Lower-GWP Alternatives in Commercial and Transport Refrigeration: An expanded compilation of propane, CO$_2$, ammonia and HFO case studies
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Executive Summary

The Climate and Clean Air Coalition (CCAC) adopted a range of activities to initiate action in key countries and within specific sectors to improve understanding of high global warming potential (GWP) HFC use and create incentives to encourage the development and transition to climate-friendly alternatives to high-GWP HFCs. The CCAC Working Group approved funding for various capacity building activities related to low-GWP alternatives to HFCs. One of these activities included the creation of a compilation of case studies on alternatives to HFCs in the commercial refrigeration sector. UNEP DTIE OzonAction worked in cooperation with the CCAC to publish this compilation in 2014.

The present publication comprises an expanded and updated compilation of case studies on lower-GWP energy efficient alternatives and technologies in the commercial refrigeration as well as the transport refrigeration sectors. It provides a number of new commercial refrigeration case studies as well as case studies from the transport refrigeration sector, including alternatives not previously considered in the first volume, to provide better geographical spread and present a more comprehensive overview of lower-GWP alternatives adopted.

This publication comprises two sections. Section 1 on commercial refrigeration, specifically retail food refrigeration firstly provides a brief sector overview and includes six new case studies and the original five case studies. The information is presented in a consistent and structured manner for each case study to allow easy comparison and cross-referencing. These new case studies cover a carbon dioxide (CO2)/hydrofluoroolefln (HFO) blend cascade system, two different ammonia and CO2 cascade systems, a CO2 transcritical system, a propane system, and a retrofit of a centralised direct expansion refrigeration systems from an HFC to a lower GWP HFC/HFO-blend refrigerant. These supplement the original case studies which covered the following technologies: two transcritical CO2 systems, a CO2 cascade system with HFC, a chiller using HFO-1234ze system and a Propane system. Section 2 provides an overview of the Transport Refrigeration Cold Food Chain sector and three case studies on transport refrigeration. These cover two CO2 systems and a liquid nitrogen system.

Each case study provides information on the type of facility and refrigerant used, an explanation and background is provided of how the transition was decided upon, designed and carried out. Information on performance and economic considerations are also included. Contact details are provided for the reader to seek out more information from the enterprises, as appropriate.

This updated compilation is primarily intended to assist relevant decision makers, especially those in developing countries, in selecting the most appropriate climate-friendly alternatives in both the commercial refrigeration as well as the transport refrigeration sectors.

Introduction

A note on this edition

This booklet presents an expanded compilation of case studies on lower-GWP alternatives in commercial and transport refrigeration and provides an update to the first set of case studies which was published in 2014 by UNEP DTIE OzonAction/CCAC (Low-GWP Alternatives in Commercial Refrigeration: Propane, CO2 and HFC Case Studies, available at: www.unep.org/ccac/portals/50162/docs/Low-GWP_Alternatives_in_Commercial_Refrigeration-Case_Studies-Final.pdf).

Section 1 of the booklet provides a number of new commercial refrigeration case studies, including alternatives not previously considered, as well as all the initial case studies from the first compilation. Section 2 provides case studies from the transport refrigeration sector.

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) is a unique global effort supporting fast actions to mitigate the impacts of short lived climate pollutants, such as black carbon, methane and many hydrofluorocarbons (HFCs) and addressing near-term climate change and air pollution at the same time. The CCAC is a voluntary partnership bringing together over 50 country and Regional Economic Integration Organization (REIO) partners and 61 non-state partners including intergovernmental organisations, representatives of civil society and the private sector.

The CCAC has launched a transformative initiative (entitled 'The HFC Initiative, Promoting HFC Alternative Technology and Standards') for rapid implementation aimed at promoting HFC alternative technologies and standards to significantly reduce the projected growth in the use and emissions of high-global warming potential (GWP) HFCs in coming decades relative to business-as-usual scenarios. The objectives of the initiative are to mobilise efforts of the private sector, civil society, international organisations, and governments to:

- Promote the development, commercialisation, and adoption of climate-friendly alternatives to high-GWP HFCs;
- Encourage the uptake of climate-friendly alternatives that could support national, regional and global policies or approaches to reduce reliance on high-GWP HFCs;
- Overcome barriers that limit the widespread introduction of these climate friendly technologies, including those related to the establishment of standards; and
- Encourage the responsible management of existing equipment and better designs for future equipment in order to minimize leaks.

The HFC Initiative will help achieve these objectives by improving global understanding of current and projected future use of HFCs, by sharing lessons on the design and implementation of policies to reduce their emissions and use, by addressing barriers, including reforming standards, and by validating climate-friendly technologies in key areas of HFC use or projected growth.

As countries phase out hydrochlorofluorocarbons (HFCs) under the Montreal Protocol on Substances that Deplete the Ozone Layer, they often need to make choices between high-GWP HFC alternatives and, when available, more climate-friendly alternatives. Depending on the alternatives selected, the increase in HFC emissions could partly offset the climate benefits achieved by the earlier reduction in ozone-depleting substance (ODS) emissions under the Montreal Protocol.

In order to assist in planning and implementing ODS transitions that minimise climate impacts, OzonAction/CCAC has developed this booklet of case studies on lower-GWP energy-efficient technologies that have been adopted in the commercial and transport refrigeration sector as alternatives to replace or avoid high-GWP HFCs. Given that the commercial refrigeration sector has a number of climate-friendly refrigerant alternatives that are already commercialised or near commercialisation in some countries and regions, the booklet presents lessons learned from real cases in commercial refrigeration and aims to stimulate further investigation to enable a smooth transition away from high-GWP refrigerants and assist in the selection of future refrigerants. The case study...
SECTION 1: COMMERCIAL REFRIGERATION

A note on Section 1

This section presents six new case studies (case studies 1 to 6) of technologies and approaches of implementation of lower GWP alternatives in the commercial refrigeration sector, specifically retail food refrigeration, not covered in the first volume to provide better geographical spread and present a more comprehensive overview of lower GWP alternatives adopted. In addition, all the initial case studies that were included in the first compilation of Commercial Refrigeration case studies which was published in 2014 in: Low GWP Alternatives in Commercial Refrigeration: Propane, CO2 and HFO Case Studies are included (case studies 7 to 11).

