigerated volume is around 45,000m<sup>3</sup> [1,588,950ft<sup>3</sup>]. It is a direct expansion system (DX), both on the low-temperature side and the medium-temperature side. This means that there are no ammonia pumps. The low- and medium-temperature capacities are 194/192kW [55.11/54.55TR] respectively, with future expansion to 284/241kW [80.68/68.47TR].

A rooftop, ultra-low-charge ammonia refrigeration system was installed at KPAC General Cold Storage in California (U.S.). The system powers an 82,000ft<sup>2</sup> [7,380m<sup>2</sup>] building with a total ammonia charge of 15-30lbs [7-14kg] per unit. Compared to the conventional HCFC-22-based system used before, KPAC General Cold Storage benefitted from a volume of space increased by 30% thanks to smaller size of the equipment, as well as a 30% decrease in energy costs.

Yokahama Reito Co., Ltd., one of Japan's leading food distribution and cold storage companies, has installed an ammonia/CO<sub>2</sub> packaged refrigeration system in Saitama, Japan, for the Satte Logistics Facility. The facility is a three-story, reinforced concrete building with a total floor area of about 204,833ft<sup>2</sup> [18,435m<sup>2</sup>]. Four ammonia/CO<sub>2</sub> units service a total refrigerated storage capacity of about 93,033ft<sup>3</sup> [8,373m<sup>3</sup>]. Frozen goods are stored at a temperature of -13°F [-25°C].

The first sub-critical heavy duty ammonia/CO<sub>2</sub> cascade refrigeration system for a cold storage application in the Philippines was installed in April 2016 for Allforward Warehousing Inc. The system provides cooling for storage of up to 6,000 MT of canning-grade whole tuna and tuna loins, at 25°C [77°F] below room temperature.

### Logistics and distribution centres

In March 2018, Lidl opened a new ammonia/CO<sub>2</sub> logistics centre for fruit in the Netherlands. The cold-storage facility will supply 78 national and regional Lidl distribution centres with fruit from the southern Dutch port town. The 26,900ft<sup>2</sup> [25,000m<sup>2</sup>] centre is to serve as a space to ripen bananas and other fruit like mangoes and avocados. It also functions as a European hub for frozen products. The ammonia/CO<sub>2</sub> booster installation has a capacity of 711TR [2.5MW].

A Carrefour distribution centre in Buenos Aires, Argentina opted for an ammonia/CO<sub>2</sub> system. The safe low-charge ammonia system is in the machine room. No ammonia is in the evaporators. The cold room has no need for CO<sub>2</sub> compressors and only requires a CO<sub>2</sub> pump for the brine/CO<sub>2</sub> system.



## SUPERMARKETS

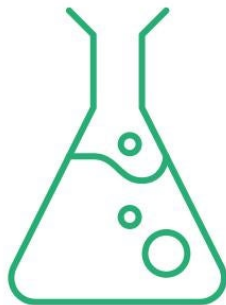
In 2015, U.S.-based retailer Piggly Wiggly installed an  $\text{NH}_3/\text{CO}_2$  refrigeration system in a supermarket in Columbus, Georgia. The retailer recorded energy savings averaging 33% over a 13-month period (October 2015 – October 2016) compared to another store in La Granda, Georgia using HFC-407A. The Piggly Wiggly store uses an ultra-low charge of ammonia (53lbs, or 0.76lbs/TR [25kg or 0.09kg/kW]), which is confined to the roof in the ammonia rack. Besides the refrigeration system the new store was equipped with a number of other energy-saving elements, including LED lights, skylights, occupancy and daylight controls, doors on display cases, and heat reclaim for hot water. However, the  $\text{NH}_3/\text{CO}_2$  system, accounting for 60% of the store's electricity consumption, was by far the most impactful on efficiency.

In California, food retailer Raley's decided to make an ammonia/ $\text{CO}_2$  overfeed system the choice for its first natural installation. The California-based chain of 123 stores has decided to implement a rooftop ammonia/ $\text{CO}_2$  refrigeration system in a new Sacramento store. The technology - ammonia DX with liquid-overfeed  $\text{CO}_2$  and no  $\text{CO}_2$  compressors - differs from the ammonia/ $\text{CO}_2$  cascade system typically used. The retailer's version includes: DX ammonia; direct-drive compressors in a two-stage configuration; liquid-overfeed  $\text{CO}_2$  for low- and medium-temperature cases and AC; water-cooled condensing and heat reclaim with plate heat exchangers; and a total ammonia charge of approximately 120lbs [55kg].

A family-owned Delhaize middle-size store in Belgium was equipped with a 110kW ammonia/ $\text{CO}_2$  system, leading to energy savings of around 40%. For this store with a sales area of 800m<sup>2</sup>, an ammonia/glycol loop is used for the medium temperature refrigeration, ammonia being confined to the machine room and glycol circulating in the store.  $\text{CO}_2$  is used for low temperature refrigeration, and the heat rejected by the  $\text{CO}_2$  condensers is recovered. 40kg of ammonia are used and confined to the machine room with a total cooling capacity of 110kW; this leads to a specific ammonia charge of only 40g/kW.



# INDUSTRY, SPECIAL APPLICATIONS & SPORTS



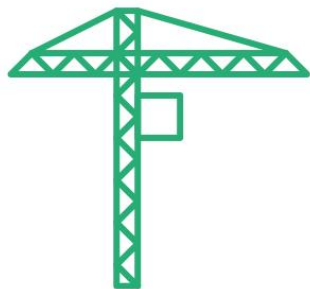
## INDUSTRIAL / CHEMICAL PROCESSING

Sylvan Pty Ltd, New South Wales, Australia uses an ammonia-glycol chiller for cooling of nutrients used for mushroom production. A DX system was installed, in combination with a dry cooler to provide the heat rejection. Compared to HFC-134a, the coefficient of performance (COP) could be increased by 39% (from 3.78 to 5.25). At approximately 2,500 full-load hours and with 20AUD/kWh, an annual saving of AUD10,670 was achieved. The chiller was designed as compact as possible, resulting in a charge of 10.78lbs [4.9kg] for 30TR [106kW] cooling capacity, which represents 0.36lbs/TR [0.05 kg/kW].



## PHARMACEUTICAL PROCESSES & LABORATORIES

Pharmaceutical company Roche installed a refrigeration package system using about 0.12kg/kW [1lb/TR] in one of its facilities in Puerto Rico. The refrigerant is confined to the packaged refrigeration system, and does not reach operation spaces. The whole system was factory-built and ready to operate when it was delivered to the site. Ready-to-operate packages allow simultaneous construction of the site foundation and equipment.



## CONSTRUCTION

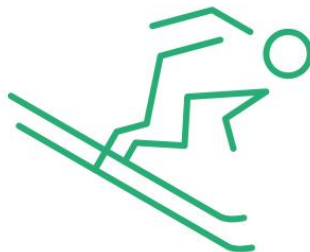
Japanese Chemical Grouting Co., Ltd., specializes in construction projects across Japan for buildings, dams, slopes and soil cleansing, and decontamination. It installed an ammonia/CO<sub>2</sub> industrial refrigeration system for an underground tunnel construction in 2017. The company claims the new system achieved 40% savings in energy consumption compared to the traditional HCFC-22-based system originally installed. This particular project dealt with soil freezing during the construction of an underground tunnel in a metropolitan area in Japan. The project began in January 2017 and was completed in March 2017. One of the biggest benefits the company saw by using the ammonia/CO<sub>2</sub> system was the reduction of the project's run time by 40% (39 days). The system's compact size greatly simplified the disassembly and removal process. Improved performance ranked among the other benefits.



## ICE RINKS

At the Covent Garden Market Rotary Rink, an outdoor ice rink in London, Ontario (Canada) installed a low-charge (65lbs [30kg]) ammonia/glycol system, which is owned and managed by the City of London, Ontario. The ice rink was installed in November 2017, as a replacement for an 18-year-old system with 700lbs [318kg] of HCFC-22 refrigerant. The system includes four "smart" products, two 50HP compressors, one chiller and one plate-and-frame condenser. According to the London Free Press, the system cost USD450,000.

Great Britain's (Team GB) wheelchair curling team, as well as its Olympic curling team, skate on a low-charge ammonia-based ice rink. The system is installed at the U.K.'s first National Curling Academy (NCA) in Stirling, Scotland since Summer 2017 when it opened, in addition to other ice rinks in Scotland. It uses an air-cooled chiller package that uses ammonia in-directly with a refrigerant charge of just 1.39lbs/TR [0.18kg/kW].



## SKI SLOPES

In Milton Keynes, England, the 558ft [170m] long Snozone ski slope was equipped with two 102TR [360kW] ammonia-glycol chillers. The ammonia charge per chiller is 187lbs [85kg], and its specific charge is 1.83lbs/TR [0.24kg/kW]. The concentration of glycol was reduced compared to the former installation with HFC-404A. A security fence was built around the system. Together with some other improvements in the system design, the energy consumption could be reduced by approximately 50%.

# CITY & BUILDINGS



## HOSPITALS

Uzbekistan's first low-charge ammonia air-conditioning (AC) system, installed between 2016 and 2017, is running at the Republican Research Center for Emergency Medicine (RRCEM) – an emergency hospital and research facility in Tashkent. The UN Development Programme (UNDP) Uzbekistan and the Global Environment Facility (GEF), a public-private NGO, funded 61% of the total USD512,000 cost of the equipment, while the remainder (39%) was contributed by RRCEM. Two outdated chillers on HCFC-22 in the centralised air-conditioning system were replaced with low-charge ammonia chillers. A total of 482TR [1,695kW] of cooling is provided by the two chillers, running in tandem, with just 176lbs [80kg] of ammonia charge to provide air conditioning to 250,000 patients and 2,600 employees annually.



## OFFICE BUILDINGS

Two HCFC-22-based air-conditioning systems in a local Council administration building in South East Queensland, Australia, were replaced by an ammonia-based, central air-conditioning installation. The new system comprises two identical water-cooled, low-charge water chilling units employing ammonia. The combined refrigeration capacity of the two units is approximately 341TR [1,200kW]. Each chiller is fitted with a shell-and-tube type discharge gas desuperheater. These heat exchangers recover heat from the discharge gas leaving the compressors prior to the gas entering the condensers. In the future, the heat recovered will be used for heating hot water and for various other purposes, yet to be determined by the Council.





## OTHER BUILDINGS

Low-charge ammonia chillers are being used to safely provide air conditioning for a bakery in a populated area of Portland, Ore. The bakery plant uses three low-charge-ammonia chillers, each at 300TR [1,055kW] and 450lbs [204kg] of ammonia (1.5lbs/TR [0.19kg/kW]), which received jurisdictional acceptance. They have four levels of ammonia release prevention, three levels of leak detection, and fresh air dilution. Each chiller has a TEWI (total equivalent warming impact) that is 32% less than that of a water-cooled HFC-507 unit.

A low-charge ammonia packaged chiller is providing air conditioning at a Campbell Soup plant in Ohio. The chiller/air handler delivers comfort cooling to a labeling and packaging section of the building where the red-and-white labels are applied to soup cans – and where a cool environment is needed to ensure proper adherence of the

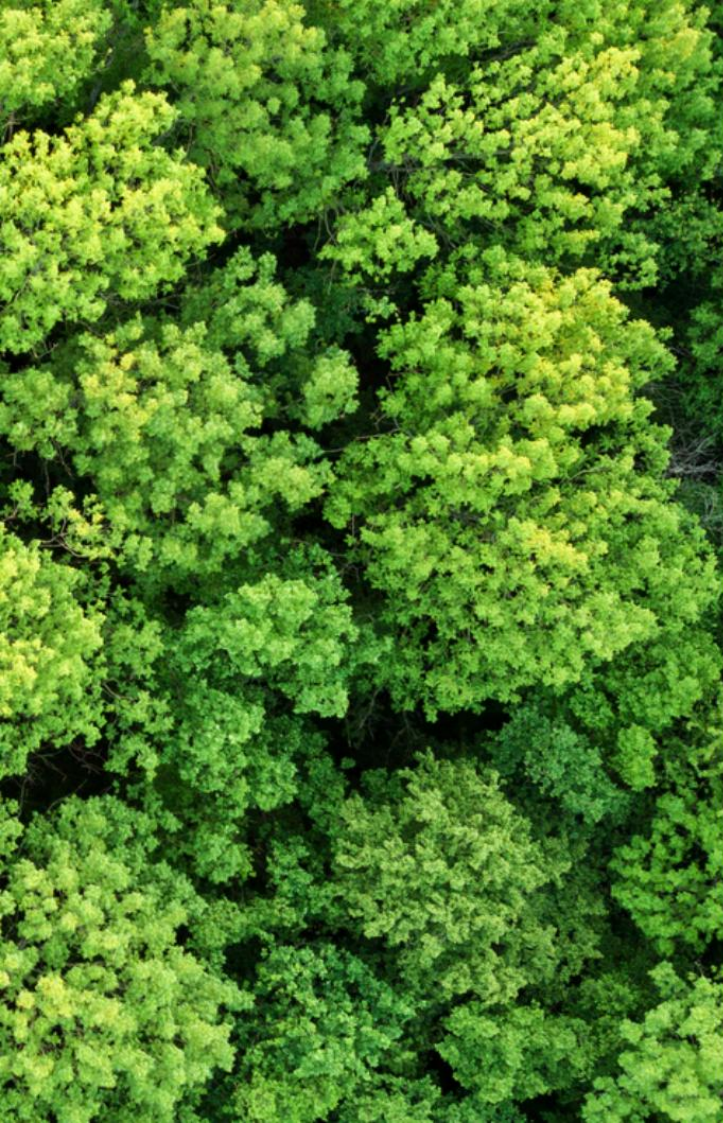
labels to cans. Using a flooded plate heat exchanger, 450lbs [204 kg] of ammonia in the chiller cools a glycol solution to 44°F [6.7°C], and the glycol is piped to an air handler in the building, where the air is cooled to about 65°F [18.3°C].

A major U.S. retailer installed low-charge DX ammonia chillers to provide air conditioning in office space at about 10 warehouse locations. The rooftop chiller is designed with only 1lb/TR [0.13kg/kW] of ammonia, which is confined to the unit; it pumps chilled water to an air handling unit, which delivers cool air to the office space. The typical chiller contains about 100lbs [45kg] of ammonia and employs a variable frequency drive (VFD) screw compressor and electronically commutated motor (ECM) motors. The AC chillers are replacement units for HCFC-22 systems using 180-220lbs [82-100kg] of refrigerant.



# ***REGULATIONS AND STANDARDS***



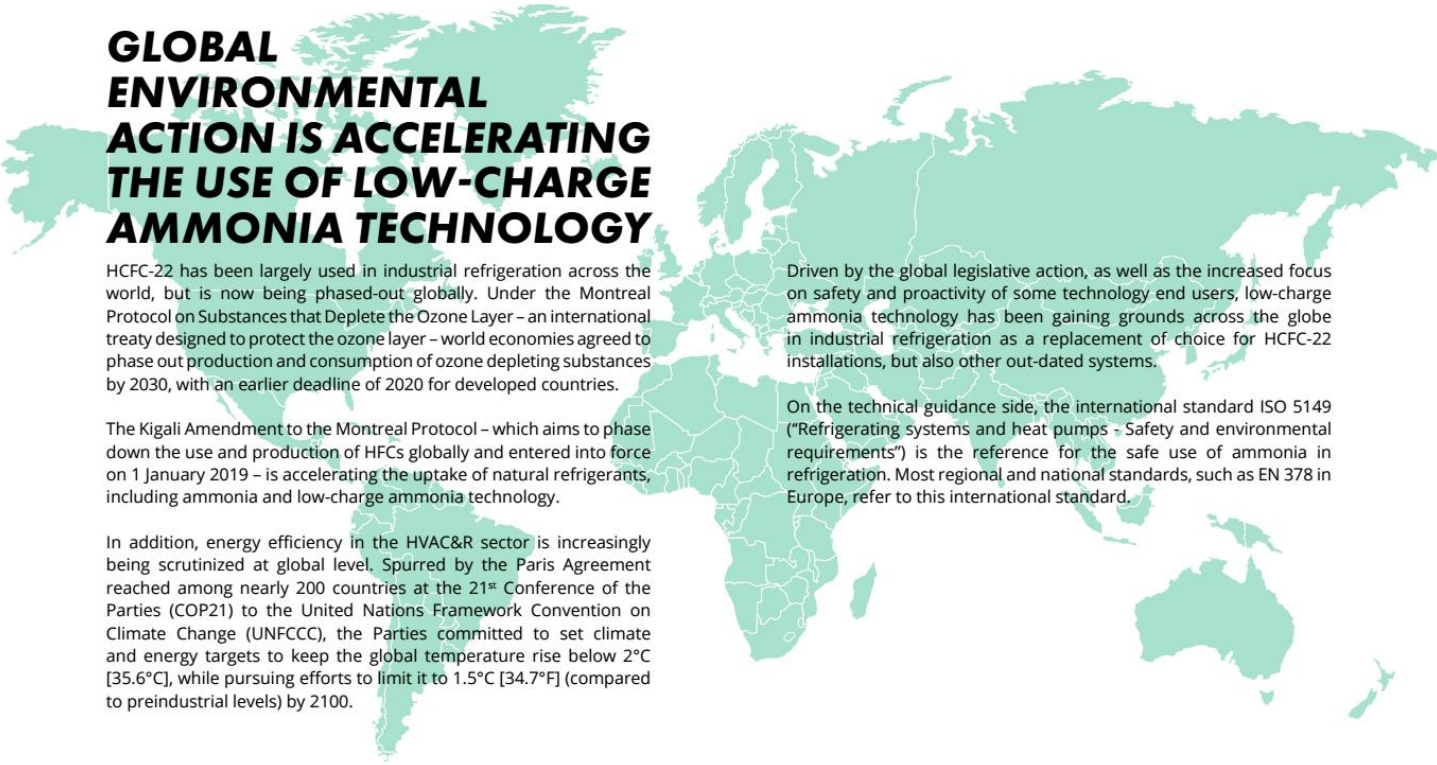


# ***An overview***

This chapter provides the regulatory framework governing the use of ammonia as a refrigerant around the world.

The use of traditional ammonia systems requires additional regulatory requirements in most countries, due to the refrigerant's classification as a hazardous and caustic fluid in its concentrated form. Those regulatory requirements are usually based on the charge of ammonia, requiring more stringent rules the larger the system is. Therefore, low-charge ammonia systems usually benefit from lighter controls.





## **GLOBAL ENVIRONMENTAL ACTION IS ACCELERATING THE USE OF LOW-CHARGE AMMONIA TECHNOLOGY**

HCFC-22 has been largely used in industrial refrigeration across the world, but is now being phased-out globally. Under the Montreal Protocol on Substances that Deplete the Ozone Layer – an international treaty designed to protect the ozone layer – world economies agreed to phase out production and consumption of ozone depleting substances by 2030, with an earlier deadline of 2020 for developed countries.

The Kigali Amendment to the Montreal Protocol – which aims to phase down the use and production of HFCs globally and entered into force on 1 January 2019 – is accelerating the uptake of natural refrigerants, including ammonia and low-charge ammonia technology.

In addition, energy efficiency in the HVAC&R sector is increasingly being scrutinized at global level. Spurred by the Paris Agreement reached among nearly 200 countries at the 21<sup>st</sup> Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC), the Parties committed to set climate and energy targets to keep the global temperature rise below 2°C [35.6°C], while pursuing efforts to limit it to 1.5°C [34.7°F] (compared to preindustrial levels) by 2100.