Sector Overview

The commercial refrigeration sector comprises the equipment, technologies and services used to store and dispense frozen and fresh foods at the appropriate temperatures. This sector includes stand-alone or self-contained systems, condensing unit systems, and centralised or ‘multiplex rack’ systems. According to the 2014 assessment of the Montreal Protocol advisory panel, the Technology and Economic Assessment Panel (TEAP) Technical Option Committee, commercial refrigeration is one of the sectors where the refrigerant demand is the highest for servicing, as a result of the high emission levels of refrigerants from supermarket systems. Also the special report of the Intergovernmental Panel on Climate Change (IPCC)/TEAP indicated that on a global basis, commercial refrigeration is the refrigeration subsector with the largest CO2-equivalent emissions, representing 40% of total annual refrigerant emissions. These emissions are categorised as direct and indirect emissions. Direct emissions refer to emissions of the refrigerant itself during system manufacturing, operation, and disposal at end-of-life. Indirect emissions refer to the emission of carbon dioxide and other greenhouse gases (GHGs) that result from the energy consumption (usually electricity) of the system over its lifetime. Reducing the leakage rates through better design and installation practices will reduce the direct emissions. As reported by the IPCC, the refrigerant emissions might represent 60% of the total emissions of GHGs resulting from system operation, the rest being indirect emissions generated by power production. A higher Coefficient of Performance (COP = heat removed/ required work) for the refrigerated system will help in reducing the indirect emissions since the amount of work required to remove the heat will decrease.

Research was conducted to generate a list of potential case studies for consideration taking into account all of the currently available zero- and lower-GWP refrigerants in commercial refrigeration applications, including “natural” or non-fluorinated refrigerants, such as hydrocarbons, carbon dioxide (CO2), ammonia, and R-290 (propane) as well as the other major category of alternatives comprising man-made chemicals such as the unsaturated HFCs known as hydrofluoroolefins (HFOs) which include R-450A and R-449A. HFOs are a new class of unsaturated HFC refrigerants which have shorter atmospheric lifetimes and lower GWPs when compared to other HFCs. Some criteria such as geographic location, refrigerant used and available information of the proposed applications were taken into consideration when selecting the case studies. These chosen case studies examine energy efficiency benefits of alternatives, as well as cost, safety, availability, maintainability, life expectancy and other sustainable and environmental considerations. Robust technical information was collected in the chosen case studies based on data provided by the source. These case studies also provide a detailed analysis for the system components, methodologies, and controls technology to optimise energy efficiency and continually update with new developments. An overview of the refrigeration cycles that are used in supermarkets is provided below.

The case studies that are covered in this section (Section 1) of the booklet address mainly centralised systems used in supermarket stores, as well as stand-alone units. The technologies presented in these case studies are only some examples of the many available options for zero- and lower-GWP substances, taking into account all design criteria, such as system performance, environmental impact, and cost analysis. The cases presented here focus on CO2, hydrocarbons and unsaturated HFC refrigerants, and other options.
which deploy ammonia and other configurations of refrigerants. Some of the case studies also provide a sustainable holistic approach with state-of-the-art energy design methodologies and tools such as computational models such as simulations techniques as well as computational air flow dynamics (CFD) and lighting simulations. All these refrigerants still have many challenges that should be considered in the design such as their flammability, toxicity, lower efficiencies in some cases, and cost. Balancing the safety, energy efficiency, cost, and environmental impact of refrigerants using a consistent and comprehensive methodology across all refrigerants and system types is essential in assessing alternatives. Good design is also important for reducing refrigerant emissions and preventing refrigerant loss during installation, operation, maintenance, decommissioning and end-of-life disposal. There are also several ways to reduce the refrigerant charge in a supermarket, such as proper piping design, type of condenser used, use of electronic expansion valves, and an efficiently designed distributed system. All these are measures to reduce refrigerant charges and therefore decrease the overall CO2 footprint of the system.

Types of Commercial Refrigeration Systems

Most supermarkets use centralised direct expansion (DX) systems to chill their products. Typically, these refrigeration systems are charged with 1,360 – 1,815kg of refrigerant and can leak in excess of twenty percent of their charge each year. Commonly used refrigerants include ozone-depleting HCFC refrigerants, often HCFC-22, and blends consisting entirely or primarily of HFCs. Both HCFCs and HFCs are potent greenhouse gases. Fortunately, in recent years there have been advances in refrigeration technology that can help food retailers reduce both refrigerant charges and refrigerant emissions. Below is a general description of a centralised DX system as well as an overview of the different advanced refrigeration options.

- Centralised DX System
- Distributed System
- Secondary Loop System
- Transcritical CO2 system
- Cascade System

Schematic of a Centralised DX System

Schematic of a Distributed System

Schematic of a Secondary Loop System

Centralised Direct Expansion System

A large number of supermarkets use centralised DX systems to cool their display cases and walk-in refrigerators. In a DX system, the compressors are mounted together and share suction and discharge refrigeration lines that run throughout the store, feeding refrigerant to the cases and coolers. The compressors are located in a separate machine room, either in the back of the store or on its roof, to reduce noise and prevent customer access, while the condensers are usually air-cooled and therefore placed outside to reject heat. The multiple compressor racks operate at various suction pressures to support display cases operating at different temperatures. The hot gas from the compressors is piped to the condenser and converted to liquid. The liquid refrigerant is then piped to the receiver and distributed to the cases and coolers by...
the liquid manifold. After cycling through the cases, the refrigerant returns to the suction manifold and the compressors. Supermarkets tend to have one DX system for low-temperature refrigeration (e.g., ice cream, frozen foods, etc.) and one or two DX systems for medium temperature refrigeration (e.g., meat, prepared foods, dairy, refrigerated drinks, etc.).

Distributed System
Unlike centralised direct expansion refrigeration systems, distributed systems use multiple smaller units that are located close to the display cases that they serve. For instance, compressors in a distributed system may be located on the roof above the cases, behind a nearby wall, or even on top of, or next to, the case in the sales area. The close proximity of the compressors to the cases and coolers allows the system to use less piping and a smaller refrigerant charge than traditional DX systems. This reduction in charge often results in a decrease in total refrigerant emissions.

Secondary Loop System
Secondary loop systems use a much smaller refrigerant charge than traditional direct expansion refrigeration systems, and hence have significantly decreased total refrigerant emissions. In secondary loop systems, two liquids are used: a primary refrigerant and a secondary fluid. The secondary fluid is cooled by the primary refrigerant in the machine room and then pumped throughout the store to remove heat from the display equipment. Secondary loop systems typically operate with two to four chiller systems depending on the temperatures needed for the display cases.

Transcritical CO₂ system
Refrigeration systems that use CO₂ as a primary refrigerant are commonly referred to as transcritical CO₂ systems. In transcritical CO₂ refrigeration systems, CO₂ is the sole refrigerant, evaporating in the subcritical region and rejecting heat at temperatures above the critical point in a gas cooler instead of a condenser. In addition to having a simple concept, this system has considerable environmental benefits in terms of reducing HFC usage completely.

Cascade System
Cascade systems consist of two independent refrigeration systems that share a common cascade heat exchanger. Each of the two systems uses a different refrigerant that is most suitable for a specific temperature range. High temperature systems use high boiling point refrigerants such as R-404a, R-507a, R-134a, propane, butane, and ammonia, whereas low temperature systems use low boiling refrigerants such as R-744 (CO₂) and R-508B. The advantages of a cascade system include a reduction in the refrigerant charge and a reduced carbon footprint.
**CASE STUDY-1**

Auchan – City center mall, France

**Name of the Store/facility:**
Auchan – City center mall

**Location:**
Epinay sur-Seine, France

**Contact Information:**
Name: Robert Kebby
Email: robert.kebby@honeywell.com
Designation: Global Marketing Manager – Commercial Refrigeration

**Type of Facility:**
New build Hypermarket, Area: 8000m²

**Refrigeration System type:** Centralised packaged CO₂ / Solstice® N13 R-450A Cascade refrigeration system

**Refrigerant Used:**
The store was originally planned to use HFC-134a / pumped Carbon dioxide (CO₂) Cascade system where HFC-134a has a Global Warming Potential (GWP) of 1430. The decision was made to use Solstice® N13 (R-450A) - a lower GWP Hydrofluoroolefins (HFO) blend from Honeywell - in place of HFC-134a in the store. Solstice® N13 (R-450A) is a Zeotropic blend of HFC-134a and HFO-1234ze (Solstice® ze). (42% HFC-134a / 58% R-1234ze). Solstice® N13 is A1 and has a GWP of 47; a near 62% reduction (883) in the GWP level of R134a with an expected, slight 3% Co-efficient of Performance (COP) improvement validated by independent party laboratory testing (Tewis Smart Solutions International).

**Project Background:**
Groupe Auchan has a preferred refrigeration design they use on their larger format stores. This system has been designed to minimise refrigerant leakage, reduce the energy consumed, whilst ensuring progress towards lowering their CO₂ footprint.

The store was a totally new build ‘flagship’ store for Auchan on the outskirts of Paris. Fig.1 shows a photo of the hypermarket in Paris. Ability to maintain the same system design was key to allowing the Axima technicians an easy introduction to the use of this new HFO blend.

The system in operation showed a slight improvement in performance, a lower condensing temperature than HFC-134a and reduced oil temperature – meaning less ‘wear and tear’ on the compressors / longer system life. Pressures, saturated temperatures and mass flow of the refrigerant Solstice® N13 was very similar to that of HFC-134a.

**New System/Installation:**
Groupe Auchan worked alongside its refrigeration partner Axima Refrigeration to develop a more environmentally conscious system for the Epinay sur-Seine store that combined the lower GWP and slightly better energy efficiency of a new refrigeration HFO blend named Solstice® N13 – and the proven performance of pumped CO₂. Solstice® N13 has a critical temperature of 104.4 °C and critical pressure of 38.2 bar.

The system uses Solstice® N13 in a liquefaction unit to convert gaseous CO₂ into a liquid that is then pumped to deep freeze containers, cold rooms and display cabinets. The CO₂ returns in a gaseous form to the Solstice® N13 liquefaction unit ready for converting again to liquid. Table 1 shows Medium and Low Temperature system details.

**Table 1**

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>MEDIUM TEMPERATURE</th>
<th>LOW TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerant</td>
<td>Solstice® N13 (R-450A)</td>
<td>CO₂</td>
</tr>
<tr>
<td>Refrigerant charge</td>
<td>1,200 kg</td>
<td>Secondary MT circuit = 2,000 kg</td>
</tr>
<tr>
<td>LT Cascade circuit</td>
<td>2,000 kg</td>
<td></td>
</tr>
<tr>
<td>Refrigeration power</td>
<td>800 kW</td>
<td>105 kW</td>
</tr>
<tr>
<td>Consumption power</td>
<td>350 kW</td>
<td>21 kW</td>
</tr>
<tr>
<td>Regime (evap./condensing temp)</td>
<td>-11°C / +45°C</td>
<td>-45°C / +35°C</td>
</tr>
<tr>
<td>Compressor type and manufacturer</td>
<td>Screw / Bitzer / Semi-Hermetic Piston / Bitzer</td>
<td></td>
</tr>
<tr>
<td>No. of compressors</td>
<td>6 in 2 packs</td>
<td>3 in 1 pack</td>
</tr>
</tbody>
</table>

All components used for the Solstice® N13 system were pre-approved by manufacturers to ensure consistent operation.

To support the yearly energy saving objectives of the project, the system includes a floating high pressure, a floating low pressure, as well as variable speed control on the compressors of the negative CO₂ rig, on the positive N13 compressor and on heat recovery units. Fig. 2 shows a schematic diagram of the refrigeration system.
CASE STUDY-1 Auchan – City center mall

Field Test Results: Proving the Value of Solstice® N13 (R-450A)

Commissioning was easy and straightforward and standard polyol-ester (POE) oil used for HFC-134a was suitable for compressors. The Solstice® N13 liquefaction rig started as it would have done with HFC-134a (insignificant glide as it is a zeotropic blend of HFC-134a and HFO-1234ze, slightly lower pressure than HFC-134a).

Since the opening of the Auchan Epinay store in October 2013, a thorough evaluation of the results by the entire project team confirmed the energy efficiency benefits of the trial; the energy consumption of the Solstice® N13 / CO2 system is slightly less (3%) than the expected energy consumption of the standard Groupe Auchan HFC-134a / CO2 system. Fig. 3 shows a photo of the system installation.

The new system was also measured against the following criteria to ensure the resulting performance was as good if not better than the current design:

- Discharge temperature at compressor head 110°C (Below that of HFC-134a systems)
- Compressor Oil temperature 55°C (Below that of HFC-134a systems)

Performance:
The test focused on assessing the merits of a system that incorporated an N13 liquefaction unit alongside a CO2 refrigerated distribution circuit.

As initially dimensioned on HFC-134a, only sanity checks were necessary to assess the capacity match with Solstice® N13. An 8% extra capacity was theoretically needed, but as the system was already oversized to anticipate future store extensions, no modifications were required.

Solstice® N13 was also positively seen, by Auchan and by the contractor Axima, as a safe and simple direct HFC-134a alternative. Being non-flammable, non-toxic and experiencing lower pressures than HFC-134a turned all the flags to green.