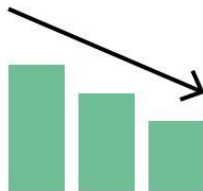
Driven by the global legislative action, as well as the increased focus on safety and proactivity of some technology end users, low-charge ammonia technology has been gaining grounds across the globe in industrial refrigeration as a replacement of choice for HCFC-22 installations, but also other out-dated systems.

On the technical guidance side, the international standard ISO 5149 ("Refrigerating systems and heat pumps - Safety and environmental requirements") is the reference for the safe use of ammonia in refrigeration. Most regional and national standards, such as EN 378 in Europe, refer to this international standard.

## SURVEY: KEY POLICY DRIVERS FOR THE UPTAKE OF LOW-CHARGE AMMONIA



**Bans on HFCs with high global warming potential (high GWP)**



**Gradual phase down of HFCs**



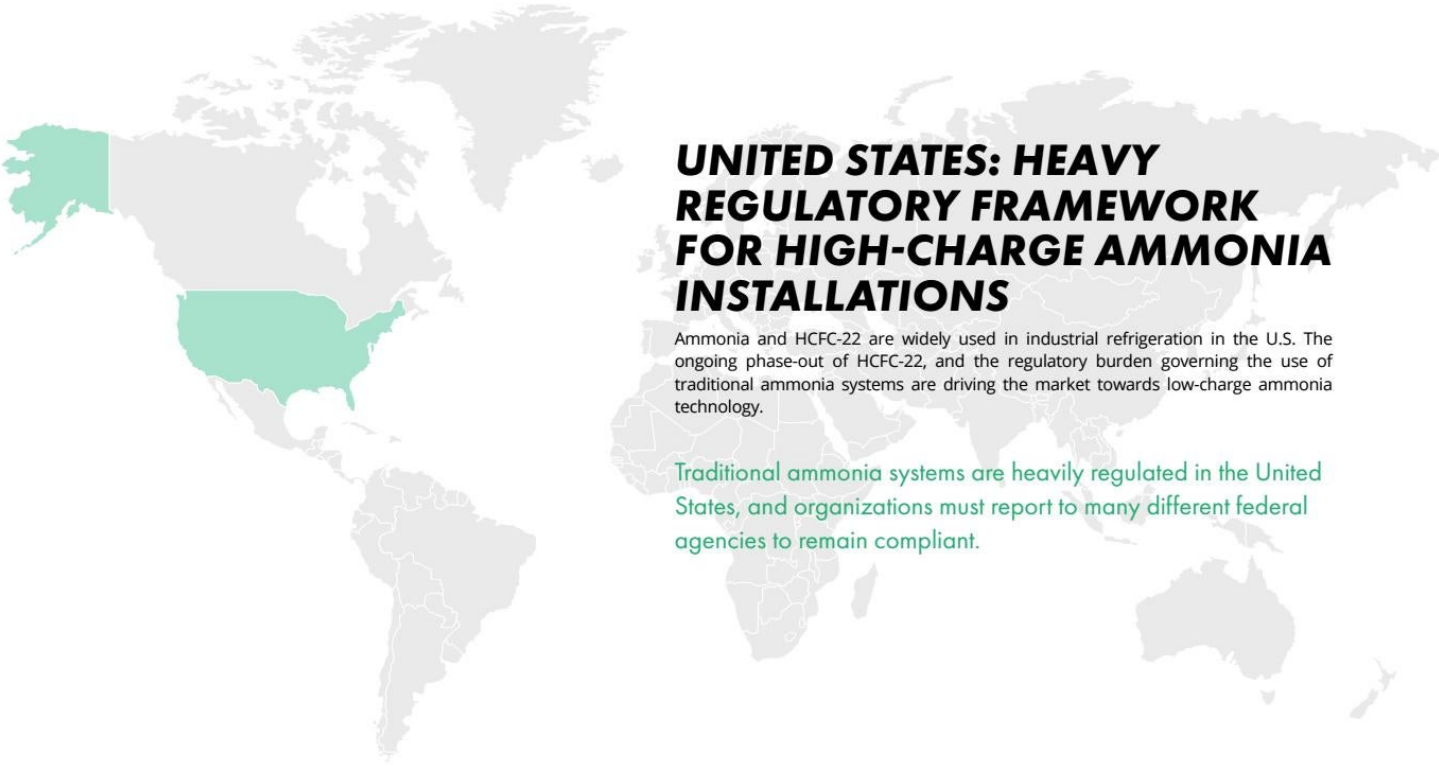
**Financial incentives for energy efficient installations**



**Minimum energy efficiency requirements**

Number of respondents: 815

Policy is traditionally among the most important drivers when it comes to shifting to new technologies and it is no different in case of low-charge ammonia systems. shecco asked industry experts in a global survey about the most effective policy measures for the uptake of low-charge ammonia technology. The findings from more than 800 respondents indicate that different types of measures play an important role and the effectiveness might depend on the regional circumstances and other factors. While all listed types of policy measures ranked similarly on scale of importance, bans on HFCs with high global warming potential received slightly more votes than others.



## **UNITED STATES: HEAVY REGULATORY FRAMEWORK FOR HIGH-CHARGE AMMONIA INSTALLATIONS**

Ammonia and HCFC-22 are widely used in industrial refrigeration in the U.S. The ongoing phase-out of HCFC-22, and the regulatory burden governing the use of traditional ammonia systems are driving the market towards low-charge ammonia technology.

Traditional ammonia systems are heavily regulated in the United States, and organizations must report to many different federal agencies to remain compliant.



# Azanechiller 2.0

Ultra-efficient, Low-charge ammonia chillers



## Flatbed Condenser

Stainless steel tube condenser for long life. Full perimeter maintenance access.

## Variable Speed Fans

EC variable speed fans with Axitop diffusers (option) for low fan power and improved air flow.

## Stainless Steel Control Panel

Allen-Bradley PLC control provides optimized performance based on ambient temperature and cooling load. Touch screen HMI, remote access, and condition based monitoring are available through broadband.

## Compressor

Standard variable speed, reciprocating compressor(s) provide linear capacity, extended compressor life, and COPs approaching 11.9 at part load.

Single or twin compressor options available.

## Heat Exchanger

Fully welded plate and shell heat exchanger. High integrity design, giving low refrigerant charge and minimizes risk of leakage.

## Drive Motor

VFD NEMA Premium Efficiency IE3 drive motor with flange mounting to ensure accurate alignment.

## Heat Recovery

Optional heat recovery from ammonia hot gas system.

World-leading manufacturers of low charge ammonia refrigeration solutions.

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Due to its toxicity, ammonia installations are regulated more strictly and additional requirements might apply. These additional requirements are not necessarily an obstacle, but they can present a large burden to manufacturers and facilities. The use of low-charge ammonia technology allows facility owners to avoid or reduce the regulatory requirements detailed below, as they do not pass the charge threshold enabling authorities to enforce the regulations.

Following the commitments under the Montreal Protocol, the U.S. Environmental Protection Agency (U.S. EPA) regulations issued **under Section 601-607 of the Clean Air Act** gradually phase out the production and import of ozone-depleting substances (ODS), including HCFC-22 from 1 January 2010 until 1 January 2030. The next step in the phase-out process will be on 1 January 2020, with a planned 99.5% reduction of the production and import of HCFC-22. As existing HCFC-22 equipment is reaching its end of life, ammonia-based systems are well positioned to be taken up as replacement technologies.

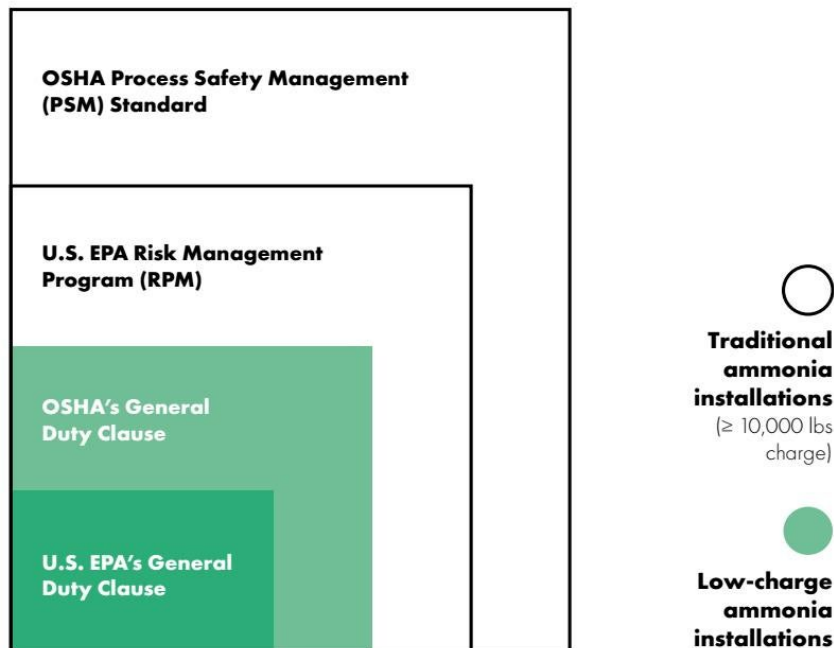
## U.S.: REGULATORY OVERVIEW

At federal level, systems with **ammonia charges above 10,000lbs [4,536kg]** may be subject to:

- **OSHA Standard “Process Safety Management of Highly Hazardous Chemicals” (PSM):** The minimum requirements for compliance are for a plant to develop, implement and maintain 14 elements listed in the PSM Program, such as the development of standard operating procedures including safe work practices, appropriate training for contractors and personnel, as well as reporting audit requirements to certify the plant complies with PSM rules.
- **The EPA “Risk Management Program for Chemical Accidental Release Prevention” (RMP):** The focus of the RMP regulation is to prevent accidental chemical releases and minimize their impact. Ammonia refrigeration facilities must comply with additional requirements detailed in the *Supplemental Risk Management Program Guidance for Ammonia Refrigeration Facilities*. EPA’s RMP duties apply to all ammonia refrigeration systems containing 10,000lbs [4,536kg] or above.
- **The Emergency Planning and Community Right to Know Act (EPCRA) Section 313, pursuant to the Homeland Security Appropriations Act of 2007:** EPCRA Section 313 sets reporting requirements to the EPA. The EPCRA also requires that facilities that are subject to Section 313 liaise with their Local Emergency Planning Committee and their State Emergency Response Commission.
- **Chemical Facilities Anti-Terrorism Standards implemented pursuant to the Homeland Security Appropriations Act of 2007:** Facility owners must report to the Department of Homeland Security (DHS) the total mass quantity of ammonia within the system and the physical state, temperature, and pressure as it exists in the vessel(s) downstream of the condenser(s).

TYPICALLY, FACILITIES USING LOW-CHARGE AMMONIA EQUIPMENT ARE NOT SUBJECT TO **PSM** AND **RMP** REQUIREMENTS

Facilities using low-charge ammonia equipment are typically not subject to OSHA's PSM and EPA's RMP requirements as their ammonia charge is less than 10,000lbs [4,536kg]. However, irrespective of the ammonia amount being used, employers are subject to both **OSHA** and **EPA's General Duty Clause**. Both OSHA and EPA can apply their General Duty Clauses to ensure employers provide a workplace free from recognized hazards.





## IIAR CREATES GUIDELINES FOR LOW-CHARGE AMMONIA

In response to the growing demand for low-charge ammonia installations, which end users increasingly recognize as an effective way to reduce the regulatory burden, the International Institute of Ammonia Refrigeration (IIAR) has developed guidelines to help users safely install, operate and maintain ammonia refrigeration systems that use a charge of 500lbs [226.8kg] or less (and under 100lbs [45.5kg] in the next step).

These guidelines, called “Ammonia Refrigeration Management – Low Charge (ARM-LC)”, are a scaled-down version of the ARM guidelines the IIAR had previously issued for ammonia systems using charges of between 500lbs [226.8kg] and 10,000lbs [4,536kg].

The overarching goal of the ARM-LC guidelines is to help end users comply with the General Duty Clause of the Occupational Safety and Health Act, which requires that a place of employment be “free from recognized hazards.”

Under the guidelines, contractors that install low-charge ammonia systems will still be responsible for training their on-site employees, although the training would be significantly less intensive than for large, industrial facilities that use bigger ammonia charges. Training of employees should revolve around a few key areas, including the safety hazards of ammonia, monitoring the system and steps to take in emergency.

The ARM-LC guidelines recommend an audit of the system every five years.

## CALIFORNIA IMPOSES STRICTER MEASURES ON AMMONIA

California is particularly stringent on the use of ammonia in refrigeration compared to the federal regulations. The **California Accidental Release Prevention (CALARP)** sets a threshold quantity limit for anhydrous ammonia at 500lbs [226.8kg], compared to the 10,000lbs [4,536kg] limit at federal level.

Facilities based in California must be inspected by the Administrative Agency every three years, while an updated Refrigerant Management Program (RMP) must be submitted to the Administrative Agency every five years. The facility also must do a compliance audit once every five years at least, and the RMP must contain two release scenarios in case of an accident.

The stringent requirements on ammonia installations in California are the key driver behind the increased uptake of innovative low-charge ammonia systems compared to other U.S. States.

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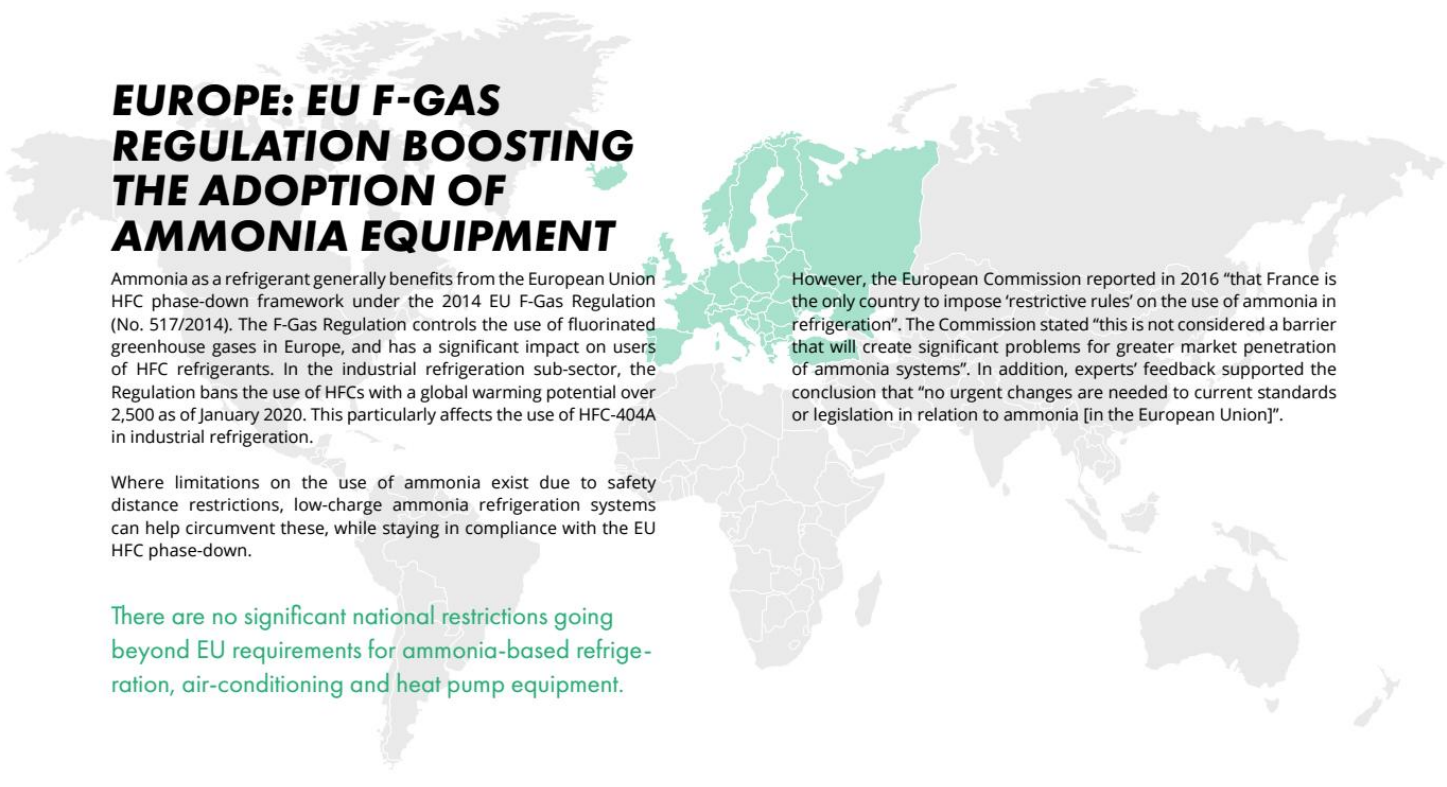
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## EUROPE: EU F-GAS REGULATION BOOSTING THE ADOPTION OF AMMONIA EQUIPMENT

Ammonia as a refrigerant generally benefits from the European Union HFC phase-down framework under the 2014 EU F-Gas Regulation (No. 517/2014). The F-Gas Regulation controls the use of fluorinated greenhouse gases in Europe, and has a significant impact on users of HFC refrigerants. In the industrial refrigeration sub-sector, the Regulation bans the use of HFCs with a global warming potential over 2,500 as of January 2020. This particularly affects the use of HFC-404A in industrial refrigeration.

Where limitations on the use of ammonia exist due to safety distance restrictions, low-charge ammonia refrigeration systems can help circumvent these, while staying in compliance with the EU HFC phase-down.

There are no significant national restrictions going beyond EU requirements for ammonia-based refrigeration, air-conditioning and heat pump equipment.

However, the European Commission reported in 2016 “that France is the only country to impose ‘restrictive rules’ on the use of ammonia in refrigeration”. The Commission stated “this is not considered a barrier that will create significant problems for greater market penetration of ammonia systems”. In addition, experts’ feedback supported the conclusion that “no urgent changes are needed to current standards or legislation in relation to ammonia [in the European Union]”.



## EU: REGULATORY OVERVIEW

The specific legislation and regulatory requirements applied in the European Union for the safe use of ammonia as a refrigerant are detailed below.

Companies operating in the European Union and using or producing ammonia-based commercial and industrial refrigeration equipment must comply with the **ATEX Equipment Directive** (ATEX/94/EC). ATEX/94/EC may apply to systems installed in facilities or locations that contain potentially explosive environments. Locations for “standard” ammonia-based refrigeration systems are “normally” not classified as hazardous areas. Ammonia is classified as a non-flammable refrigerant – under ATEX requirements.

In addition, ammonia systems must be installed in compliance with the **ATEX Workplace Directive** (ATEX 99/92/ED). This regulation requires Hazardous Area Classification (HAC) to be carried out where there may be a risk of explosion due to the presence of flammable substances in the form of gases, vapours, mist of dust – including ammonia. The regulation also requires that to ensure safe operation, any equipment (both electrical and non-electrical) used in a classified area falls within the scope of the regulation and must therefore be suitable for use in the respective zone.

Area classification is carried out by reference to codes. **Standard EN 60079-10** (Explosive atmospheres) establishes a quantitative method to identify sources of release of flammable gas, vapour or mist. EN 60079 is harmonized with the ATEX Directive. The standard covers electrical systems used in potentially explosive atmospheres, and establishes three different categories of environments that present certain dangers when using electrical equipment. EN 60079 also sets technical requirements for electrical equipment used in these environments.