When the system was commissioned, Solstice® N13 was a few months from commercial availability worldwide, so a full charge of product was made available on site in case of a catastrophic leakage. It went commercial a couple of months later and is now fully available in the distribution network. In between, the main component manufacturers (for compressors, controls, etc.) released qualified product ranges to enable spreading the technology.

The system was finally compared with Auchan’s current standard set-up that uses HFC-134a and glycol water with CO2. The results to date have been encouraging, and include:

- Easy commissioning, with similar expected electricity consumption as HFC-134a (no monitoring).
- A global saving of 90 tons CO2 eq / year compared with a secondary Glycol /HFC-134a / CO2 system and savings of 960 tons CO2 eq / year compared with using a standard HFC-404A DX system.

The system was commissioned in October 2013 and has been running without issue since.

Cost and Economic Considerations:
The cost of the new system is almost same as original HFC-134a design. Maintenance cost is expected to be same or less due to the lower operating pressures of the system when compared to HFC-134a. Also, less work for compressors due to lower pressures and improved efficiency for Solstice® N13 over HFC-134a.

Other tests and trials conducted at Honeywell R&D laboratories, and in laboratories and supermarkets in various European countries by an independent energy consulting company (Tewis), have shown up to 3% reduction in energy consumed when compared directly against R-134a. The refrigerant cost for Solstice® ze is a major portion of the blend.

Disclaimer:
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**CASE STUDY-2**

**Pick’n’Pay stores, South Africa**

**Name of the Store/facility:**
Pick’n’Pay stores, South Africa

**Location:**
- “Strand” Store: Fagan Street, Strand, 7140, Western Cape (Cape Town Area)
- “Rand Park Ridge” Store: Rand Park ridge Mall, Cnr John Vorster & Ferero Str, Rand-Park ridge, 2156, Gauteng (Johannesburg Area)

**Contact information:**
Name: Bernhard Siegele
Email: bernhard.siegele@giz.de
Designation: GIZ Proklima Programme Manager

**Type of facility:**
Two Supermarkets:
- Trading area for store at Strand: 1800 m²
- Trading area for store at Rand Park Ridge: 2300 m²

**Refrigeration System type:**
Cascade system

**Technology Transition:**
Transition from HCFC-22 systems to cascade refrigeration systems, using a combination of ammonia (R-717; NH3) and carbon dioxide (CO2) systems.

**Refrigerant Used:**
The new refrigeration system runs with ammonia in the compressor and uses a heat transfer medium for the distribution into the cold rooms and cabinets in the trading area. A CO2 cascade provides the temperatures dependent on ambient temperatures and the type of machinery rooms in the basements. There was no possibility for an open air setting for the propane using components. The selected option of Ammonia with a CO2 cascade for low temperature was also evaluated to be the best solution for the climatic conditions. One site is located in Johannesburg and the other in Cape Town. Temperatures are generally higher in Cape Town, reaching up to 40°C.

One major focus of the project was building local capacity to ensure proper maintenance as well as further replication and development of these new technologies. Local engineering firms were commissioned for the project and the refrigeration systems were engineered and manufactured locally. Installation started in 2009 and corresponding training for technicians on the safe handling of Ammonia and CO2 was also carried out. By spring 2010, the new systems were fully operational. In addition to the performed conversions, an extensive energy management system was also developed in the course of the project, which allowed Pick’n’Pay to monitor their energy consumption and make corresponding adjustments where needed.

**New System/Installation:**
In the store in Rand-park Ridge, there are 44 cabinets for medium temperature products and 18 for frozen goods. This adds up to 172 meters of refrigeration displays and 204 m² of cooled display area. There are also 230 m² of cold rooms for storage and a 72 m² butcher preparation area. The ammonia compressor rack was sourced from GEA Grasso: a 3x310 chiller package with an ammonia charge of 150 kg. The CO2 compressor is manufactured by the Australian company eCO2 Technologies and contains 70kg CO2. Fig. 2 shows the installation of 3 x 310 Chiller package at Pick’n’Pay store in Rand-park Ridge.

**picked out text:**
- One major focus of the project was building local capacity to ensure proper maintenance as well as further replication and development of these new technologies. Local engineering firms were commissioned for the project and the refrigeration systems were engineered and manufactured locally. Installation started in 2009 and corresponding training for technicians on the safe handling of Ammonia and CO2 was also carried out. By spring 2010, the new systems were fully operational. In addition to the performed conversions, an extensive energy management system was also developed in the course of the project, which allowed Pick’n’Pay to monitor their energy consumption and make corresponding adjustments where needed.

**Images:**
- Fig. 1: Photos of Pick’n’Pay stores
- Fig. 2: GEA Grasso 3x310 Chiller package at Pick’n’Pay store in Rand Park Ridge
The indirect system with propylene glycol as heat transfer medium has a number of advantages compared to conventional direct expansion systems such as the following:

- reduced primary refrigerant charge (since the refrigerant remains inside the machinery room)
- higher quality and lower risk for leaks due to factory assembly of the primary refrigeration system
- possibility for using flammable or toxic refrigerants because refrigerant does not circulate inside the store area
- more stable levels of air temperature and humidity in display cases and therefore less shrinkage of the refrigerated food stuff (this increased stability is a result of the lower temperature fluctuations of the glycol loop and higher surface temperatures of the heat exchangers inside the cabinets that lead to higher air humidity)
- fewer defrost cycles necessary
- secondary loop can be constructed in plastic piping and fittings which may be cheaper than copper piping traditionally used with direct expansion systems.

Performance:
The energy performance was monitored and compared to samples of other stores located in the same climatic region. The methodology was adopted from the German supermarket Quick-Check tool, developed by VDMA (Verband Deutscher Maschinen- und Anlagenbau, German Engineering Federation). The reference parameter is the cooled display area installed in the store (i.e. the area of the openings of all display cabinets). In this way, differently sized supermarkets can be compared.

There was no direct comparison undertaken between the old and the new system, because the condition of the old systems was far beyond what is considered as "state of the art". Instead, comparisons of energy efficiency were made between the installed natural refrigerant systems and other state-of-the-art direct expansion systems using synthetic refrigerants.

The monitoring results for two years showed clearly that energy efficiency is higher for the natural refrigerant systems. Energy savings are on average about 13% for Strand and 21% for Rand-Park Ridge. The charts below show the average consumption of the project stores in comparison to the other stores in the corresponding area and demonstrate a clear advantage in the project stores. The charts also reveal that as technological development continues, the specific energy consumption of an average store decreases constantly. This was achieved through improved components and control systems – a development that can be observed with both synthetic and natural refrigerants. It should also be noted that these were pilot installations in South Africa, which require system settings for optimum energy efficiency to be continually updated with new developments. Fig. 5 shows the energy consumption of Pick’n’Pay store at Strand, Cape Town and Fig. 6 shows the energy consumption of Pick’n’Pay store at Rand-park Ridge, Gauteng.