**Standard EN 378** (Refrigerating Systems and heat pumps – Safety and environmental requirements) applies to nearly all refrigeration systems within all European Union member states. The Standard includes specific provisions related to ammonia use as a refrigerant, including leak monitoring. EN 378 states that leaks and other faults in the system must be remedied immediately by a qualified person.

All refrigeration and air conditioning systems must comply with the requirements of the **EU Pressure Equipment Directive (PED)** (97/23/EC). For most systems, this means manufacturers must identify the maximum system pressure (PS) of their equipment, ensure all components are suitable for PS and adequately protected, identify the hazard category the equipment falls into, ensure materials are up to the correct standard and traceable, ensure brazers and welders are qualified and work to an appropriate standard, pressure test the system correctly, and CE mark the system if necessary. Under Article 9 of the PED, ammonia is considered a group 1 fluid, due to its toxicity and flammability.

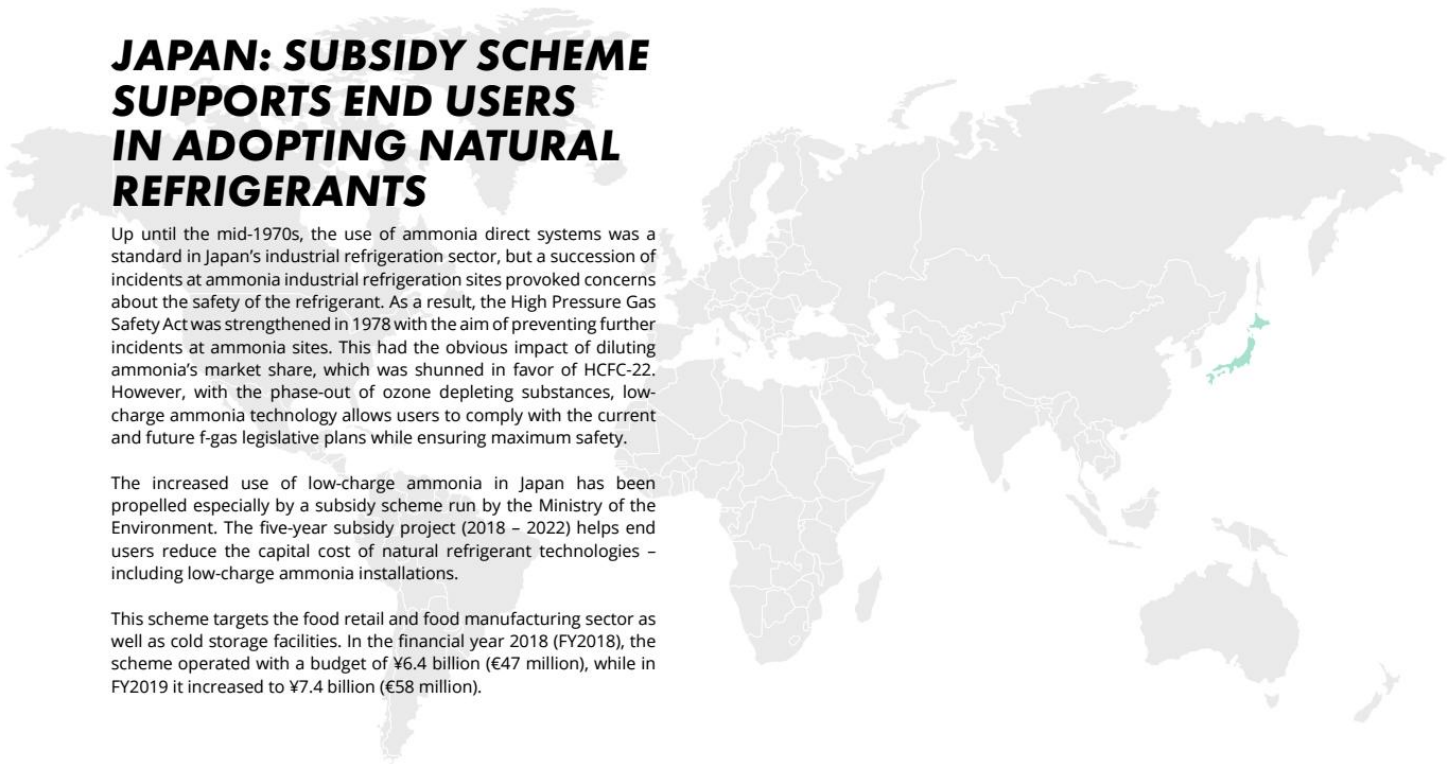
## FRANCE: SPECIFIC REQUIREMENTS FOR AMMONIA-BASED INSTALLATIONS

In France, facilities using ammonia-based systems with a charge from 150kg to 1.5 tons are subject to mandatory reporting and periodic inspections by approved organisations (Article L. 512-11 of the French Environment Code).

Users intending to equip their site with a refrigeration system or systems whose total charge is greater than to 1.5 tons of ammonia require authorization from the prefecture (which represents the French state in each of France's regional *départements*) before they can do so.

The European Union recognizes that French legislation represents a barrier for a wider uptake of ammonia-based technology in the country. French trade unions have been advocating for an administrative easing to encourage the use of ammonia in industrial refrigeration even before the adoption of the EU F-Gas Regulation.

However, ammonia installations in France are often eligible for an Energy Saving Certificate (CEE), thanks to the heat recovery offered by these technologies. CEE is an energy-efficiency bonus issued by the state that finances energy efficiency-related works.



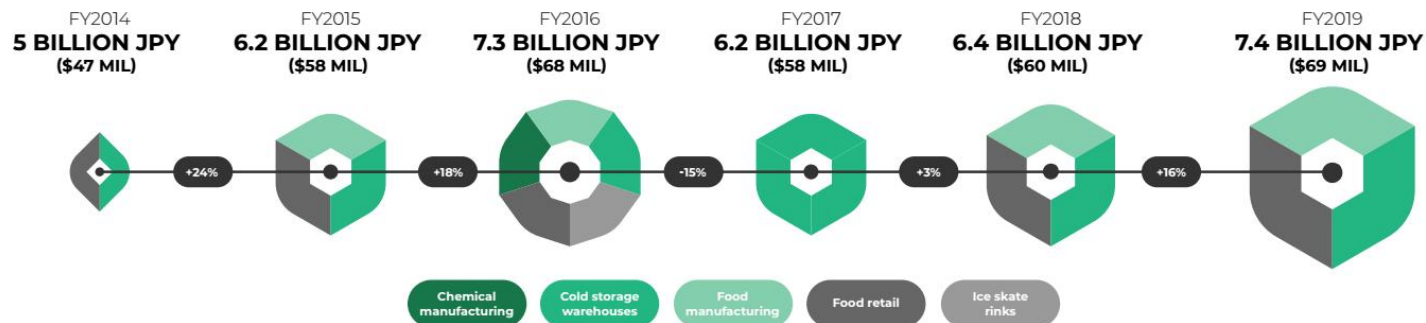
## **JAPAN: SUBSIDY SCHEME SUPPORTS END USERS IN ADOPTING NATURAL REFRIGERANTS**

Up until the mid-1970s, the use of ammonia direct systems was a standard in Japan's industrial refrigeration sector, but a succession of incidents at ammonia industrial refrigeration sites provoked concerns about the safety of the refrigerant. As a result, the High Pressure Gas Safety Act was strengthened in 1978 with the aim of preventing further incidents at ammonia sites. This had the obvious impact of diluting ammonia's market share, which was shunned in favor of HCFC-22. However, with the phase-out of ozone depleting substances, low-charge ammonia technology allows users to comply with the current and future f-gas legislative plans while ensuring maximum safety.

The increased use of low-charge ammonia in Japan has been propelled especially by a subsidy scheme run by the Ministry of the Environment. The five-year subsidy project (2018 – 2022) helps end users reduce the capital cost of natural refrigerant technologies – including low-charge ammonia installations.

This scheme targets the food retail and food manufacturing sector as well as cold storage facilities. In the financial year 2018 (FY2018), the scheme operated with a budget of ¥6.4 billion (€47 million), while in FY2019 it increased to ¥7.4 billion (€58 million).

## JAPAN'S SUBSIDY PROGRAM DRIVING UPTAKE OF LOW-CHARGE AMMONIA IN INDUSTRIAL APPLICATIONS



### JAPAN: REGULATORY OVERVIEW

Some key regulations and standards in Japan relevant for the use of ammonia as a refrigerant are described below.

The **Chemical Substances Control Law** mandates evaluation, monitoring and reporting of certain hazardous properties of chemical substances that are intended to be manufactured or imported to Japan, including ammonia.

Ammonia-based HVAC&R equipment must comply with the **High Pressure Gas Safety Act**. The Act applies to stationary applications, such as air conditioning and refrigeration. The act regulates the alignment of facilities and equipment with technical regulations, the preparation of guidelines for safe administration by the operators, and the allocation of qualified personnel.

Equipment using ammonia is also regulated by the **Offensive Odour Control Law**. Each Japanese prefecture is responsible under the Act to define how and where the control of odorous substances would be enforced.

The **Poisonous And Deleterious Substances Control Act** controls the production, import, sale, storage, transportation and display of toxic substances for non-medical purpose, including ammonia. The Act sets safety requirements in the production, handling, transport and disposal of ammonia.

Standard **JIS B 8612** (Commercial Refrigeration Cabinets) specifies materials and appropriate usage for refrigerated display cases for food retail applications, including ammonia-based equipment.



## AUSTRALIA: HFC PHASE-DOWN ACCELERATING ADOPTION OF LOW-CHARGE AMMONIA TECHNOLOGY

Australia's HFC phase-down began on 1 January 2018. The country is aiming to reduce its HFC consumption by 85% by 2036 in line with obligations under the Kigali Amendment to the Montreal Protocol. This will be achieved by gradually reducing the maximum permitted amount of bulk HFC imports.

As legislation drives the industry away from high-GWP refrigerants, there is potential for further growth of low-charge ammonia equipment replacing HFC-based equipment in an estimated 100,000 refrigerated warehouses.

### AUSTRALIA: REGULATORY OVERVIEW

Under **Australian work health and safety laws**, workplaces with ammonia-based refrigeration systems must have a documented emergency plan in place.

The Australian government provides an online **Occupier's Guide to Emergency Planning** assisting users in preparing and implementing an emergency plan for ammonia-based refrigeration systems. Emergency planning guidance for all hazardous industries is also provided online in **Emergency Planning: A Guideline for Hazardous Industry**.

In addition, a **Workplace Health and Safety Queensland (WHSQ) Safety tool** for ammonia refrigeration safety (which included an audit checklist and supporting reference material) is currently being updated<sup>1</sup>. The tool will raise awareness of the hazards and risk control measures and provides additional educational and training material about ammonia safety in the industrial refrigeration industry.

The Australian technical standard of reference for ammonia-based refrigeration systems is **AS/NZS 5149:2016**, which refers to the international standard ISO 5149.

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# CHINA: ADHERENCE TO SAFETY STANDARDS KEY TO AMMONIA'S FUTURE

China is currently in the process of phasing out the use and production of HCFCs, giving low-charge ammonia a competitive edge as a replacement of choice for HCFC-22 in industrial refrigeration. By 2015, China had already achieved its preliminary policy objective of reducing HCFC consumption by 10% by 2015. Total phase out of HCFC use and production in China is planned for 2040.

In addition, the government's support for energy efficiency and technology development to maintain the country's competitive edge in the world market, in the industrial sector, could lead to a much greater use of natural refrigerants in China, both by manufacturers and end users.

Ammonia has been used in industrial applications for more than 60 years. However, it has gained a certain level of attention among the Chinese public and government, especially due to two fatal accidents that occurred in 2013. This, in turn, has resulted in strict regulation of the refrigerant in the Chinese market, including blacklisting of ammonia by local governments. Nevertheless, under the increasing pressure to phase out synthetic refrigerants, safe use of ammonia is a clear priority that China needs to address.

Increased focus on safety standards and practices combined with more training of technicians would be key to the return of ammonia use in the country. The Chinese Association of Refrigeration is driving efforts for creating and enforcing proper design and operational standards that guarantee safety when working with ammonia systems.

The safe use of ammonia in China is regulated by a set of safety standards. The adoption of the **Safety Code for Cold Stores (GB28009-2011)** at the end of 2012, paved the way for the safe use of ammonia as a refrigerant in China's cold storage infrastructure. The standard sets out detailed safety rules and principles for cold storage design, construction, operation and maintenance management. It applies to both direct and indirect refrigeration systems using



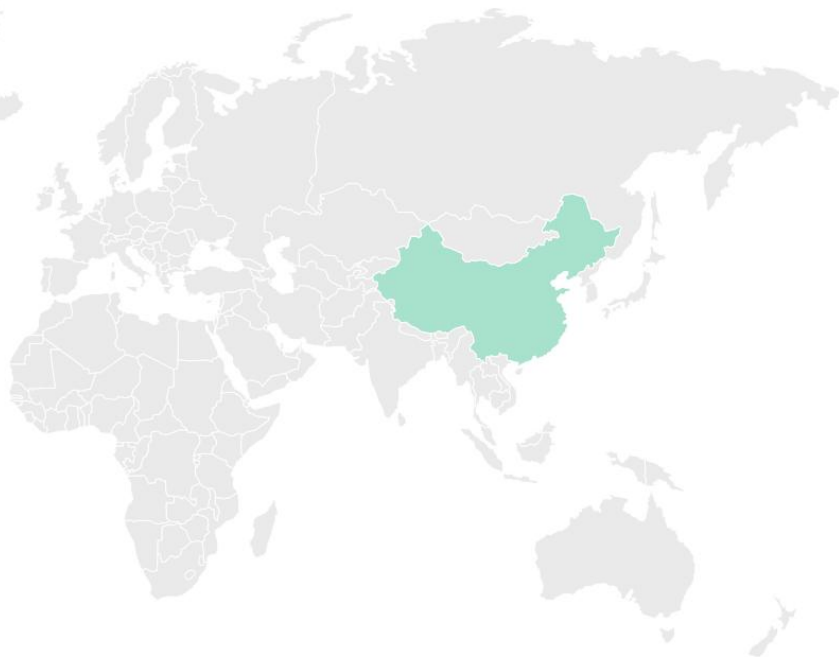
ammonia and fluorinated refrigerants (HFCs and HCFCs) and includes detailed rules regarding safety management for the machinery room, refrigeration equipment and systems, refrigerating compressors and other auxiliary refrigeration equipment.

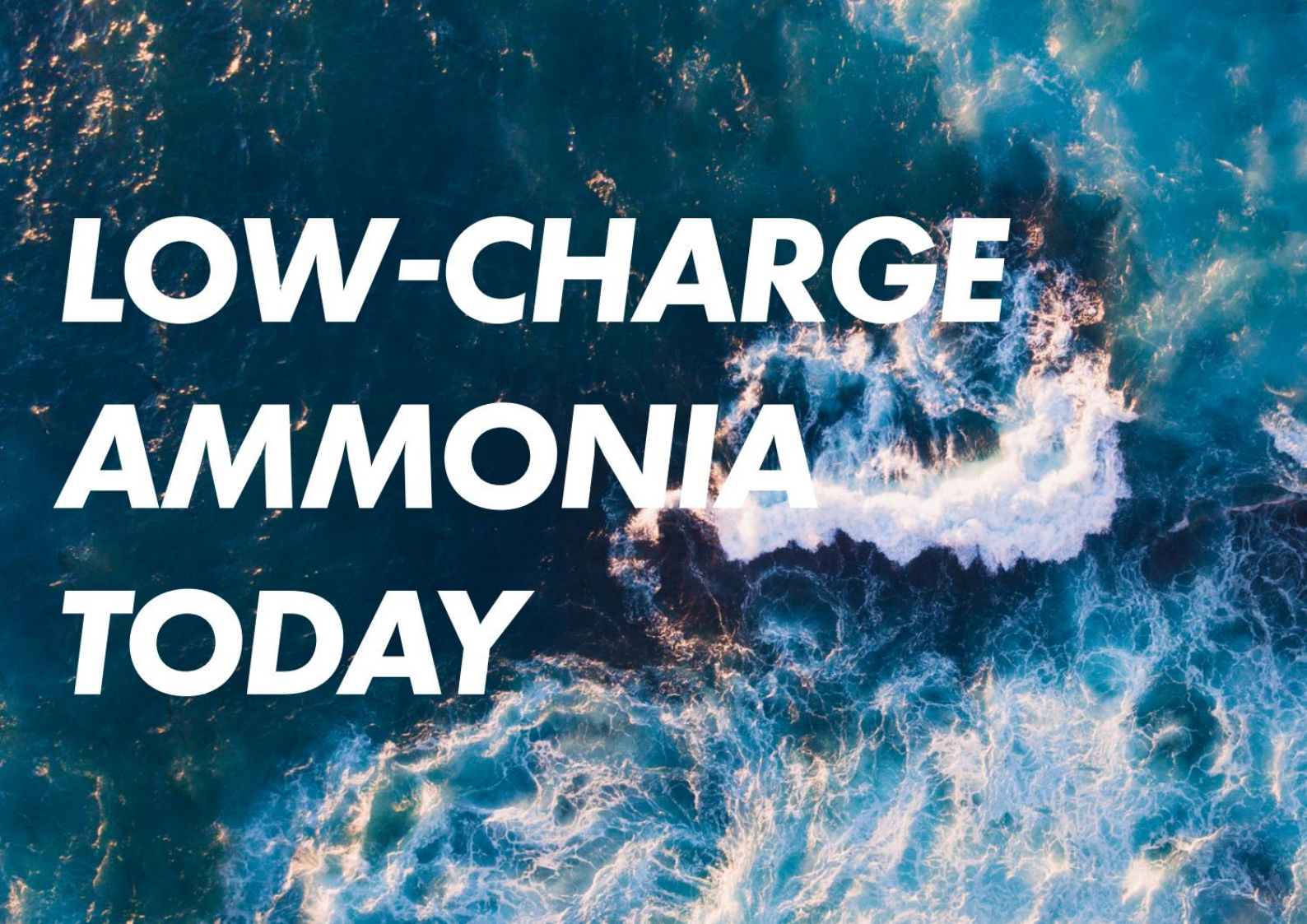
In addition, according to China's code for **Design of Cold Stores (GB50072-2010)**, which has recently been under revision, facility owners must carry out regular system maintenance to ensure the refrigeration system is in good condition and minimize the risk of ammonia leaks.

The growing restrictions imposed on ammonia use, revisions of safety standards and involvement of leading industry groups, are expected to create suitable market conditions for accelerated adoption of low-charge ammonia solutions, which have already seen rapid development over the past ten years in China.

"If the end users can show the government that, though ammonia use does entail legitimate safety concerns, they can be easily managed with proper standards and training, then progress in China can be made," said Jin Ma, Deputy Director of the Cold Storage and Cold Processing Committee at the Chinese Association of Refrigeration

*"If the end users can show the government that, though ammonia use does entail legitimate safety concerns, they can be easily managed with proper standards and training, then progress in China can be made."  
Jin Ma, deputy director of the Cold Storage and Cold Processing Committee at the Chinese Association of Refrigeration*



An aerial photograph of a turbulent ocean. The water is a deep, dark blue, with white foam from the waves creating intricate, swirling patterns. A faint rainbow is visible in the center-right of the image, arching over a patch of white foam. The overall scene conveys a sense of power and natural beauty.

**LOW-CHARGE  
AMMONIA  
TODAY**





# An overview

This chapter of the Guide will aim to paint a picture of the low-charge ammonia market today, highlighting the potential of this technology in various sectors and applications.

It explores different types of low-charge ammonia systems available today and how they compare, before moving on to market trends around the world. This is done with the data collected from a global industry survey, giving first-hand insight into the low-charge ammonia industry.

Partner case studies from selected Original Equipment Manufacturers (OEMs) working with this technology are also shared to show low-charge ammonia in application, as well as advances in R&D. (A more comprehensive collection of applications around the world can be found in Part 2 of the Guide.)

With the help of literature research, industry expert input and interviews with end users, OEMs and other professionals working with this technology, this chapter will share real-life lessons learnt to assist in the acceleration of low-charge ammonia in the future.



# TYPES OF LOW-CHARGE AMMONIA SYSTEMS

Low-charge ammonia does not offer a one-size-fits-all solution. There are various types of low-charge ammonia systems available on the market today. These are described in the following section, comparing the available designs for low-charge configurations. It includes pumped recirculated liquid systems, direct expansion systems, cascade systems, secondary/indirect systems and distributed/packaged systems.

After describing how each of these options work, the systems are compared briefly in terms of ammonia charge, costs (installed and maintenance costs), energy consumption, and applications.

## PUMPED RECIRCULATED LIQUID SYSTEM

The traditional design for an ammonia refrigeration system is a centralized two-stage system using pumps and liquid overfeed. A two-stage system is a refrigeration system working with two-stage compression and usually also includes two-stage expansion.<sup>[1]</sup>

The pumped recirculated system uses a centralized machine room with pumps recirculating expanded, cooled liquid to and from the evaporator(s). To increase the heat transfer in the evaporator, excess liquid is fed into it.<sup>[2]</sup> It is not customary to transform the whole quantity of liquid into vapor during evaporation.

The basic refrigeration cycle can be described as follows:

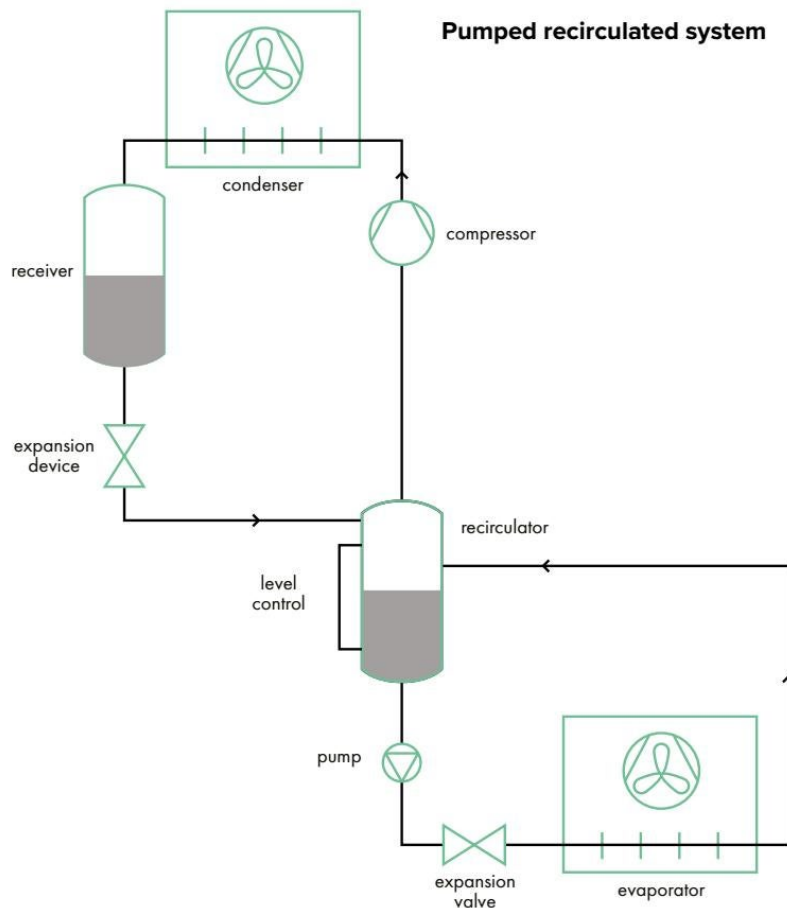
1. Heat from the space to be cooled passes through the evaporators, into the refrigerant liquid, and makes the liquid evaporate. More liquid is sent to the evaporator than is needed to meet the refrigeration load, and consequently, both liquid and vapor pass out of the evaporator and are sent back to a vessel known as the recirculator. Then, the vapor in the recirculator is separated from the liquid and drawn to the compressor, while the liquid drops to the bottom of the recirculator where it can be pumped back to the evaporator (to provide additional cooling).
2. Refrigerant in gaseous state (refrigerant vapor) is drawn to a compressor where pressure and temperature are increased.

3. Once the desired pressure is achieved, the vapor is fed to a condenser where it rejects heat, and eventually becomes all-liquid. It is then "stored" in a vessel known as a high-pressure receiver.
4. The high-pressure liquid then passes through an expansion valve where both the temperature and the pressure are reduced. Then, it is stored in the recirculator.

As there is such a high amount of liquid that is not evaporated and merely circulating in the system, the amount of ammonia used in this type of system is considerably higher than in other types of systems.<sup>[3]</sup>

The three main components in a pumped system holding excess refrigerant are:<sup>[3]</sup>

- The recirculator vessel(s);
- The evaporator(s); and
- The piping system between evaporator(s) and recirculator(s).



## DIRECT EXPANSION (DX) SYSTEM

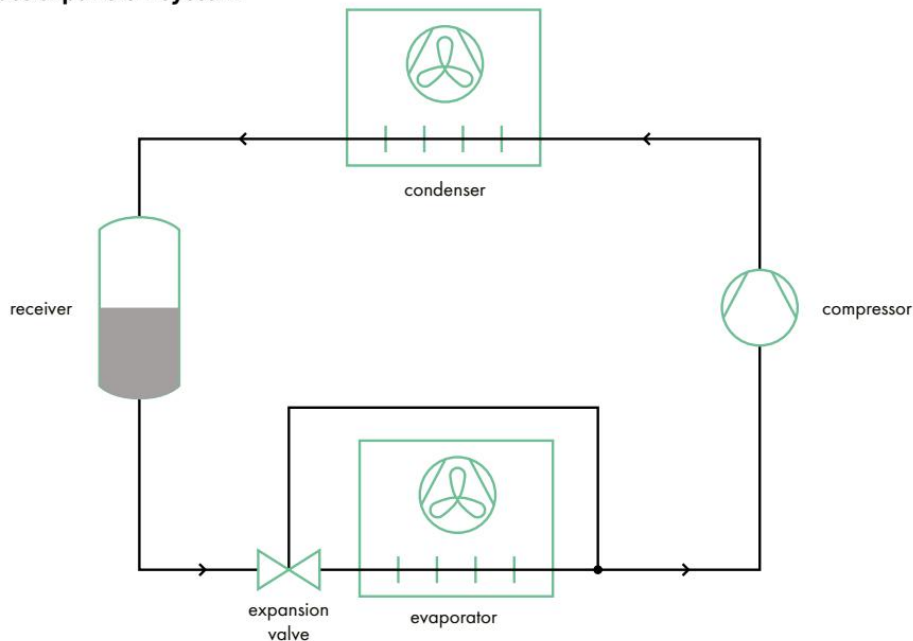
Direct expansion (also known as Dry Expansion or DX) systems have been used in refrigeration for years, but the use in industrial refrigeration with ammonia has only recently been taken up.<sup>[3]</sup>

In basic terms, a direct expansion system is a manual expansion valve, which regulates the feed-in into the evaporator based on observing the frost line on the suction line going from evaporator to compressor. Frost on the suction line means that liquid refrigerant is present. This is how the expansion was manually controlled early on; nowadays thermostatic, or more often electronic control, valves are used.<sup>[4]</sup>

A direct expansion system regulates the refrigerant feed into the evaporator by means of a thermostatic or electronic expansion valve measuring superheat and/or refrigerant quality in the suction line after the evaporator (measuring gas temperature and pressure)<sup>[5]</sup>. Superheat is the difference between the gas saturation temperature and the gas temperature at the evaporator outlet; i.e. superheat is the additional heat added to the refrigerant when it passes its boiling point<sup>[6]</sup>. Quality is the mass fraction of vapor in the saturated mixture.<sup>[7]</sup> In this way, it ensures that all of the refrigerant is in the gaseous state.

The key difference between a liquid recirculation and a dry expansion system is that in a dry expansion system, the high-pressure liquid is fed directly to each evaporator via the expansion valve at the evaporator inlet, not using a recirculator<sup>[3]</sup>. The aim is to ensure that the refrigerant is completely evaporated and in the gaseous state when it leaves the evaporator. In other

## Direct expansion system



words, the liquid refrigerant is fed to the evaporator at a rate that allows it to evaporate so there is no liquid present in the suction line (known as dry suction)<sup>[7]</sup>.

An additional method to improve the evaporator design is surface enhanced evaporators with capillary effects; meaning that the internal surface of the evaporator should allow the liquid to stick better, not to fall down

to the bottom of the tubes and to be evaporated at a higher quantity<sup>[5]</sup>.

Compared to a recirculated and pumped system, a properly-designed DX system uses less material because it does not require pumps and it might use smaller vessels because of the lower quantity of ammonia.<sup>[8]</sup>



## CASCADE SYSTEM

A cascade system uses a combination of two centralized refrigeration systems. The high-temperature refrigeration system (usually ammonia) cools the lower-temperature refrigeration system (usually CO<sub>2</sub>)<sup>[2][3]</sup>. The evaporator for the ammonia system is also the condenser for the CO<sub>2</sub> system<sup>[3]</sup>. The lower-temperature refrigeration system (usually CO<sub>2</sub>) typically uses recirculated liquid to cool the evaporators<sup>[2]</sup>.

In most of these systems, the ammonia refrigerant is contained within the machine room.

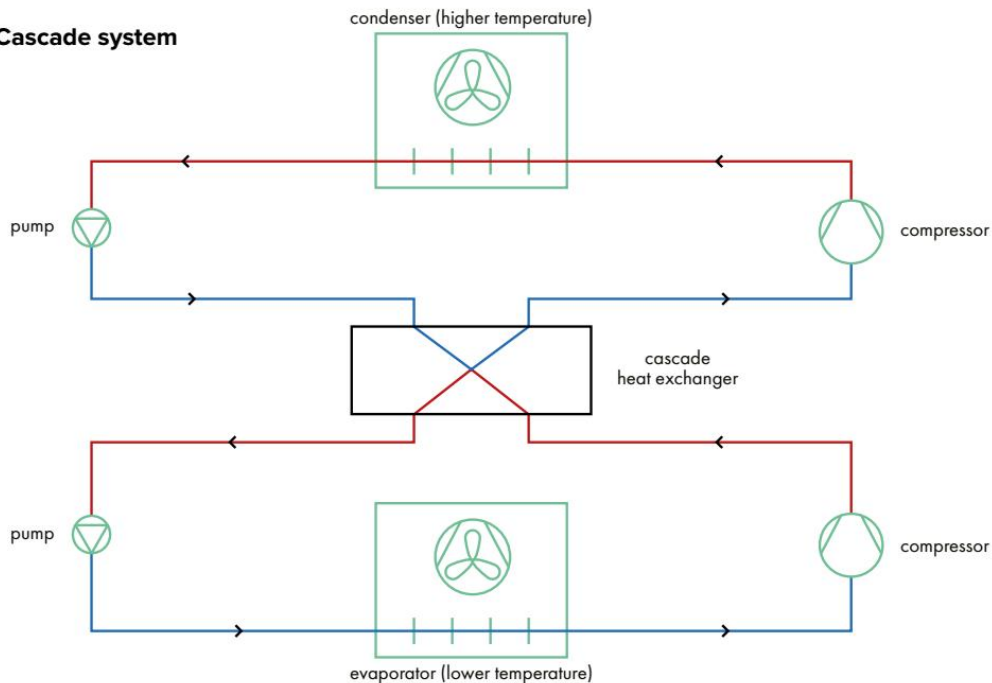
In refrigeration systems employing only CO<sub>2</sub>, the low critical temperature of CO<sub>2</sub> of 31.1°C (88°F) causes the operating pressures to reach relatively high levels, particularly at high ambient temperatures. In order to limit the pressures, the ammonia refrigeration system provides the condensing for the CO<sub>2</sub> systems and thereby limits the pressure, which would exist if only CO<sub>2</sub> was used in a typical refrigeration cycle.<sup>[3]</sup>

The type of heat exchanger used between the ammonia system and CO<sub>2</sub> system is known as cascade heat exchanger and can be constructed in a number of different ways:

- Shell-and-tube;
- Welded-plate; or
- Shell-and-plate.<sup>[3]</sup>

The refrigerant inventory depends on the design of the heat exchanger, with shell-and-tube requiring

### Cascade system



the most refrigerant and welded plate requiring the least refrigerant.<sup>[3]</sup>

The overall ammonia inventory depends on several factors:

- The type of cascade heat exchanger;
- Type of condenser; and
- The size and amount of piping connecting the CO<sub>2</sub> and ammonia systems.<sup>[3]</sup>

## Indirect system

### SECONDARY/INDIRECT SYSTEM

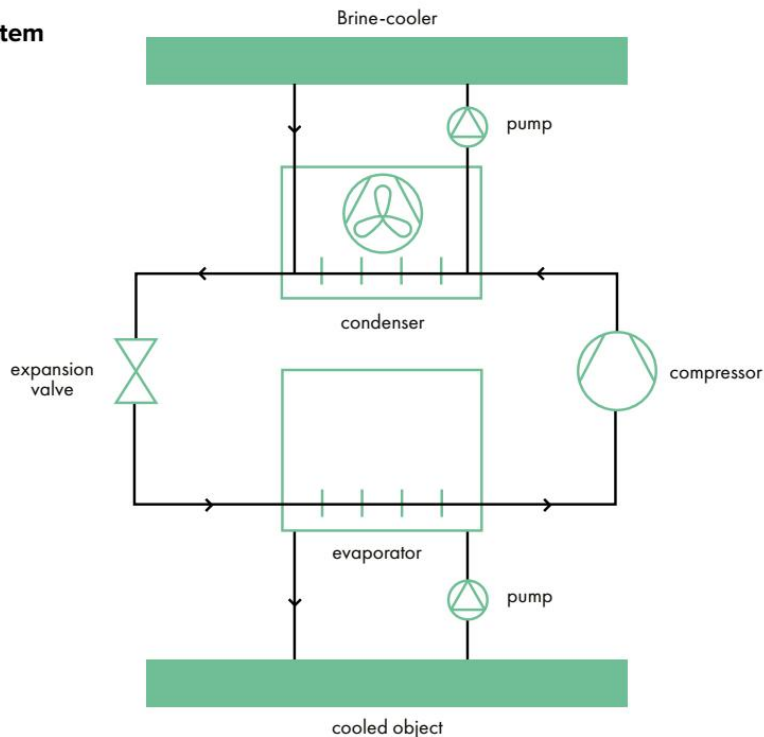
A secondary/indirect refrigerant system uses a centralized system to cool a secondary fluid (secondary brine or glycol). The secondary fluid is pumped to each consumer. The consumers can be air coolers, processing equipment or glycol/chilled water heat exchangers. The primary refrigerant is confined to the machine room, so the primary refrigerant inventory is minimized as are the risks to system personnel.<sup>[1]</sup>

Principle of an indirect refrigeration system <sup>[10]</sup>

The primary refrigeration cycle is shown in the center of the image. It contains all the required components – evaporator, compressor, condenser and expansion valve. The secondary refrigerant cycle on the lower side contains a heat exchanger between the refrigerated space and the secondary fluid and a pump to transport the secondary fluid from the refrigerated space to the evaporator.

With indirect systems, it is possible to reduce the lengths of the distribution lines containing primary refrigerant and to make the parts containing primary refrigerant very compact. By how much the primary refrigerant inventory can be reduced in comparison with direct systems depends to a large extent on the application.<sup>[8]</sup>

The disadvantage of indirect systems is the additional heat exchange between the primary and the secondary refrigerants. Furthermore, the pumping power necessary for circulating the secondary fluid reduces the energy efficiency.<sup>[8]</sup> The pumping power required can be reduced by using volatile secondary refrigerants such as CO<sub>2</sub>.<sup>[9]</sup>



### DISTRIBUTED/PACKAGED SYSTEM

A distributed system or so-called “packaged system” is used very locally, only where the cooling is needed. The refrigeration system is located near the cooled space and the evaporator.<sup>[2]</sup> Each evaporator has its own compressor(s) and condenser(s). This way, the primary refrigerant inventory is kept low.<sup>[2]</sup>

There are several advantages when it comes to reducing ammonia refrigerant charge in these systems:

- Elimination of the machine room;
- Elimination of the large-scale vessels required for holding ammonia charge; and
- Minimization of distribution piping throughout the facility.<sup>[3]</sup>

However, there might be disadvantages such as high mass on the roof and decentralized maintenance.<sup>[9]</sup>

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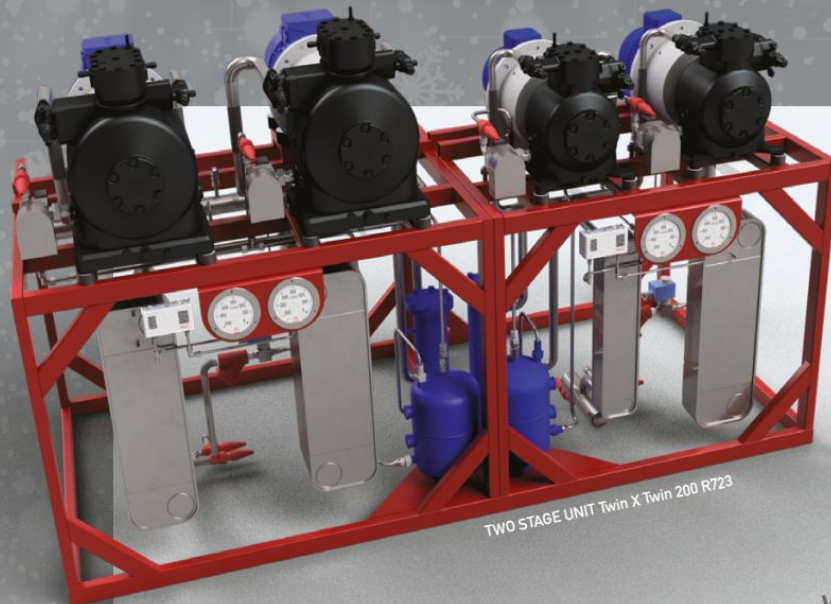
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## KEY PARAMETERS FOR COMPARISON OF LOW-CHARGE AMMONIA SYSTEMS

The systems described above all come with their own set of advantages and potential drawbacks. When selecting a low-charge ammonia system, it is important to first consider the application to determine which system will be most suitable.

Cost will also always be a key deciding factor for system selection. It is important to not only look at capital expenditure (CAPEX) of the equipment. Instead, it's worth considering the total life cycle cost, which includes maintenance and installation costs – as well as energy consumption.

The various low-charge ammonia systems discussed compare as follows in terms of ammonia charge, cost (installed and maintenance cost), energy consumption, and applications.



### AMMONIA CHARGE

All low-charge ammonia systems have significantly reduced ammonia charges compared to the recirculated pumped system type. The International Association for Refrigerated Warehouses (IARW) released a white paper in 2014 entitled “Low Ammonia Charge Refrigeration Systems for Cold Storage” wherein it ranked these systems in terms of ammonia charge in lbs/TR [kg/kW], from highest to lowest.