Cost and Economic Considerations:
The installation cost for these two pilot plants were considerably higher than the existing market prices at the time. This price difference can be explained by the pilot character of the project in South Africa. An exact overview of the market would be necessary to evaluate current prices, but it can be assumed that the installation of both systems have decreased in cost and are comparable to synthetic refrigerant systems, when considering investment and operating costs.

With an assumed extra cost of 30% compared to a conventional system, a payback period of 7 years can be expected – taking the rising electricity prices announced in South Africa into account. Given a higher expected system life time of up 30 years for the ammonia system compared to conventional direct expansion systems, this also increases the economic feasibility of the systems. Additionally, the systems were pilots venturing into new design and type of systems, built by local engineering offices and manufacturers. Therefore both systems were hugely over-designed. Consequently optimisation works and cost-reduction measures would lead to significant increase of economic feasibility. Maintenance costs for natural refrigerant systems and conventional systems are comparable while some savings of up to 4000 to 5500 ZAR (South African Rand) annually per natural refrigerant system could be achieved due to lower cost for refrigerant refill.

Both supermarkets were built and maintained by branches of the same servicing company. Employees of the company received training in safety requirements and energetic optimisation regarding the use of Ammonia and CO2. There are no reported problems with the availability of spare parts.

Installed safety features include gas detection systems, as well as ventilation and emergency blow off valves.

It was ensured that the systems would meet European standards EN 378 through safety and quality checks by the German TÜV.

It was the first indirect system to be built in a supermarket in South Africa. Presently, quite a few new supermarkets are choosing to use indirect systems using CO2 in a cascade for low temperature.

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Lackland Air Force Base Commissary, USA

The previous refrigeration system contained more than 7,000 pounds (≈ 3200 kg) of HFC-404A—a greenhouse gas refrigerant blend with a global warming potential (GWP) of 3,922. Based on an annual average leak rate of roughly 8.5%², the system leaked more than 600 pounds of refrigerant each year—equivalent to roughly 1,100 metric tonnes of CO₂. The system was over 13 years old and was ready for retirement.

The NH₃/CO₂ cascade system that has been installed at the Lackland commissary consists of three key pieces: (1) an NH₃ direct expansion system, (2) a CO₂ secondary loop system, and (3) a CO₂ direct expansion system. The NH₃ system, which is contained in an outdoor enclosure on the roof of the building, relies on a condenser water loop to connect the NH₃ compressors with the evaporative fluid cooler, and is used to condense vapor CO₂ into a liquid. The liquid CO₂, which is stored in a tank adjacent to the NH₃ system, is circulated throughout the store to remove heat from both the low and medium temperature cases. On the medium temperature side, the liquid CO₂ passes through a coil to remove heat from the refrigerated space and then returns directly to the liquid CO₂ tank prior to being condensed again by the NH₃ system (utilizing a secondary loop design). On the low temperature side, the liquid CO₂ first passes through an expansion valve, evaporates into a gas as it removes heat from the refrigerated space, and then is compressed prior to returning to the roof.

In total, the system has a low temperature cooling capacity of 304 thousand British Thermal Units per hour (MBTU/hr) and a medium temperature cooling capacity of 1,233 MBTU/hr. The system consists of nine ammonia modules, each containing nine pounds of refrigerant, for a total of 81 pounds of NH₃ as well as roughly 1,800 pounds of CO₂. To increase energy efficiency, LED lighting is used in all refrigerated cases and cold storage rooms. Additionally, display cases with glass doors are used for the majority of products (except produce and fresh meat).

DeCA chose to adopt a NH₃/CO₂ cascade system for two main reasons: (1) to control future capital and operating costs, and (2) to meet the energy and sustainability goals the U.S. Government has established for all public buildings³.

Prior to their decision, DeCA reviewed the possible refrigeration systems that could be used to meet their goals. DeCA wanted to use a refrigerant with low or no GWP to eliminate climate risk and address the regulatory uncertainty around climate policies, which could impose future penalties on the use or emissions of high-GWP refrigerants or even force a refrigerant conversion. DeCA also wanted to adopt a system that is more energy efficient than standard industry rack systems that typically use R-404A refrigerant, and eliminate safety concerns. They also aimed to adopt equipment that can be easily serviced and wanted to keep costs reasonable.

With these criteria in mind, DeCA considered installing either a transcritical CO₂ system or an NH₃/CO₂ cascade system. Due to the hot climate of southern Texas, the NH₃/CO₂ cascade system was deemed the most suitable choice for the Lackland Air Force Base commissary⁴. The greatest challenge DeCA faced in implementing the NH₃/CO₂ cascade system at the Lackland commissary was public acceptance of using NH₃ in a building near sensitive areas, such as day care facilities and schools. To address this concern, the National Renewable Energy Lab (NREL) and the Environment Protection Agency (EPA)—with technical assistance from CTA Architects Engineers and Hillphoenix—conducted an ammonia plume study, which analyzed the potential effects of ammonia being released from the system into the community. Results of the study showed that the system poses minimal threat to human health, with impacts mainly limited to short-lived unpleasant odors.

The risk of public health impacts can be mitigated through the use of a continuous leak monitoring system. In addition to conducting the study, DeCA also conducted public outreach to community leaders to effectively communicate the results of the study and alleviate concerns. While DeCA is confident that concerns over the use of NH₃ will fully dissipate, a key lesson learned is the need to actively engage the community from the start in order to proceed with an ammonia system.

Other key lessons learned include the need to prepare maintenance teams and maintain spare parts on hand. For instance, because the NH₃/CO₂ cascade system is designed differently than conventional systems, DeCA’s personnel must be trained on how to service and maintain them. To address this important issue, Hillphoenix will conduct training sessions over the course of several days to educate DeCA maintenance teams on how to handle the system. These training sessions are incorporated into the Hillphoenix service contract. In addition, DeCA recommends having spare system components on hand (e.g., ammonia compressor) to allow for timely repairs, since parts delivery may take several days until the technology is more widely in use. As more NH₃/CO₂ cascade systems are adopted across the United States and more technicians are trained on how to service these systems, personnel training and component availability will pose less of a challenge for users.