According to the report, the highest ammonia charge is contained within a DX system [7.5lbs/TR; 0.95kg/kW], followed by a cascade system [6lbs/TR; 0.76kg/kW] and an indirect system [6lbs/TR; 0.76kg/kW]; with the lowest charge being for a packaged system [4.3lbs/TR; 0.54kg/kW].

Interestingly, while the charge variation between the different types of low-charge systems is quite minimal actually, the difference between a traditional recirculated pumped system [23lbs/TR; 2.9kg/kW] and a DX system [7.5lbs/TR; 0.95kg/kW] is more significant.



## COST (INSTALLED AND MAINTENANCE COST)

As costs depend on multiple factors, a comparison of different systems is rather complex. Moreover, ammonia is still predominantly used in large industrial installations, which are non-standardized and custom-made, making any one-to-one comparison difficult.

Furthermore, there are relatively few examples of cost data collection now as installers and operators of different refrigeration systems are usually reluctant to share this information<sup>[10]</sup>.

Installed costs are all the costs required to bring an HVAC&R system to operational status. It includes design costs, equipment costs, installation costs, and space usage.<sup>[11]</sup> The size, type, design temperature, and location of the cold storage facility determine the installed costs. For large facilities, there is an economy of scale favoring centralized systems.

For industrial installations, operators tend to consider the overall lifecycle costs rather than merely the installed cost. As a consequence, the running costs are very important.

In the IARW paper, the maintenance costs are the same for a recirculated pumped system and most of the other types of systems (DX system, cascade, indirect systems). For packaged systems, it found that the maintenance costs are less than for a recirculated pumped system.<sup>[3]</sup>

Stefan Jensen, Managing Director of Scantec Refrigeration Technologies<sup>[9]</sup> reports that maintenance costs for centralized low-charge ammonia systems are lower than for liquid overfeed systems because pumps for the ammonia are not required, making the liquid management becomes much easier.

In the case of packaged systems, the price point is expected to go down in the coming years as the packaged systems become a standardized product, explained Kurt Liebendorfer, Vice President of Evapco.<sup>[12]</sup> The mass production of these systems should make the price point go down. This is especially important as this type of low-charge ammonia technology enters the commercial markets (both refrigeration and air conditioning) where the price premium plays an important role in purchasing decisions of end users. Now, the price is still the predominant barrier.

Here are some comments from industry on the cost of the different low-charge ammonia systems installed:

■ **Bruce Nelson, President at Colmac Coil** said: "What is helping to drive adoption of the ADX system is its lower cost – 2% to 5% less than that of a traditional overfeed system. Tim Cox, Liberty Cold Storage, also saw "an advantage on price" with the ADX system being a little less expensive (in equipment plus installation) than a liquid-overfeed system.

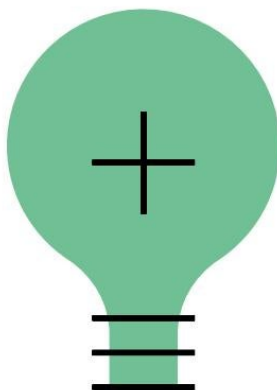
■ According to **John Scherer, Chief Technology Officer at NXT Cold**, package systems are less expensive. "First costs are highly competitive – compared to ammonia systems with central engine rooms,

our systems are usually less, but they are more than for packaged HFC systems."

■ **David Bornemeier, Western Gateway Cold Storage**, also commented on packaged systems: "In terms of equipment and installation costs, the Evapcold units are 'comparable to or less' than a conventional ammonia system. That includes the oversizing of the units and the additional structural costs to support the weight of the units on the roof, which were balanced by lower labor and equipment costs for installation, energy savings, and a USD\$60,000 utility incentive."

■ **Joseph Burch, Neptune Foods** on packaged system: "The unit's simple design reduces the initial cost of the equipment and the cost of installation, which took only two days."

■ **Yuta Shioya, Chemical Grouting**: "One of the biggest benefits we saw by using the NH<sub>3</sub>/CO<sub>2</sub> system was the reduction of the project working period by 40% (39 days). The system's compact size greatly simplified the disassembly and removal process."



## ENERGY CONSUMPTION

With regards to the available low-charge ammonia systems, the energy consumption does not only depend on the refrigeration system but also on the facility's construction (insulation, doors, etc.).<sup>[3]</sup>

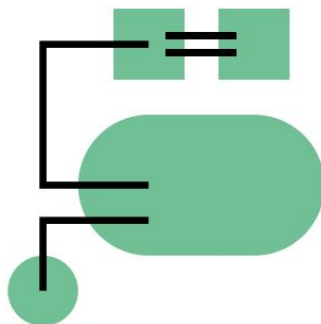
There are two recent studies comparing the energy consumption of different low-charge ammonia systems.

All systems described in IARW paper<sup>[3]</sup> have approximately the same electrical power consumption in kW/TR [kW/kW] – approximately 2.5kW/TR [COP = 1.44].

In a technical paper submitted for peer review, Dr. Andy Pearson, Group Managing Director of Star Refrigeration<sup>[13]</sup> documented extensive field measurements of pumped ammonia systems, ammonia/CO<sub>2</sub> cascade systems, secondary refrigerant systems and other systems with reduced ammonia charge used in cold storage.

The results indicate that all the systems have a similar energy performance in terms of specific energy consumption (SEC), measured in kWh/m<sup>3</sup>/year. The values are in between 8kWh/m<sup>3</sup>/year and 12kWh/m<sup>3</sup>/year. The energy use was measured at the individual refrigeration units, not for the sites as a whole. The secondary refrigeration systems in the study by Pearson were less energy-efficient (19.5kWh/m<sup>3</sup>/year) because the pumps for the glycol were constantly running. However, a much lower SEC could be achieved with extensive use of variable speed drives on pumps and fans and by using waste heat for defrost instead of electric heaters<sup>[13]</sup>.





## APPLICATIONS

Low-charge ammonia is already being used in many different applications in industrial refrigeration, commercial refrigeration, as well as the HVAC sector (see Chapter 3 of the Guide). The air-conditioning sector is an important market for natural refrigerants, especially since it accounts for 65% of global HFC use<sup>[14]</sup>. Although there are some companies working with ammonia in air-conditioning, but there is no standardization yet.<sup>[15]</sup>

When it comes to the question of which type of low-charge ammonia system is suitable for which application, there is no clear answer as it will vary from project to project depending on a number of factors. For cold storage and larger industrial installations, it is possible to use any of the low-charge ammonia systems if the conditions are suitable for such a system. Packaged systems would, in most cases, be more suitable for facilities smaller than 100,000ft<sup>2</sup> [9,000m<sup>2</sup>]<sup>[3]</sup>.

From interviews with end users conducted by shecco, it is clear that ammonia/CO<sub>2</sub> cascades or indirect systems are already in use in supermarkets and that there is potential for further deployment in this sector. These systems perform very well, however, many end users are still hesitant to use ammonia in a retail application.

At the International Institute of Ammonia Refrigeration (IIAR) Natural Refrigeration Conference and Expo, held March 4-6, 2019 in Phoenix, Arizona (U.S.), executives who have worked on four of the U.S. installations of ammonia/CO<sub>2</sub> said that the relatively small amount of ammonia used in these systems should not pose a safety concern.

In air conditioning, the market is slowly experimenting with low charge ammonia. Logan City Council south of Brisbane in Australia recently converted its existing air-cooled R22-based air-conditioning system to a new water-cooled ammonia-based system. Not only did this new system reduce Logan City Council's annual energy consumption by around 50%; it also eliminated any commercial and environmental risks associated with future releases of chemical refrigerants.<sup>[16]</sup>

# LOW-CHARGE AMMONIA AROUND THE WORLD

## INSTALLATIONS MAP

shecco conducted a data collection in 2019 with companies manufacturing low-charge ammonia systems to quantify the number of installations on the market globally.

The system manufacturers were asked how many installations of low-charge ammonia they have completed to date. All types of low-charge ammonia systems were taken into consideration, including DX systems, indirect systems (using secondary refrigerant or cascades), packaged systems, chillers, as well as any other system where the design intent is to reduce the ammonia charge.

The findings indicate there are more than 4,000 installations using low-charge ammonia systems globally, with clear hotspots in Europe, North America, and Japan. Considering that the first commercially available ultra-low-charge ammonia system was introduced in Japan in 2008, this is a major shift in an industry that for decades has been using traditional ammonia technology.

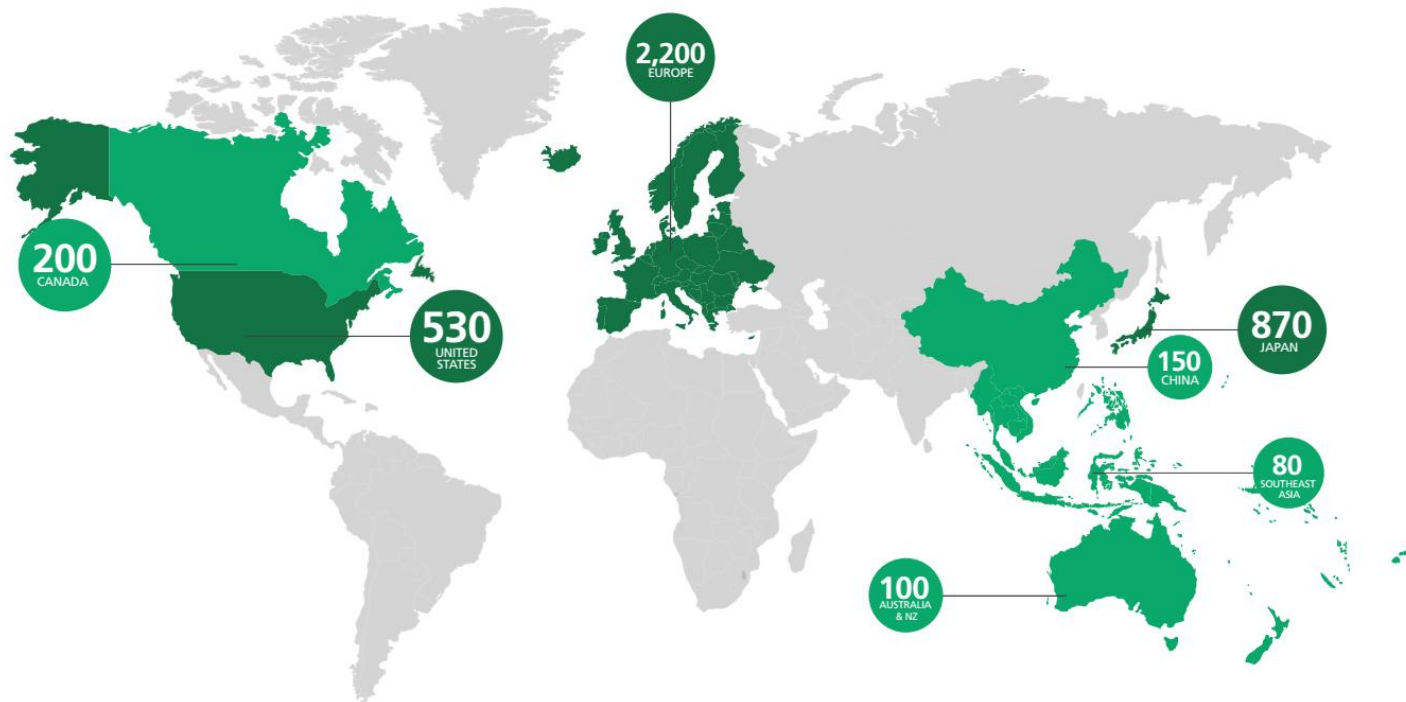
During the data collection it became clear that in the U.S., there is a strong trend towards packaged systems. This trend is mostly driven by heavy regulatory

requirements for installations with large ammonia charges (see Chapter 4 “Regulations and Standards”). There are already several manufacturers offering packaged systems and scaling up their production as end users become more familiar and confident with the benefits.

In Europe, there is a large number of manufacturers who have traditionally been producing ammonia-based equipment for large installations. The focus on lowering the ammonia charge has been mostly driven by safety and energy efficiency requirements of end users. Low-charge ammonia chillers and centralized systems with reduced ammonia charge are often considered business-as-usual in Europe. Packaged systems are not as common as in North America although this might change in the future with some companies already offering such products today.

In Japan, the use of cascade ammonia/CO<sub>2</sub> systems is prevalent. The uptake has mostly been driven by incentives for end users to replace outdated HCFC-22 technology. Japanese manufacturers have also started to export the technology to other regions, especially Southeast Asia. <sup>[15]</sup>

## LOW-CHARGE AMMONIA INSTALLATIONS AROUND THE WORLD, 2019



*These figures are based on the 2019 survey of leading manufacturers of low-charge ammonia technology. While reasonable efforts have been made to portray an accurate picture of the market, these figures are not exhaustive and shall serve as an indication of the market for low-charge ammonia.*



## LOW-CHARGE AMMONIA GLOBAL TRENDS – A SURVEY

A survey conducted by shecco in summer 2019 among more than 300 industry experts from different branches like equipment manufacturing, refrigeration contracting and consultancy, provides insights into the extent to which low-charge ammonia is used, different kinds of systems, drivers and barriers for adoption, and a comparison between low-charge packaged systems and traditional centralized systems.

Ammonia has been widely used as the refrigerant of choice in industrial refrigeration for more than a century<sup>(13)</sup>. Currently, ammonia is used in 90% of large industrial refrigeration facilities in Europe and in 95% of large industrial refrigeration facilities in North America (food and beverage processing, cold storage). In China, industrial facilities using ammonia are common and the use of ammonia is currently being expanded due to the increasing number of large cold storages.

The concept of low-charge ammonia is not new, but due to increasing pressure because of stricter safety requirements and demand for energy efficiency, low-charge ammonia has become more popular. At the moment, the overall market share of low-charge ammonia in the industrial refrigeration sector is difficult to quantify and estimated to be relatively low. However, it is growing rapidly and there is a huge potential for growth. This conclusion was also supported by the results of the industry survey that shecco conducted.

The survey findings indicate that different stakeholders are already using low-charge ammonia and that its use will further increase in the coming years. Out of the group of component and equipment manufacturers, refrigeration and general/building contractors, consultants, and others; 61% already use low-charge ammonia. Out of the group of end users, 23% do so. Many plan to install it in the coming years, i.e. 44% of the component manufacturers and equipment manufacturers, refrigeration contractors and general/building contractors; consultants and other.

### Estimation of the current market share for new installations using low-charge ammonia in industrial refrigeration in own region.

When the survey respondents were asked what they think the current market share for new installations using low-charge ammonia in industrial refrigeration is in their region, most estimated it to be relatively low. 47% of the respondents for this question estimated the share for new installations using low-charge ammonia in industrial refrigeration in their region to be between 0% and 5%, while 25% estimated it at 6-10%.

#### Key legend for survey infographics

- All Participants
- End Users
- Equipment manufacturers, component manufacturers, refrigeration contractors, consultants, general building contractors, other

0% to 5%  
market share

**47%**

6% to 10%  
market share

**25%**

11% to 20%  
market share

**16%**

21% to 50%  
market share

**7%**

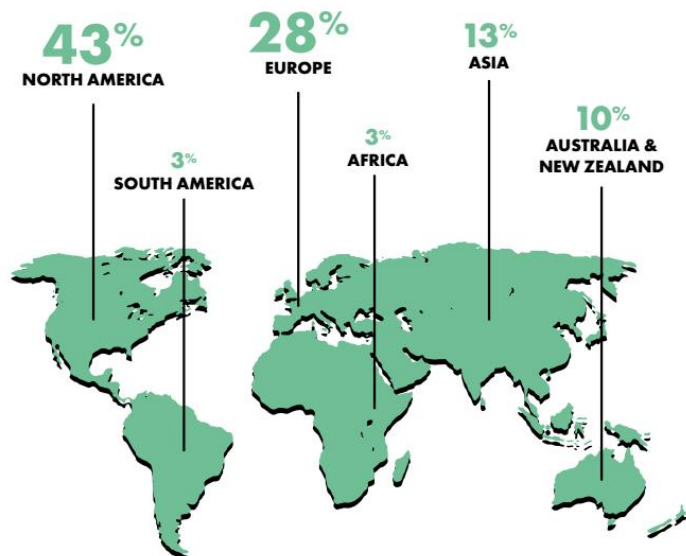
more than 50%  
market share

**5%**

215 respondents

### Representation dominated by North America and Europe

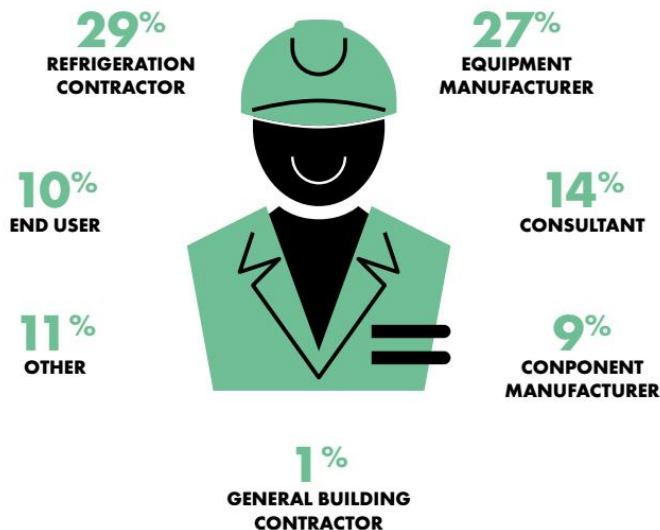
Almost half of the survey respondents were from North America (43%). Europe was well represented with 28% of respondents coming from this region. It was then followed by Asia (including Japan and China) on 13% and Australia representing 10% of correspondents.



252 respondents

### Contractors and manufacturers prevail

When it comes to the type of organization represented in the survey, over half of respondents were either refrigeration contractors (29%) or equipment manufacturers (27%). Consultants (14%), end-users including operators of refrigerated warehouses, supermarkets and manufacturing facilities (10%) and component manufacturers (9%) were also among the respondents.

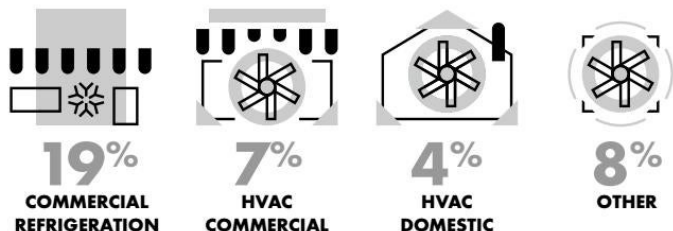
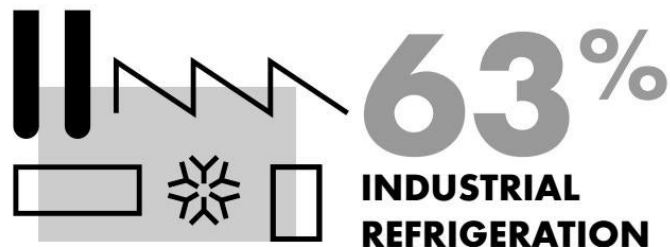


251 respondents

## Manufacturers and contractors: Large majority active in industrial refrigeration

In the following, many questions will be either for end users or for the other groups of respondents, which will be summarized as “non-end users”. The organizations that are non-end users were queried about their primary market sector.

Almost two-thirds of these respondents indicated they work in industrial refrigeration (63%), followed by commercial refrigeration (19%). A smaller share said that they are active in the HVAC part of the industry.



226 respondents

## Manufacturers and contractors: two-thirds work with low-charge ammonia

Among the organizations that are not end-users, nearly two-thirds indicated that they already work with low-charge ammonia.



225 respondents

### End users: industrial refrigeration and retailers represented

Overall, a large majority of end users that participated in the survey were operators of industrial refrigeration installations, including refrigerated warehousing (40%) and food manufacturing (20%). About a quarter of end user respondents were food retailers.



25 respondents

### A third of end users currently have low-charge ammonia installations

These end-users were asked if they currently have low-charge ammonia installations. 32% answered with yes, 68% with no.



25 respondents

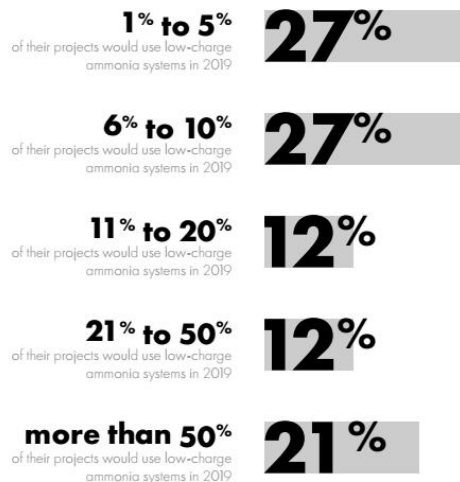


## SHARE OF BUSINESS WITH LOW-CHARGE AMMONIA

### Manufacturers: Huge potential for scaling up business with low-charge ammonia

Out of the organizations that are not end users and who are already working with low-charge ammonia, the equipment manufacturers and component manufacturers were asked what percentage of their products will be used for low-charge ammonia in 2019.

Answers were mostly found in the lower category: currently, for a majority of those that work with low-charge ammonia it represents a very small share of their overall business. But given that, they already have, or are building, expertise in this field. Also interesting is the relatively high share of those that have more than 50% of business with low-charge ammonia.

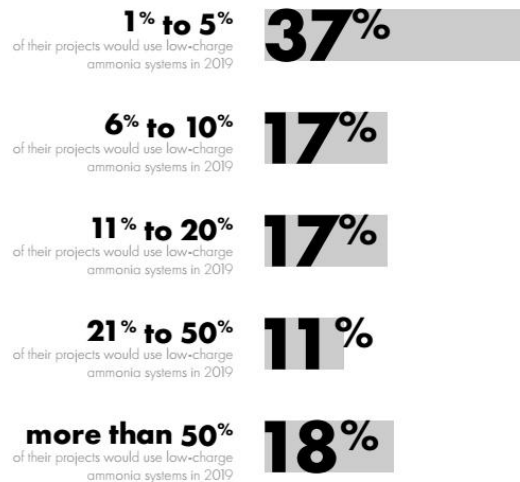


66 respondents

### Contractors: Considerable potential for scaling up business with low-charge ammonia

Refrigeration contractors, general/building contractors, and those of the category "other" that already work with low-charge ammonia, were asked what percentage of their projects would be used for low-charge ammonia in 2019. The results are similar to those for manufacturers – answers were mostly found in the lower category (54% use low-charge ammonia in a relatively low percentage of projects, up to 10%). However, only a relatively small share of respondents use low-charge ammonia for more than 50% of their projects (18%).

Given that all of them already have or are building the expertise for low-charge ammonia, there is considerable potential to scale up its use.



71 respondents

# ADX<sup>®</sup> TECHNOLOGY

*for low charge ammonia evaporators*



## SAFER TECHNOLOGY FOR INDUSTRIAL AMMONIA REFRIGERATION APPLICATIONS

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Less expensive to install

Excellent evaporator performance

Reduced regulatory requirements

Enhanced tube technology results in efficient DX ammonia performance even at low temperatures

# CENTRALIZED, LOW-CHARGE $\text{NH}_3$ SYSTEMS – THE ULTIMATE ENERGY PERFORMANCE BENCHMARK?



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Contact information  
Stefan S. Jensen  
[ssjensen@scantec.com.au](mailto:ssjensen@scantec.com.au)

## ABOUT THE COMPANY

Since its founding in 1996, Scantec Refrigeration Technologies has completed more than 2,000 industrial refrigeration projects in the refrigerated warehousing, beverage and food processing industries. The disciplines Scantec covers range from design through to installations, control systems and service.

Scantec Refrigeration Technologies specializes in centralized, low-charge ammonia refrigeration systems both plug-and-play (ScanPAC) and stick-built type. Twenty systems of this type are in commercial operation today in Australia and China. These feature exceptionally low recorded energy consumption values and contain three to five times lower ammonia inventories than conventional liquid overfeed systems.

## INTRODUCTION

The width and depth of experience has enabled Scantec to gradually refine design concepts based on recorded energy performances of the systems installed. In this context, the metric for mixed refrigerated warehouses is specific energy consumption (SEC) measured in kWh/m<sup>3</sup> per year where m<sup>3</sup> represents refrigerated volume. One of the latest and most modern centralized, low-charge ammonia systems is depicted in Figure 1. The ammonia charge of this system is 1.6kg/kW [12.1 lbs/TR].



Figure 1: Centralized low-charge  $\text{NH}_3$  plant

## ABOUT THE NEW SYSTEM

The centralized, low-charge ammonia refrigeration systems are dual stage, dual temperature systems with design focus on the refrigerated warehouse and food service industries. There are no upper limits with respect to system capacities and/or sizes. Centralized, low-charge ammonia solutions are also highly viable in the retrofit market – particularly in warm and hot jurisdictions in Australia. The most recent HFC-404A to

ammonia conversion records SEC reductions of 71%. The charge in this case is 2.7kg/kW [21.4lbs/TR].

Stefan Jensen, Managing Director at Scantec Refrigeration Technologies:

"It is, in my view, meaningless to discuss the merits of any refrigeration concepts (at least for refrigerated warehouses) without at the very least considering to what extent the concept in question approaches the latest best practice energy performance."

In this example, the investment in a replacement low-charge ammonia system is potentially cash flow neutral to cash flow positive from the start. This is because the energy savings exceed the cost of financing the new system. Compared with merely investing in a replacement refrigerant with limited to no energy performance benefits, investing in a new system with a future proof refrigerant that at the same time delivers tangible operating cost reductions is a much more attractive proposition to investors.

Centralized, low-charge ammonia systems tend to be more energy efficient than other systems as a result of:

- Superior part load performances by paying attention to compressor combinations, compressor sequencing and capacity control,
- Elimination of all liquid in all suction lines always and under all operating conditions,
- Multiple compression stages,
- SH/X refrigerant injection employing a combination of superheat and quality-based injection control,
- Oversized condenser(s),



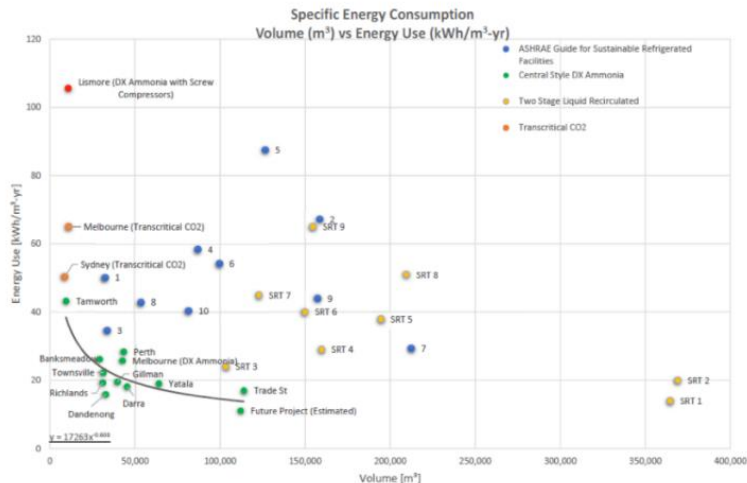


Figure 2: SEC-values for Various Refrigeration Plant Types.

- Oil and moisture management,
- Bespoke, optimized evaporator designs,
- Hot gas defrost management,
- Low friction interconnecting refrigerant pipelines,
- Elimination of ammonia pumps,
- Variable frequency drives on everything.

## RESULTS

Figure 2 details recorded specific energy consumption (SEC) of a range of different types of refrigeration systems as indicated. All the systems service refrigerated warehouses or food processing facilities.

The values represented in green are those achieved by Scantec centralized low-charge ammonia systems. An interesting observation here is how close together the cluster of green values is compared with the spread that is evident for other system concepts. This

is explained by the far superior turn-down ratio of the low-charge ammonia systems represented.

The SEC-value for the Sydney-based transcritical CO<sub>2</sub> system is based on energy performance recordings for the autumn/winter months. For an entire calendar year, the SEC-value shown is likely to increase. The system is fitted with an adiabatically assisted gas cooler and parallel compression. It services a seafood processing system comprising one relatively small freezer and a series of medium temperature process and storage rooms.

The yellow values represent highly energy optimized Scantec liquid overfeed ammonia systems constructed between 1999 and 2013. The SEC-values were provided by the system owner and are the result of years of fine-tuning by a full-time energy manager.

The blue values originate from the ASHRAE 2018 “Guide for Sustainable Refrigerated Facilities and Refrigeration Systems”. They are the result of an investigation carried out in 2010 by Dr. Doug Reindl and Dr. Todd Jekel both of Industrial Refrigeration Consortium, Wisconsin

## SUMMARY/ CONCLUSIONS

The question asked at the outset was whether centralized, low-charge ammonia refrigeration systems represent the ultimate energy performance benchmark. The answer to such a question usually starts with “it depends”. In this case the factors to consider include part-load energy performance, evaporator design, and overall system control.

The red value titled “Lismore” in Figure 2 illustrates how significant the impact of the poor part-load performance of a single-stage economized screw compressor system is on overall annualized energy performance. Lismore is 2.5 times higher than Tamworth, yet both warehouses are identical, belong to the same entity, are used for the same purposes, both employ ammonia refrigerant and are geographically close (within 300km/186mi).

Liquid overfeed systems employing ammonia refrigerant (depicted by yellow and blue values in Figure 2) often include dozens of wet suction risers. At reducing system load, it is not customary to reduce the amount of ammonia circulated by the ammonia pumps. This means that wet suction risers often experience rising overfeed rates at reducing heat loads. This generally coincides with reducing vapor velocities leading to flow reversal in the risers and elevated pressure drops.

This is a common phenomenon in almost all existing ammonia-based liquid overfeed systems across the world. The consequences are illustrated by the significant spread in the blue and yellow values in Figure 2.

The answer to the original question “does centralized low-charge ammonia represent the ultimate energy performance benchmark” is therefore yes, provided it is done well. ■



# VAHTERUS PSHE COMBINED TECHNOLOGY PIONEERS LOW-AMMONIA CHARGE SOLUTION

## VAHTERUS

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Contact information  
Jonathan Pascoe, President, Vahterus Americas  
[jonathan.pascoe@vahterus.com](mailto:jonathan.pascoe@vahterus.com)

### ABOUT THE COMPANY

Established in 1990, Vahterus specializes in Plate and Shell Heat Exchanger (PSHE) technology. Today, Vahterus heat exchangers are used in many demanding processes in the oil and gas, chemical and process, as well as energy and refrigeration industries worldwide. With its headquarters and largest manufacturing facility in Finland, and subsidiaries in the U.S., U.K., Germany and China, Vahterus currently employs over 300 people.

Vahterus heat exchangers are built with the future in mind: they save energy, are compact in size, custom-made, and because of their fully welded structure, are durable enough for even the most demanding conditions.

### INTRODUCTION

Green Group, a partner of Vahterus for more than a decade, is primarily based in Norway and Lithuania. It is an engineering company with a strong commitment to creating harmony with the environment by using cutting-edge ecological technologies.

"Our cooperation with Vahterus started with ammonia heat-recovery units (desuperheaters) and extended into chillers, condensers and combined units," explained Egidijus Vilkauskas, Managing Director of Green Group. "The technology is pioneering the reduction in footprint and decrease of refrigerant charge. The units are easy to insulate and allow for maintenance-free lifetime use. At Green Group, we are continuously developing our container machinery concept and applying new innovations to benefit our end-customers through simple and efficient installations for the future," Vilkauskas added.

In 2018, Vahterus and Green Group worked together on a project for a European designer, manufacturer, and supplier of a wide range of medical devices for respiratory support. The end user, experiencing strong growth year on year, faced an expansion problem due to limited production area. This created the need for a system with a small footprint and very low ammonia charge. Vahterus' compact plate heat exchanger design, ideal for low-charge ammonia solutions, was a perfect fit, aligning with Green Group's expertise in container machinery design.

### ABOUT THE SYSTEM

#### **A single-shell solution with an integrated separator**

Vahterus PSHE Combined is a compact heat exchanger solution suitable for both flooded evaporator and flooded cascade applications. It integrates the evaporator and separation system within a single vessel, which reduces the overall unit size as compared to a traditional system, as well as providing a low refrigerant-charge solution.

The compact size enables easy integration into package design and container machine rooms, as well as simple installation within tight spaces with limited accessibility. Most notably, footprint and package height are minimized. The footprint of Vahterus Combined also realizes savings in insulation and associated piping, as well as final transportation costs.

Constructed from fully-welded circular plates enclosed in a durable shell construction, Vahterus PSHE Combined ensures safe and reliable operation, and is suitable for use with all refrigerants. The fully-welded construction eliminates the need for gaskets, providing operational benefits, both in terms of cost and safety.

Vahterus PSHE Combined can be customized according to application. It is composed of an oversized shell which can be tailored accordingly to increase system fluctuation volume, or conversely, can be equipped with filling boxes, which lower the refrigerant charge

for critical charge systems. These inert internal filling boxes are chemically resistant to ammonia and oils. Providing customized solutions is a standard concept in the design of a Vahterus Combined unit. For example, in ammonia systems, oil recovery has been catered for and all connections to manual or automatic oil drains are supplied.

The design concept of the system is shown in Figure 1.



Figure 1: Green Group's container machinery design concept.

## RESULTS

To maximize the system efficiency, ammonia was chosen as the refrigerant in this case. The conceptual design devised by Green Group divided the total system capacity between two high-efficiency reciprocating compressors, working together with one Vahterus PSHE Combined unit.

The Vahterus PSHE Combined creates a highly efficient and compact heat exchanger solution, with the primary aim of significantly reducing the ammonia charge, as demonstrated in this case. With a total ammonia refrigeration system capacity of 264TR [950kW] and an ammonia charge of 418lbs [190kg], this correlated to 1.58lbs/TR [0.2kg/kW].

Furthermore, aided by a smart control system and an oil return system with a novel design philosophy, the system ensured efficient oil separation before the heat exchanger, which helped provide a high compressor Coefficient of Performance (COP) of 6.44 for the water chilling.

The Vahterus PSHE Combined is shown in Figure 2. ■



Figure 2: Vahterus PSHE Combined.

# ALFA LAVAL IS SAVING ENERGY, REDUCING CHARGE WITH COOL RESULTS



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## ABOUT THE COMPANY

Alfa Laval is a Swedish component manufacturer within the key technology areas of heat transfer, separation and fluid handling. The company was founded in 1883. Its key products include: heat exchangers, separators, pumps, and valves. It has customers in nearly 100 countries and 42 major production units (22 in Europe, 10 in Asia, 8 in the U.S. and two in Latin America). The company has over 17,000 employees, the majority of whom are located in Sweden, Denmark, India, China, the U.S. and France.

## INTRODUCTION

L.A. Farm S.A. began as a small family business and today it is a rapidly growing dairy industry based in Thessaly, in the north of Greece. Since its establishment, it prides itself on consistently producing excellent dairy products, using only the best and purest ingredients.

Contributing to the progress and well being of local society is one of the main values of L.A. Farm S.A. The relationship that the company has built with the society over several decades encompasses many dimensions where safety and environmental awareness are the main pillars that support not only the philosophy, but the entire existence of L.A. Farm S.A.

When it was time to invest in a new 14,000m<sup>3</sup> [150,695ft<sup>3</sup>] or 110,000m<sup>3</sup> [3,884,613.34ft<sup>3</sup>] refrigerated logistics center, the importance of energy efficiency and low environmental impact was high on the agenda. How could a system become safe, energy efficient and respect both the local and global environment?

## ABOUT THE SYSTEM

### **A single-shell solution with an integrated separator**

The local partner's own experience, in combination with Alfa Laval and other quality suppliers of refrigerant components, made it possible to design and install a low-charge ammonia refrigeration system that met these requirements for a safe, energy efficient solution.



*The ammonia machine room at L.A. Farm S.A.*



To take care of the dairy facility's cooling needs, which includes a 100% redundancy and high efficiency, Alfa Laval proposed two compact ammonia evaporator systems each consisting of an Alfa Laval TK20 semi-welded plate heat exchanger with a U-Turn plug-and-play liquid separator. Each of these is capable of supplying the system's required 1,400kW [284.3TR] capacity, only containing a very low charge of ammonia.

The low charge results much from the concept of the U-Turn™ separator module that in addition to conventional gravitational separation, utilizes agglomeration, surface tension, and centrifugal forces to improve the separation function, reducing the refrigerant charge. In combination with a low-pressure drop – up to four times lower than in a conventional separation system – it becomes more energy-efficient and further reduces the required refrigerant charge.

The final system design resulted in a total ammonia charge for the dairy of only 680kg (1,499lbs) including the externally placed evaporative condensers that hold 200kg (441lbs) each. This corresponds to a specific charge of 0.49kg/kW [3.74lbs/TR].

In addition to the compact design and low ammonia charge, the Alfa Laval semi-welded plate heat exchangers allow for a very close refrigerant approach which makes it possible to save energy.

The secondary fluid applied (Temper-15), also plays an important role. It is approved for food use, environmentally friendly and a very efficient heat transfer fluid used in a wide range of refrigeration applications. This secondary fluid is used instead of direct pumped ammonia circulating in the cold storage plant, cooled from a return temperature of -3°C (26.6 F) down to a supply of -7°C (19.4°F). This could be done with a very satisfactory total refrigeration coefficient of performance (COP) of 3.9 for the plant.