² Assuming that a 3.16 times more damaging to the climate than CO₂ on an equal mass basis.
³ Based on the average leak rate of the existing R-404A system during 2012 and 2013.
⁴ Federal mandates (i.e., Executive Order 13423 on Strengthening Federal Environmental, Energy, and Transportation Management, as well as the Energy Policy Act of 2005) require that energy consumption be decreased by 30% in new buildings and 20% in renovated buildings.
⁵ According to DeCA analysis, transcritical CO₂ systems are the preferred system for use in cooler climates.
Construction began at the Spangdahlem commissary in February 2014. The new commissary, which will use a transcritical CO2 refrigeration system, is expected to be complete by the spring of 2016.

**CASE STUDY-3 Verdemar Commercial Refrigeration**

**Performance:** Compared to the existing R-404A rack system, it is expected that compressor energy use of the new system will be reduced by 8%, resulting in a system-wide energy reduction of roughly 3%.

DeCA anticipates adopting NH3/CO2 cascade systems as the standard technology at other commissaries located in warm climates. NH3/CO2 cascade systems will also be considered for installation in other types of facilities such as DeCA’s cold storage and central distribution center at Sagami General Depot in Japan. In addition, transcritical CO2 systems will be considered for use at commissaries in cooler climates, such as at the facility at the U.S. Air Force Base in Spangdahlem, Germany and in the commissary in Newport, Rhode Island. Worldwide, there are approximately 250 U.S. commissaries.

**Cost and Economic Considerations:**

Upfront costs of the NH3/CO2 cascade system were more than $2.5 million, roughly 15% higher than a standard system—an incremental cost of roughly $300,000. Refrigerant costs are expected to be over 90% lower than the previous system. Maintenance costs are also expected to be almost 40% lower. Overall, operational savings from energy use, refrigerant use, and maintenance costs are expected to offset the incremental capital cost, resulting in only a small net cost increase over the estimated 20-year lifetime of the system. Once the technology reaches large scale commercialization, it is expected that the life cycle cost of future systems will be equal to or less than a typical R-404A rack system.

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CASE STUDY-4
Alfamidi Convenience Store, Indonesia

Name of the Store/facility:
Alfamidi Convenience Store, Indonesia

Location:
Various locations in Jakarta, Indonesia

Contact information:
Name: Hiroyuki Matsuuti
Email: hiroyuki.matsuuti@lawson.co.jp
Franchisee Operation Support Division
Name: Ming Li
Email: ming.li@lawson.co.jp
Designation: Technical Public Relations department, Lawson, Inc

Type of Facility:
Convenience Store, Area: 260m² (approx.)

Technology Transition:
Transition from HCFC-22 systems to CO₂ systems.

Refrigeration System Type:
Transcritical direct expansion systems

Refrigerant Used:
CO₂ is a natural refrigerant, non-toxic and non-flammable.

Project Background:
“Alfamidi” is a convenience store operated by PT MIDI UTAMA INDONESIA Tbk (Hereinafter referred to as MIDI). MIDI is an Indonesian company allied with Lawson. Most of the stores considered in this case study were opened in the year 2014-2015. A photo of Alfamidi store is shown in Fig. 1.

As a general configuration at Alfamidi, there are 3 reach-in showcases with 6 feet width display area and there is an open showcase with 6 feet width. There are several manufacturers supplying these showcases above, and the manufacturer varies at each store as shown in table 1.

There are two separated centralized remote refrigeration systems for refrigeration and freezing at each store. They are transcritical, direct expansion systems. Fig. 2 represents a general schematic of Refrigerant systems used in Alfamidi stores.

In Japan, the enforcement of amended “Fluorocarbons Recovery and Destruction Law” started in April 2015. It is required to control the refrigerant leakage for refrigeration system users. So, Lawson started to build the organization to do it. There is no such a law or legislation in Indonesia but MIDI voluntarily install CO₂ refrigeration systems there. The first reason is GWP of CO₂ is 1, much less (approx. 1/1,800 compared to R22) than HCFCs or HFCs, the second reason is CO₂ refrigeration system can reduce energy consumption by approx. 18% compared to HCFC-22, and this reduction corresponds to 6% of total store energy consumption. Installing CO₂ refrigeration system can reduce global warming impact almost by half including the direct effect and indirect effect.

There are two projects, both Japanese government funded Joint Crediting Mechanism (JCM) related, one is from Ministry of Economy, Trade and Industry (METI), JCM feasibility study, another is from Ministry of the Environment (MOE), project financial support and JCM credit issue.

New System/Installation:
The refrigeration system installed in Indonesia employs “split cycle” refrigeration circuit as same as installed in Japan. Split cycle is a variation of refrigeration cycle using 2-stage compressor. The split refrigerant from the condenser outlet cools down the main stream refrigerant then returns to the 2nd stage compression. In short, it slightly increases compressor input and it increases cooling capacity at the same compressor rotation speed. It enhances the cooling capacity and the efficiency of CO₂ refrigeration systems. The efficiency is better with commercial refrigeration evaporating temperature range compared to HFC-404A refrigeration systems. (16% better in refrigeration and 25% better in freezing, estimated at Japanese climate condition).

The energy saving really depends on the outdoor temperature. High outdoor temperature gives less energy saving. MIDI estimation still gives approx. 20% energy saving compared to HCFC-22 considering the inverter drive of CO₂ system.

In Indonesia, the refrigeration systems installed in convenience stores are changing. There were only several ice-cream and drink showcases but the display area of refrigerated items are increasing. So, energy conservation is one of the most important issues for the convenience stores today.

These conventional showcases are self-contained. The heat pumped from inside the showcases is rejected to the sales floor space. According to the increment of refrigerated showcase, the system configuration has to be changed from self-contained to remote type.

If they install remote type refrigeration systems like commonly used in Japan, the energy consumption and the global warming impact from refrigerant leakage will be a concern because the power consumption is higher and the refrigerant charge amount is larger. Each self-contained showcase is equipped with several hundred watts output compressor and contains several hundred grams of refrigerant. Typical remote type refrigeration system used for convenience stores has 5-6 kW output compressors and the refrigerant charge is around 30 kg. MIDI had evaluated NH₃ refrigeration systems, field tested at actual stores as New Energy and Industrial Technology Development Organization (NEDO) funded project in FY 2010. Considering global warming impact, installing and safety, MIDI decided CO₂ is suitable for convenience stores.

MIDI have set the CO₂ refrigeration system as standard system for new stores since Sep. 2014 in Japan. MIDI will have installed CO₂ refrigeration systems at 912 stores by the end of Aug. 2015. Before that, MIDI evaluated the feasibility of CO₂ system step by step:
- Pilot store showed energy saving more than expected, FY 2010
But previous research showed CO₂ refrigeration systems reduced electricity consumption by 20% in Okinawa in 2012. (Equipment replaced at existing store, Comparison with HFC-404A system) So, it was decided to field test CO₂ system in Indonesia.