*Alfa Laval flooded evaporator TK20 with U-turn™ ammonia separator.*

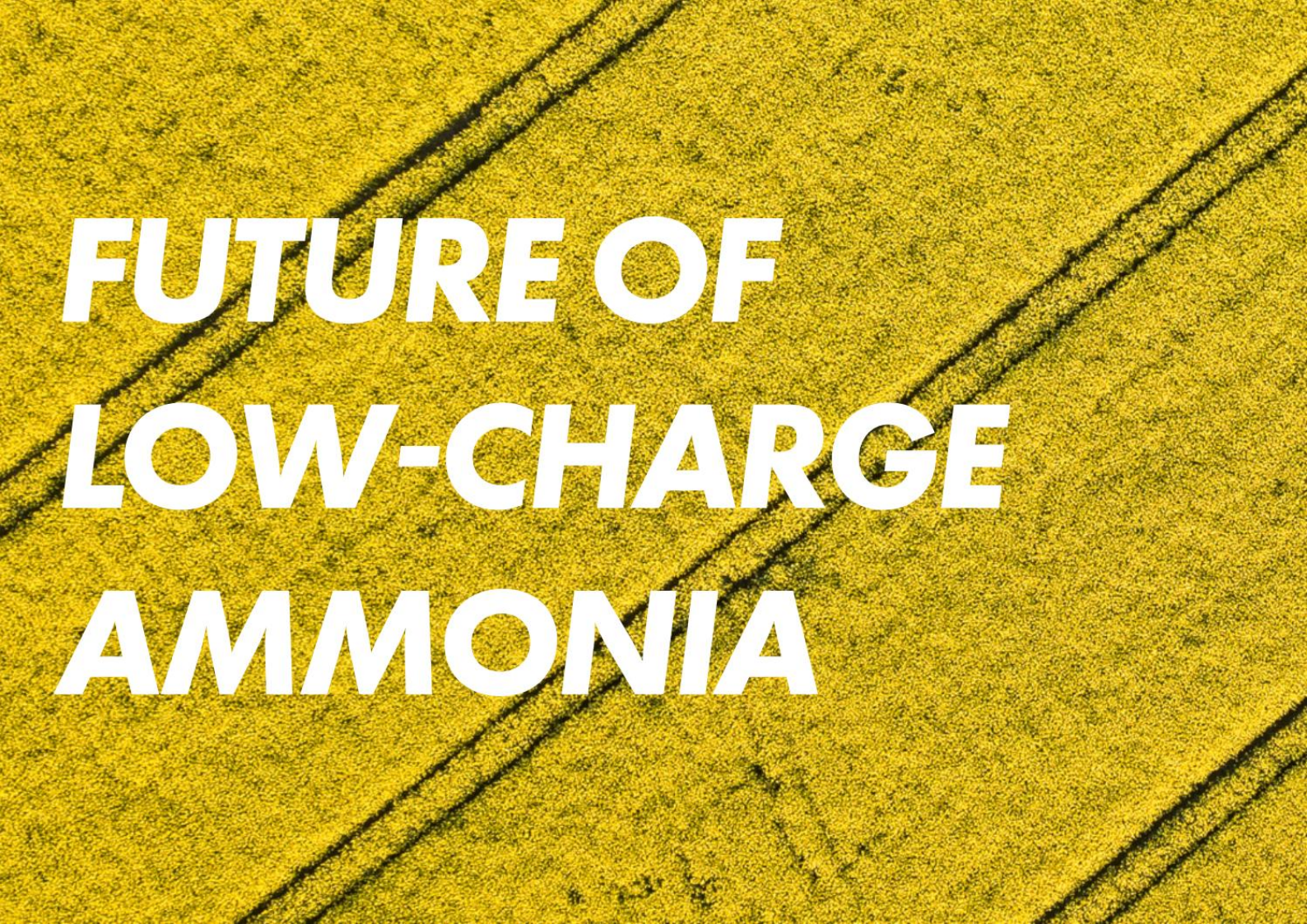
Major equipment in the system:

- Four Sabroe compressors with inverter motor producing 390kW (111TR) each at 1,800rpm.
- Two Mita Axial evaporative condensers of 2,200kW (625.6TR) heat rejection.
- Defrost function with an Alfa Laval Albanova fusion bonded heat exchanger using ammonia discharge energy.
- Two 1,400kW (284.3TR) Alfa Laval TK20-BW semi-welded plate heat exchangers equipped with U-turn ammonia evaporation gravity separator module.
- Temper technology's Temper-15 heat transfer fluid.
- Contractor: Cool Dynamic – Industrial & marine refrigeration, Perama, Greece
- Consultant: ecoRef – Engineering Consultants, Athens, Greece

## RESULTS

L.A. Farm S.A. now has a successful low-charge ammonia installation containing an ammonia charge of 0.49kg/kW [3.74lbs/TR] operating at a COP of 3.9. This is due to the low refrigerant charge design of the U-Turn and plate heat exchanger. Furthermore, there is an improved efficiency of the cooling system and therefore reduced energy consumption. ■



The background is a bright yellow color with a fine, grainy texture. Several dark, slightly irregular diagonal lines run across the image from the top-left towards the bottom-right, creating a sense of movement or a stylized pattern.

# ***FUTURE OF LOW-CHARGE AMMONIA***





# **An overview**

This chapter investigates the future market potential of low-charge ammonia systems. It looks at key factors for growth based on the global survey results as well as assessments by industry experts.

It includes an interview with Kurt Liebendorfer, Vice President of Evapco, an U.S. OEM investing in low-charge ammonia systems and technology. He speaks about the global trends and potential for this technology in the U.S. in particular.

The chapter also discusses potential barriers and drivers for low-charge ammonia systems around the world, looking at the various factors influencing the uptake with input from industry as well.

# LOOKING AT THE FUTURE OF LOW-CHARGE AMMONIA IN THE U.S.

## PARTNER INTERVIEW WITH KURT LIEBENDORFER, VICE PRESIDENT OF EVAPCO



Kurt Liebendorfer, Evapco.



### What does “low-charge ammonia” mean in your view?

Ammonia has been around for 150 years and has stood the test of time over that entire period. I believe that this low-charge ammonia technology will greatly expand its use. It addresses the safety issues that have hindered new applications of ammonia because of its toxicity. But also, because ammonia is the most effective and efficient refrigerant out there, and the low-charge technology allows it to be applied easier and safer. Because of that, it will not only grow in the applications where ammonia is already used – in the industrial markets – but it will allow it to be adopted at first into adjacent markets, and then over time, in some commercial markets too.

The debate of the last five years has been to define “low-charge” in one or two ways. The first way has been to define it in lbs/TR or in kg/kW. This has been a relatively easy metric and allows comparisons to traditional large charge systems, which can vary greatly in charge. However, that metric has changed to the definition now being around a fixed amount. The example is 500lbs (226.8kg) or less per package. I see the fixed amount definition sticking and being used.

There is a perfect analogy of this that has taken hold around the commercial use of propane and its new regulatory threshold of 500g [17.6oz]. You can't regulate

based on the lbs/TR metric because all the safety regulations are applied around a known, definable quantity of a refrigerant. It has to do with how much physical quantity can affect human safety, or how much is related to fire hazards. Most regulations are built around safety and fire, and those are only quantifiable from a regulatory standpoint based on a fixed amount, where you reach that threshold quantity. So, that's what's going to happen around 500lbs per low charge ammonia package.

### What have been the most important regulatory and industry developments for low-charge ammonia technology in the U.S.?

The International Institute of Ammonia Refrigeration (IIAR) has been hard at work over the last three years developing standards and guidelines around the use of low-charge ammonia. They recently published a guideline called Ammonia Refrigerant Management Low Charge (ARM LC). It's not a regulatory requirement, but it's a guideline to instruct manufacturers, contractors and owners of the requirements to easily implement low-charge ammonia safely. It properly addresses the safe use of ammonia, particularly for new users, but in the end, it alleviates some of the burden because the industry is used to the more burdensome requirements for large-charge ammonia systems. The historical



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practice is that there is this pushdown effect, from the requirements associated with large charge systems, being improperly applied to lower charge systems. ARM LC is establishing a stake in the ground that says you do not need to do some of these things if you have low-charge systems. The next step is to build on that success and find other areas through testing and R&D that can eliminate additional regulatory criteria.

Another important development has to do with the new White Paper by the Construction Code Committee of the Global Cold Chain Alliance (GCCA), and low charge ammonia technology being applied to the global cold chain. Because low charge is a new technology, it's important to know what is inherent with its concept, that it's a standardized packaged and distributed refrigeration solution, versus traditional systems that are custom built field-erected central-plant systems which are different for each project. So, an inherent benefit of this new low-charge technology is that the manufacturing world is embracing it as pre-engineered packaged system product lines that deliver optimized and guaranteed performance. This is a big change and I see tremendous growth looking forward. The GCCA White Paper called "Distributed Low Charge

Refrigeration Systems" helps contractors and owners understand the changes and apply this new technology to their buildings.

## **Where do you think the biggest opportunities for low-charge ammonia lie?**

The current use of ammonia is predominant and thriving in the food and beverage market. The refrigerated food supply chain is very large, from the producers to the consumers, and ammonia is prevalent in the top half of this supply chain from the producers to halfway through the distribution supply chain. Applying the new technology of low-charge ammonia has easily been started in that core market where ammonia is already dominant.

In the next year or two, low-charge ammonia will be applied further down this supply chain and displace the synthetic refrigerant packages that are common in smaller distribution and food service facilities. In addition, low-charge ammonia will also grow into adjacent markets. The adjacent markets are those that may use some ammonia already, such as the pharmaceutical industry. Pharmaceutical companies often have large cooling loads and many need actual refrigeration as well. Some have already started to apply the packaged low-charge technology. Pharmaceutical companies are massive users of synthetic refrigerants, but an increasing number have sustainability commitments to use natural refrigerants. They have the resources to understand the use of ammonia and converting to low-charge ammonia in the next one or two years on an accelerating pace is anticipated.

The other market that is a similar story is the chemical and manufacturing industries. There are already packaged low-charge ammonia systems in service at chemical plants for process cooling

applications and manufacturing facilities for process cooling or HVAC. And again, these are industries that use massive amounts of synthetic refrigerants, many of which are on the phase out list. So, we expect to be displacing the use of synthetic refrigerants with more efficient low-charge ammonia systems.

The commercial market opportunity that's already happening is the application of ice rinks. Ammonia is already used at ice rinks, but it is estimated to only represent 20% of the rinks in North America, while the remaining 80% use synthetic refrigerants. This represents a great growth opportunity for the more efficient and environmentally friendly packaged low charge ammonia systems.

## **What do you think will be the major developments for low-charge ammonia in the U.S. in the next five years?**

The major investment in this technology from manufacturers such as Evapco is going to do two things. It's going to improve the technology through continued product development, making it safer and easier to use, and through growing sales and production. It is going to bring down the price point.

Once that happens over the next few years, I think it will not only significantly expand into the markets mentioned above, but it can also further penetrate the supermarket and light commercial markets because it will become more competitive with commercial grade equipment, along with already being more energy efficient. ■

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# DRIVERS AND BARRIERS

As with any technology, there are various drivers and barriers affecting the uptake of low-charge ammonia systems around the world. It is important to carefully consider both sides as to make an informed decision regarding whether or not to install such a system.

## DRIVERS



### SAFETY:

Safety considerations are one of the major reasons why operators and end users choose

low-charge ammonia systems. First of all, in case of a leak, less ammonia is released when compared to systems with a larger charge.

Also, the design of certain types of low-charge ammonia systems such as packaged systems and indirect systems, makes it possible to use the refrigerant locally, limiting safety risks. The system can be put either on the roof or restricted to the machine room.

Furthermore, low-charge systems reduce the overall material use, requiring less piping and fewer vessels when compared to traditional ammonia systems. This means that there are fewer places where faults and leakages can possibly occur.

Another key consideration is policy and legislation. Because the charge is less, low-charge ammonia systems are not as restricted as systems with higher charges. In some countries, where policy would previously prevent the use of ammonia because of safety regulations, low-charge systems offer an acceptable alternative, bound by fewer safety restrictions due to the reduced risk.

## INDUSTRY VIEWPOINTS

### David Bornemeier, Western Gateway Cold Storage:

*"Improved safety was one of the biggest reasons we went with a low-charge system. You want to build your system so there are no releases. Any ammonia leak can be handled from the outside, and there's no chance the evaporator coils that contain ammonia will be hit by any operations in the warehouse."*

### Joseph Burch, Neptune Foods:

*"If we have a spill, there's no danger. With such a low charge, it evaporates into the air."*

### Tim Cox, Liberty Cold Storage:

*"With penthouse evaporators on the roof, no ammonia is in the room itself. That means they are out of reach of forklifts that may bump into a hanging evaporator. The penthouse evaporators are a little more expensive but you see more people going to them, just from a safety standpoint. A major leak in the penthouse units could still spill into the refrigerated space through the ducts, but a small leak would just go up in the air."*

### Michael Lynch, US Cold Storage:

Lynch believes that the  $\text{NH}_3\text{-CO}_2$  system has given them a competitive advantage. *"It helped to grow our business," he said. "We haven't had a  $\text{CO}_2$  leak but the effect of  $\text{CO}_2$  on food would be benign. Our customers like that; our insurance company loves it."*

### Caleb Nelson, refrigeration engineer/ VP Business Development at Azane:

*"Low-charge means safe and reliable operation."*





## COSTS:

Although equipment costs are often considered a barrier, when looking at the total life cycle, costs are also an important driver for the uptake of low-charge ammonia systems. Due to a more compact design of the systems, costs for installation and maintenance are often lower than for systems with a high charge.

Also, with the high energy efficiency of low-charge ammonia systems, the energy costs are usually lower too, depending on the application.

Furthermore, insurance costs might be lower too due to the increased safety of the systems. Not to mention quicker installation times, which lead to fewer man hours during construction.

## INDUSTRY VIEWPOINTS

### David Bornemeier, Western Gateway Cold Storage:

*"In terms of equipment and installation costs, the [packaged] units are 'comparable to or less' than a conventional ammonia system. That includes the oversizing of the units and the additional structural costs to support the weight of the units on the roof, which were balanced by lower labor and equipment costs for installation, energy savings, and a USD\$60,000 utility incentive."*

### Joseph Burch, Neptune Foods:

*"The [packaged] unit's simple design reduces the initial cost of the equipment and the cost of installation, which took only two days."*

### Yuta Shioya, Chemical Grouting:

*"One of the biggest benefits we saw by using the NH<sub>3</sub>/CO<sub>2</sub> system was the reduction of the project working period by 40% (39 days). The system's compact size greatly simplified the disassembly and removal process."*

### Tim Cox, Liberty Cold Storage

He also saw "an advantage on price" with the ADX system being a little less expensive (in equipment plus installation) than a liquid-overfeed system.

### Stefan Jensen, Managing Director at Scantec Refrigeration Technologies:

*"An investment in a low-charge ammonia system is an investment with real returns and not merely an investment in replacing the working fluid with a low GWP refrigerant. The returns are in the form of significantly reduced energy consumption and a reduction in annual maintenance costs by at least a factor two compared with HFC404A."*

### John Scherer, Chief Technology Officer at NXT Cold:

*"There is a slew of benefits associated with low charge: highly competitive installation costs, reduced operating (energy and maintenance) costs, lower insurance costs, simplified and lower-cost back-up power options, and smaller land and building requirements. In addition, the low-charge technology enables the end user to focus more on 'core' business activities."*

### Bruce Nelson, President at Colmac Coil:

*"What is helping to drive adoption of the ADX system is its lower cost – 2% to 5% less than that of a traditional overfeed system."*

## ENVIRONMENT:



There is no difference in terms of environmental impact for low-charge ammonia systems compared to

large-charge ammonia systems, as the Global Warming Potential (GWP) is 0 in both cases, regardless of the charge. However, the low-charge technology allows for ammonia to be used in more applications than previously. Thus, there is the possibility to replace HFC systems, which have a much higher GWP. In this way, low-charge ammonia helps to reduce negative impacts on the climate.

## INDUSTRY VIEWPOINTS

### Paul Arrowsmith, Sainsbury's Supermarkets, talking about his NH<sub>3</sub>/CO<sub>2</sub> cascade system:

*"We looked at ammonia only, we took HFCs as a benchmark, and we looked at pure commercial CO<sub>2</sub> refrigeration. What we've installed here gave us the best balance between cost, energy and Global Warming Potential – all the main measures you look at in an installation."*



#### POLICY:

One of the most important drivers for the uptake of low-charge ammonia, is policy. In countries where

there is regulation concerning ammonia systems with high charges, and where this regulation is seen as strict and burdensome, the use of low-charge ammonia systems is more widespread than in other countries.

#### INDUSTRY VIEWPOINTS

##### John Scherer, Chief Technology Officer at NXT Cold:

*"The biggest initial driver of low-charge-ammonia adoption has been the opportunity to potentially lower the federal regulatory burden imposed on systems that have more than 10,000 pounds of ammonia, as well as reduce the hazards and potential legal liability that large charges present."*

##### Michael Lynch, US Cold Storage:

*"The biggest regulatory burden on cold storage facilities that use more than 10,000 pounds of ammonia refrigerant is complying with OSHA's PSM (process safety management) and the EPA's RMP (risk management plan) requirements. Using an ammonia-CO<sub>2</sub> system, we stay below the 10,000-pound threshold, which removes filing protocols and puts our plants at less of a risk during an audit."*

##### David Bornemeier, Western Gateway Cold Storage:

*"We were looking at this building lasting a good long time, not only from a regulatory standpoint but for operations and maintenance as well. So hands-down, low-charge ammonia was a better decision."*



#### ENERGY EFFICIENCY:

Ammonia as a refrigerant is very energy-efficient. Low-charge ammonia systems may be even more efficient than

traditional ammonia systems because of reduced piping, fewer pumps, and optimized evaporator design. However, this depends on the application and cannot be generalized.

It can however be said that DX systems are usually more efficient as compared to liquid overfeed systems, because of the elimination of pumps and excess liquid refrigerant, thus eliminating liquid refrigerant in suction lines.

#### INDUSTRY VIEWPOINTS

##### Tim Cox, Neptune Foods:

*"We saw the benefits with the cost of energy. We're trying to raise the bar by being more efficient with energy and having less ammonia."*

##### Yuta Shioya, Chemical Grouting:

*"By switching from traditional R22-based systems to Mayekawa's NH<sub>3</sub>/CO<sub>2</sub> industrial refrigeration system, we were able to achieve 40% savings in energy consumption. Besides, due to the high efficiency of CO<sub>2</sub> and its low viscosity, the new method is able to freeze the soil more quickly and at lower temperatures."*

##### Stefan Jensen, Managing Director at Scantec Refrigeration:

*"Energy consumption of low-charge ammonia is much lower than for an HFC system and CO<sub>2</sub> transcritical."*

##### Kurt Liebendorfer, Vice President at Evapco:

*"Comparing low-charge ammonia to CO<sub>2</sub>: Ammonia is more efficient, the systems are simpler and the energy costs are lower. That means that overall, ammonia is winning."*

## BARRIERS



### COSTS:

Often, one of the greatest barriers to opting for a low-charge ammonia system is investment costs. However, it is important to note that especially in large-scale industrial refrigeration facilities, operating costs are more important than initial costs or capital costs. Higher capital costs for low-charge ammonia systems could be compensated by lower maintenance costs or increased energy efficiency in advanced systems.

### INDUSTRY VIEWPOINTS

Kurt Liebendorfer,  
Vice President of Evapco

*"Cost is still a big barrier, meaning the actual cost and a better understanding of what is included."*

In the survey, capital and life cycle costs were evaluated as the most important by the end users, followed by the possibility to have factory-tested systems.

Less important, were incentives to reduce capital costs of equipment, opportunity to have "customized" products, and others.



### AVAILABILITY OF TRAINING AND INDUSTRY KNOWLEDGE:

According to the "Guide on Training in 2017" report by shecco: in Europe, the uptake of training on natural refrigerants is progressing rapidly, mainly as a consequence of the F-Gas Regulation that promotes moving away from high-GWP HFCs. Nevertheless, there are still some barriers to overcome with regards to training. These include lack of awareness; and investment costs related to both setting up training facilities and taking part in courses.

As ammonia has been around for a long time, training should be less of a barrier than for other natural refrigerants. However, the awareness about low-charge ammonia in comparison to traditional ammonia is limited, especially in developing countries. This could make suitable courses hard to come by and/or expensive.

### INDUSTRY VIEWPOINTS

Caleb Nelson, refrigeration engineer/ VP Business Development at Azane:

*"There is not enough awareness in the industry for low-charge ammonia; more education/information is needed."*

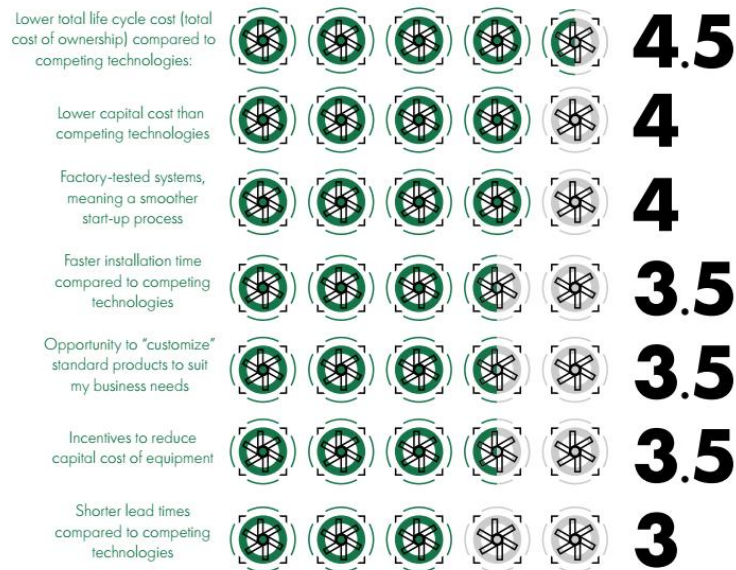
But, as low-charge ammonia systems become more popular, training will become a necessity driven by demand. This should drive down the costs and increase availability of training in future.



## Life cycle cost – the most important factor for new equipment purchases

Deciding factors for equipment purchases for end users (Ranking from 1 to 5 with 5 being the most likely)

End users that do not have any low-charge ammonia installations at the moment were asked which factors they consider most important for their purchasing decision. The most important factor for buying a low-charge ammonia system was lower life cycle cost compared to competing technologies. Another important driver was the benefit of factory-tested systems, which means a smoother start-up process.

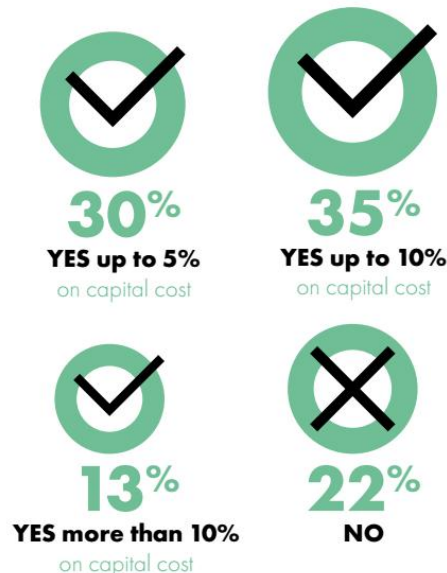


15 respondents

## More than 75% are willing to pay a premium

When all the respondents were asked if they, or their customers, would pay a premium to reduce the ammonia charge, 30% answered that they would be ready to pay a premium of 5% on capital cost. 35% are even ready to pay 10%. 22% of the respondents answered this question with "no".

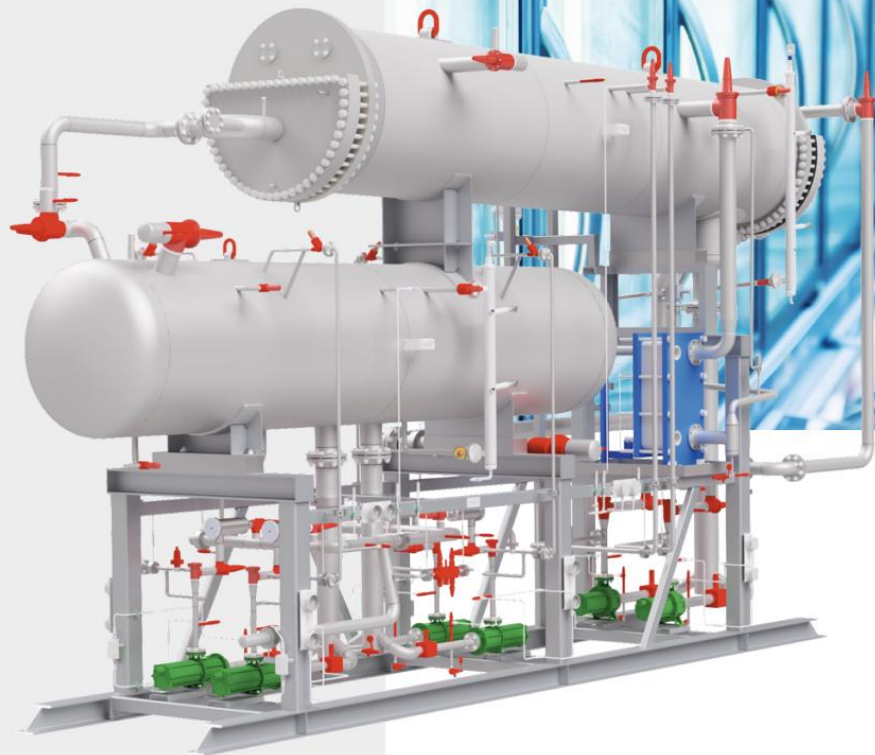
These results indicate that the capital costs are not as important to study participants as the overall costs, including operation and maintenance of the installations.



199 respondents

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Holger Andreasen & Partner GmbH  
Sustainable Solutions

## POTENTIAL FOR FUTURE GROWTH

There is a huge potential for growth of low-charge ammonia systems, not only in conventional applications such as industrial installations but also new markets not previously considered, such as commercial refrigeration and even air-conditioning.

"In the next three to five years, the market for commercial applications will grow, maybe even residential," said Tony Lundell of the International Institute of Ammonia Refrigeration (IIAR).

As legislation such as the Kigali Amendment to the Montreal Protocol increasingly clamps down on HFC use in an attempt to mitigate the problem of carbon emissions and the growing so-called "climate crisis," interest in natural refrigerants will continue to grow. Close to 100 countries have ratified this treaty already with more promising to do so in the near future.

Ammonia as a refrigerant is particularly appealing to end users because of its potential efficiency, particularly in large-scale applications. Thus, as energy costs continue to increase globally, energy efficiency in HVAC&R systems will continue to be a key consideration for end users, driving the uptake of ammonia.

The main barrier for the widespread use of ammonia remains safety concerns, from governments in the form of legislation as well as from manufacturers and operators. This is why low-charge ammonia specifically has great potential as it uses a much lower charge, thus reducing the risk associated with a high charge.

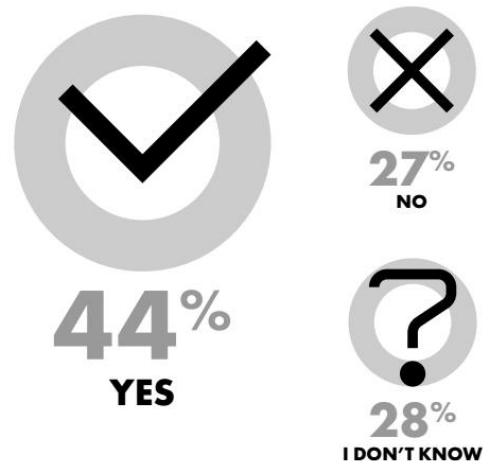
As industry continues to invest in research and development of these systems, and more end users pilot projects using this technology, further innovations in low-charge ammonia refrigeration systems might open up new markets while the standardization of the products drive the costs down.

"Low-charge ammonia will be used more in the future; especially for extensions to existing plants it makes sense," said Stefan Jensen of Scantec Refrigeration Technologies.

## FUTURE PLANS OF SURVEYED COMPANIES NOT WORKING WITH LOW-CHARGE AMMONIA TODAY

**Manufacturers and contractors: Almost half plan to start working with low-charge ammonia in future**

From the surveyed organizations that are non-end users and not currently working with ammonia, nearly half (44%) plan to work with low-charge ammonia in the future. The rest either do not know (28%) or are not planning to work with low-charge ammonia in the future (27%).



Key legend for survey infographics

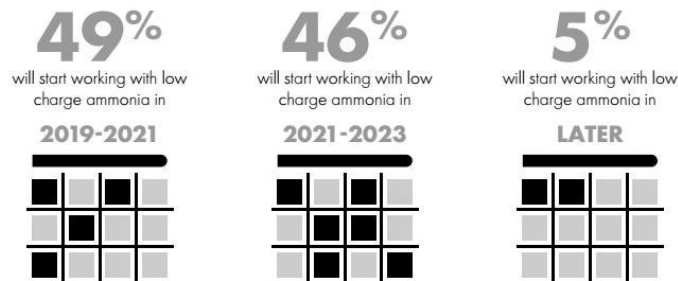
- All Participants
- End Users
- Equipment manufacturers, component manufacturers, refrigeration contractors, consultants, general building contractors, other

88 respondents



## Manufacturers and contractors: More low-charge ammonia products expected in near future

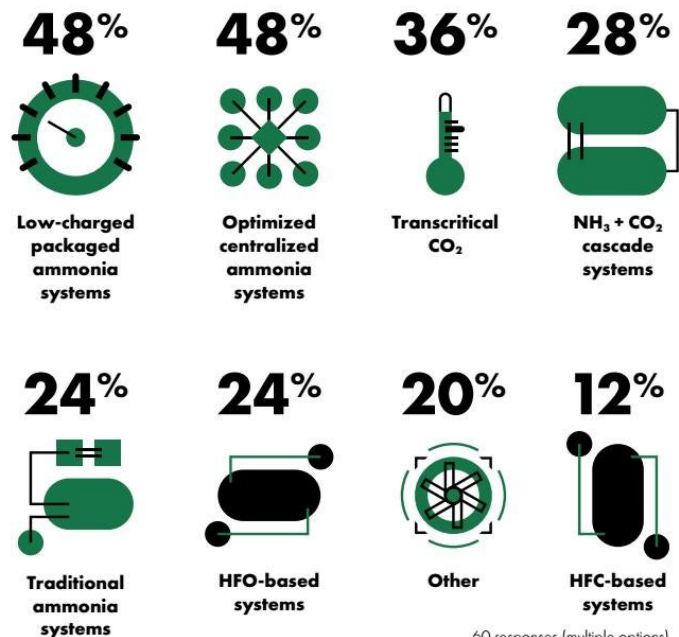
Out of those organizations that plan to start working with low-charge ammonia in the future, 95% want to do so by 2023. This indicates that within the next few years more companies are expected to introduce low-charge ammonia products.



39 respondents

## End users likely to consider low-charge ammonia in future projects

All end-users were asked which refrigerant technologies they would consider for future projects. The most positive results were for low-charge packaged ammonia systems and optimized centralized ammonia systems (such as DX, low overfeed, etc.), which were considered by nearly half of the respondents (48% each). 28% of respondents would consider ammonia/CO<sub>2</sub> cascade systems while about one quarter also considered traditional ammonia systems (24%).

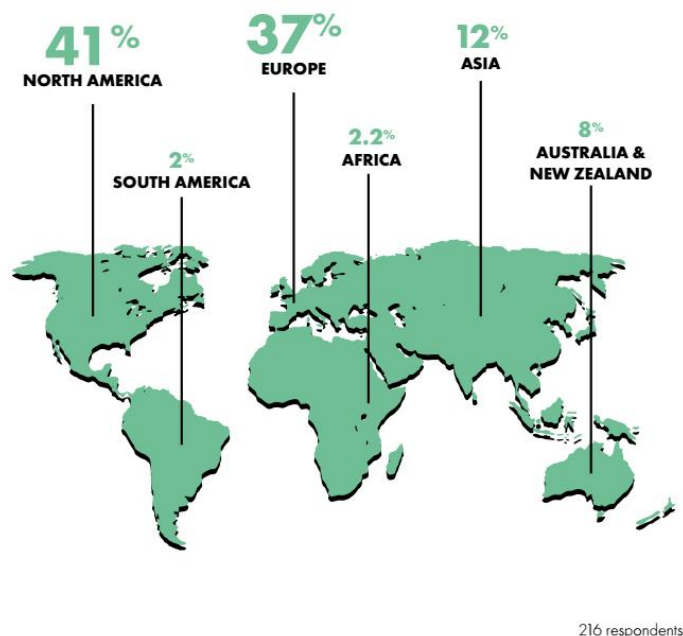


60 responses (multiple options)

## FUTURE MARKET SHARE AND KEY REGIONS

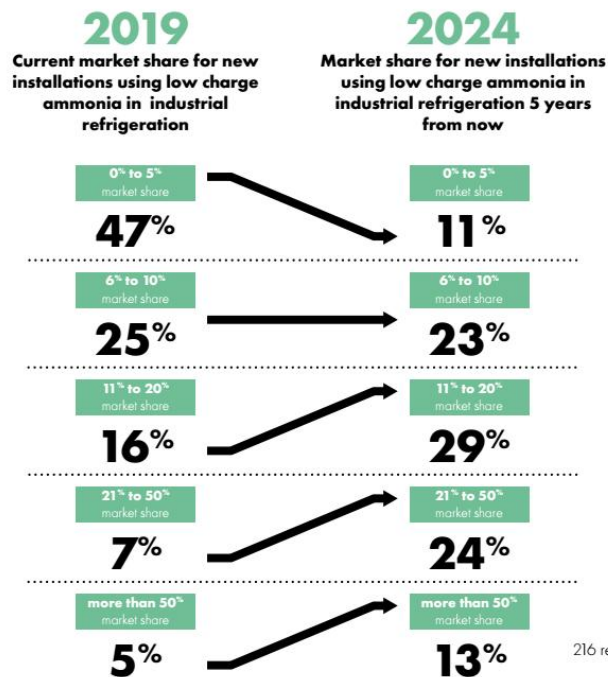
### Growth mostly expected in North America and Europe

This increase in installations using low-charge ammonia is expected mostly in North America (41% of respondents) and Europe (37% of respondents). The lowest growth is expected in South America (2%) and Australia/New Zealand (8%).



### Market share of low-charge ammonia installations expected to grow

When asked what the market share of new installations using low-charge ammonia in industrial refrigeration in their region will be like five years from now, the picture looks a little bit different. The majority of respondents (52%) estimate the share between 6% and 20%; while 24% estimate it to be much higher between 21% and 50%. This shows that these respondents expect the share for new installations using low-charge ammonia in industrial refrigeration to grow exponentially within the five years.



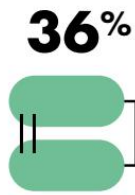
## APPLICATIONS FOR FUTURE USE

### Low-charge ammonia expected to dominate refrigerated warehousing in the future

When asked to compare various refrigeration systems, the technology that is estimated to dominate refrigerated warehousing 10 years from now, is low-charge ammonia (51%), followed by ammonia/CO<sub>2</sub> cascade (36%). 13% of the respondents went for traditional ammonia systems in their estimate.



**Low charged packaged ammonia systems**



**NH<sub>3</sub> + CO<sub>2</sub> cascade systems**



**Transcritical CO<sub>2</sub>**



**Traditional ammonia systems**



**Other**

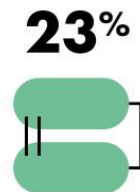
296 responses (multiple options)

### Food retail applications still hesitant about using ammonia

The answers for the same question concerning food retail applications paint a different picture. Transcritical CO<sub>2</sub> is clearly dominant with 57% and the next option, ammonia/CO<sub>2</sub> cascade, is only at 23%. This reflects the common distinction between use of ammonia in industrial refrigeration and use of CO<sub>2</sub> in commercial refrigeration.



**Transcritical CO<sub>2</sub>**



**NH<sub>3</sub> + CO<sub>2</sub> cascade systems**



**Self-contained hydrocarbons**



**Other refrigerant + CO<sub>2</sub> cascade**



**Hydrocarbons water loop**



**Synthetic refrigerants**



**Other**

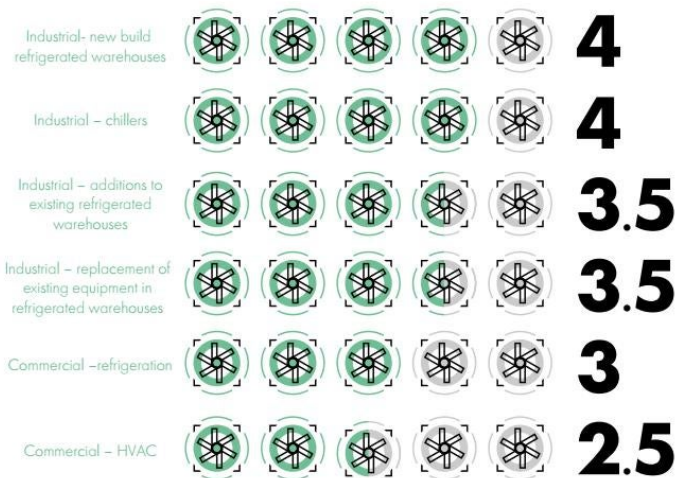
310 responses (multiple options)



### Biggest potential in industrial refrigeration

Drivers to change (potential 1 out of 5)

The respondents see the biggest potential for growth of low-charge ammonia systems in industrial refrigeration, voting chillers and new build refrigerated warehouses as having the greatest potential (potential of 4 respectively out of 5). The least potential is noted as commercial HVAC at only 2.5 out of 5.



200 respondents

## CONCLUSION

Although ammonia has been used in the HVAC&R industry for more than 150 years, the advent of low-charge ammonia systems is propelling this age-old technology into the 21st Century.

There is currently no agreed set definition for what exactly is considered a "low-charge" ammonia system, but definitions proposed by different stakeholders range from 0.5lbs/TR to 10lbs/TR [0.065kg/kW to 1.3kg/kW] – with some preferring a fixed charge limit.

Regardless of how low exactly the charge is, thanks to its reduced safety risks when compared to traditional larger charge ammonia systems, low-charge ammonia installations are once again making this natural refrigerant a viable option for those previously put off by safety concerns and policy restrictions.

By means of a data collection from manufacturers and an industry-wide survey, it was found that there is an increasing number of low-charge ammonia installations world-wide and that the key regions are Europe and North America. Currently, the share of low-charge ammonia installations is relatively low; but there is huge potential to scale it up.

Even for applications previously not considered suitable, low-charge ammonia now offers an environmentally friendly, natural alternative to synthetic refrigerant installations. It's no longer just large-scale industrial projects that can benefit from ammonia's well-known efficiencies. It can also be used in commercial installations such as supermarkets and even in air conditioning, where low-charge ammonia is believed to hold a huge potential in view of the growing regulatory restrictions on chemical refrigerants.

With extensive research, the "World Guide to Low-Charge Ammonia" shows that ammonia is once again a viable refrigerant option and that low-charge ammonia systems are worth considering for future HVAC&R installations.





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Get in touch with shecco's market development team to learn more about the market for natural refrigerants or find out how we can help you in gathering market intelligence and proactively building your business with our tailored market development services, to get your technology faster to market.

Email us at  
[md@shecco.com](mailto:md@shecco.com)

Talk to us on the phone  
**shecco Europe** +32 2 230 3700  
**shecco America** +1 (347) 763-7043  
**shecco Japan** +81-3-4243-7095

Our mailing address  
**shecco Europe**  
Rue Royale 15, 1000 Brussels,  
Belgium

**shecco Japan**  
Global Business Hub Tokyo,  
Otemachi Financial City Grand Cube 3F  
Otemachi 1-9-2, Chiyoda-ku, Tokyo, 100-0004

**shecco America**  
81 Prospect St, Brooklyn,  
NY 11201

**shecco**MarketDevelopment 

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