Cost issue is the barrier to be removed. The equipment cost and the installation cost are higher compared to HFC refrigeration system even in Japan. The cost gap is larger in Indonesia or other developing countries. Some subsidies or financial support are necessary for CO₂ refrigeration system spreading in short term, but public relations would be more important that showing the importance of refrigerant leakage control for global warming prevention in long term.

Configuration of CO₂ refrigeration system:
1. 1 of Outdoor unit for Refrigeration, 10hp output compressor
2. 3 of 6 feet width open showcase
3. 1 of 6 door walk-in refrigerator
4. 1 of Outdoor unit for freezing, 2hp output compressor
5. 1 of 2 door reach-in freezer

Operating conditions:
1. Cold room temperature (Refrigeration): 5 deg. C ± 2K
2. Cold room temperature (Freezing): -20 deg. C ± 2K

All the equipment and parts of CO₂ refrigeration and LED lighting was exported from Japan for this project because they are commercially available only in Japan. For the maintenance, Partner company PT. SIGMA BIMED provides 24/7 service for MIDI, storing service parts including backup outdoor units, showcases and lighting parts. A/C equipment is supplied in Indonesia. CO₂ refrigerant is non-flammable and non-toxic. Only high concentration CO₂ affects human body, so a CO₂ detector is placed inside space of walk-in refrigerator and flash light alarm notifies in case of refrigerant leakage. CO₂ concentration in sales floor space can't reach hazardous level with CO₂ refrigerant charge amount. Assuming that the air volume is 750m³ and the refrigerant charge is 15kg, the CO₂ concentration is approx. 13,000ppm, it’s lower than the safety limit of 40,000.

Performance:
The CO₂ refrigeration systems installed in Lawson stores have been supplied by Panasonic. Lawson and Panasonic have worked together from the R&D stage of CO₂ refrigeration system, it has contributed much on system development, field testing, establishment of installation and engineer training and so on. The supplier of commercially available CO₂ refrigeration system is very limited in Japan today, but MIDI are expecting more manufacturer come into CO₂ refrigeration system market and compete together for the innovation, quality and cost reduction. That is necessary to spread CO₂ refrigeration system.

The measured power consumption shows the energy savings from CO₂ refrigeration, A/C and LED lighting are 15-20% more than expected as shown in Fig. 4. 3 stores of the project opened early 2014 have been operated for more than 1 year. These data have been stored through a remote monitoring system from the opening.

The knowledge of energy conservation on store operation will be obtained from the analysis of 13 stores data. We would continuously share it with MIDI for energy saving.

Figure 4 shows the energy saving of CO₂ refrigeration systems. The power consumption data were taken at three stores in Jakarta from 1 April 2014 to 31 March 2015. Compared with the power consumption estimated for the same capacity HCFC-22 refrigeration system, the three stores’ averaged electricity saving is 17,624 kWh/Year and it corresponds to 12.9 ton CO₂/Year (Assuming that CO₂ emission factor in Jakarta is 0.73 Kg-CO₂/KWh) per store.
Cost and Economic Considerations:
Cost issue is the barrier to be removed. The initial cost of CO₂ refrigeration system including installation is approx. 1.5 times as much as conventional HFC system (HFC-404A) even in Japan. The cost gap is larger in Indonesia or other developing countries. Some subsidies or financial support are necessary for CO₂ refrigeration system spreading in short term, but public relations would be more important that showing the importance of refrigerant leakage control for global warming prevention.

Disclaimer:
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The plant is fully operated with natural refrigerants. A separate refrigeration circuit with a natural propane refrigerant is located inside the integral plant. With this circuit the “standard cooling” for goods above 0°C and the heat for the whole branch is being produced. Compared to the widely-used natural refrigerant 

\[ \text{CO}_2 (R-744) \]

Propane has a comparable ODP and only marginal higher GWP, but has much better thermodynamic characteristics. As a result, propane needs lower pressures in the refrigerant circuit, which significantly reduces the electrical energy consumption of the plant’s components. In terms of energy balance, propane therefore is the more environment-friendly alternative.

Propane was so far used in systems with very low filling capacities (<150g) such as plug-in deep-freezers. In this field, propane has been established for a long time because of its energetic advantages and economic aspects. For years LIDL therefore exclusively used deep-freeze rooms with the natural refrigerant propane, which are state-of-the-art in terms of energy efficiency, and avoid harmful effects on the world’s climate. Fig. 3 and 4 shows a sectional view and schematic diagram of integral plant concept used in Lidl.

With comprehensive emergency systems and the outdoor-use of the integral plant these remarkable advantages could be transferred to a larger plant. Inside the LIDL markets an environment-friendly brine solution ("Temper") based on organic salts is being used exclusively as refrigerant in the secondary system. Temper is neither inflammable nor toxic and is therefore an ideal refrigerant due to its high heat capacity and good cold flow characteristics.
The Temper-circuit transports the cooling energy to the multi-deck cooling cabinets. There the salt solution provides it cold to the food and heats up at the same time. After that, the warm solution flows back into the integral plant, where the heat is transferred into the Propane circuit. The Propane is further heated using a compressor. The resulting heat is used in winter via a water circuit for the heat energy supply in the market, as described above.

**Performance:**
Since all heat consumer appliances consequently have been designed to low system temperatures, the integral plant can operate exceedingly efficiently and cover 100% of the heating energy demand from the waste heat of the cooling process. For peak load situations, where the heating energy demand would exceed the waste heat level from the chillers, the chiller compressor can operate as an additional heat pump system. With the exception of the electrical power supply no fossil fuels such as oil or gas is required in any branches.

During summer, 100% of the waste heat from the chillers still can be expelled to the outside air. At the same time, the integral plant can provide cooling energy, to supply the concrete core activation (i.e. the floor heating / cooling system) for the branch’s cooling. In addition to the conventional heating system a separate cooling system therefore can also be omitted.

Compared to a conventional food market the various measures result in savings of about 16 MWh of electricity – the annual consumption of four single family homes. The heating energy demand is reduced by about 100 MWh – the annual consumption of eight single family homes. The branch furthermore has an overall CO₂-emission reduced by 55 tons per year – this represents the average annual emissions of 30 cars.

In October 2009 this sustainable energy concept of the new LIDL branches has been awarded with a special Energy management-Award for extraordinary technical achievements. The concept which has been rolled out as a new standard and has furthermore been labelled with a silver-award of the German Council for sustainable buildings (DGNB).

With the new branch concept LIDL also has become a member of the European Green Building-Partner-Programme, which has been initiated by the European Commission in order to support the reduction of energy consumption and CO₂-emissions of non-residential buildings.

**Cost and Economic Considerations:**
It has been found that, Lidl is able to save an amount of approx. 7T€/annum of energy costs. That provides a Return on Investment (ROI) of approx. 5 years.

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CASE STUDY-6
Ahold, Netherlands

Name of the Store/facility:
Ahold, Netherlands

Location:
Various

Contact information:
Name: Peter W. Vlaskamp
Email: peter@vlaskamp.biz
Designation: Refrigeration Consultancy for Ahold group

Type of Facility:
Supermarkets

Technology Transition:
Retrofit from HFC-507A centralised direct expansion refrigeration systems to Opteon TM XP40 (R-449A). HFC-507A has a Global Warming Potential (GWP) of 3985 and R-449A has a GWP of 1397.

Refrigerant Used:
The new refrigerant used is Opteon™ XP40 (R-449A) which is part of the new lower GWP (Global Warming Potential) refrigerant portfolio from Chemours and is suitable as an alternative to HFC-404A/HFC-507A for the retrofit of commercial and industrial medium and low temperature refrigeration systems. With a GWP of 1397 (IPCC AR4, Intergovernmental Panel on Climate Change, 4th Assessment Report), its global warming potential is 65 percent lower than HFC-507A (IPPC AR4 GWP of 3985). The formula of Opteon™ XP40 is R-32/125/123/4y/134a at 24.3/24.7/25.3/25.7 w/w.

Project Background:
As part of its program to cut its carbon dioxide (CO2) emissions, Ahold, a Dutch retailer, converted the refrigeration systems in some 200 of its supermarkets to new Opteon™ XP40 (R-449A) refrigerant from Chemours. This decision was the outcome of practical trials which the company carried out in close cooperation with Chemours Fluoro-products and the Dutch consultants PW Vlaskamp B.V. Refrigerants Consultancy, Sleenwijk. In comparison with HFC-404A/ HFC-507A, Opteon™ XP40 from Chemours has around 65 percent lower global warming potential and is also significantly more energy efficient. Moreover, its elevated energy efficiency means it can help in bringing about a significant reduction in the overall CO2 emissions arising from refrigeration system operation. Ahold has the target of cutting its CO2 emissions per square meter of its sales floor by 20 percent relative to 2008 levels by 2020. This involved reducing the overall greenhouse gas emissions arising from leaks and energy consumption of their Copeland medium and low temperature compressors, which had originally been operated with HFC-507A. The company accordingly tested various alternative refrigerants with reduced global warming potential.

Over the course of this project, three medium-sized centralized direct expansion (DX) supermarkets in Amsterdam and Marum, Holland were converted to Opteon™ XP40, one from R-407F and two from HFC-507A. XP40 was specifically chosen due to its GWP properties lower than HFC-404A and 507A, lower discharge temperature compared to R-407F and the potential for energy efficiency increases. With non-flammability and low toxicity, Opteon™ XP40 was also chosen as the replacement refrigerant due to the low risk it poses to both employees and customers. Fig. 1 shows a picture of Ahold supermarket in Netherlands.

New System/Installation:
The conversion was carried out in November 2013, by Retail Technics B.V., Nijkerk, The Netherlands. The work took three to four hours in each case and was carried-out outside opening hours. Once the original refrigerant charge had been removed, the filter dryer was firstly replaced, as is usual during servicing. The system was then evacuated, subjected to leak testing and filled with Opteon™ XP40. Since the company uses electronic expansion valves and the Danfoss ADAP-KOOL® System, the system set up was very easy for Opteon™ XP40 with new coefficients entered via laptop. No further components had to be replaced nor was an oil change required. Measurements before and after the retrofit revealed that this refrigerant has an 8% higher energy efficiency than the previously used HFC-407F and HFC-507A. Fig. 2 shows a picture of the system installation at Ahold supermarket.

The technical manager from Ahold said: “The conversion to Opteon™ XP40 was completely straightforward and unproblematic in every case. Calculations carried out together with Chemours and Vlaskamp have shown that the capital expenditure will be paid back within an acceptable time due to the refrigeration systems’ significantly lower energy consumption. Management has therefore decided to convert some 200 systems which are currently operated with HFC-507A to the new refrigerant from Chemours. Work started in September 2014 and was completed less than a year later in June of 2015.”

Performance:
The consultant has calculated that full conversion of about 200 stores to Opteon™ XP40 will cut total direct greenhouse gas emissions by 10,360 tonnes of CO2 per year. Ahold had decided to switch to XP40 as a result of the new European F-Gas Regulation (EU) No. 517/2014 which entered into force on 1 January 2015 and specified that the number of tons of CO2 equivalents available on the market will be gradually reduced over a 15 year period. In addition, from 1 January 2020, servicing systems using HFCs with a GWP value of 2500 or more will be prohibited for the majority of commercial applications. Changing HFC-404A/HFC-507A refrigeration systems over to Opteon™ XP40 will ensure that these installed base systems will continue to comply with the requirements of this regulation for the remainder of their service life. This discipline is for the company an extra step next to the future new installations which will be built according to the Consumer Goods Forum (CGF) resolution, which aims to begin phasing-out HFC refrigerants in new commercial systems as of 2015. Fig. 3 and 4 shows the Energy consumption versus ambient temperature chart for medium and low temperature systems respectively.

Opteon™ refrigerants, including XP40, are now commercially available within the EU and the United States, and are being used to transition a variety of applications across numerous industries to lower-GWP refrigerants. Chemours has made significant investments to bring Opteon™ products with no ozone depletion and lower global warming potential to the market, and plans to bring additional capacity online to serve a wide range of applications.
Cost and Economic Considerations:
Following the retrofits, Ahold experienced an average energy consumption reduction of 8% for their combined medium and low temperature systems. Due to the lower energy consumption, the retrofit investment costs are calculated to be paid back in less than five years, assuming typical operating conditions in the Netherlands.

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CarrefourSA Express Kurtköy Commercial Refrigeration, Turkey

Name of the Store/facility: CarrefourSA Express Kurtköy
Location: Kurtköy, Turkey
Contact information: Jean-Michel Fleury, Jean-Michel_Fleury@carrefour.com
Type of Facility: Hypermarket, Store Area ~765 m², Food & Department Store.
Technology Transition: Transition from High-GWP refrigerant R-404A to CO₂.
Project Background: As part the Carrefour Group’s effort to mitigate climate change by reducing HFC refrigerant charge and refrigerant leakage, the Group has set a goal to phase out HFCs in new refrigeration equipment by 2015. Currently Carrefour is progressively rolling out full CO₂ systems, having installed its first CO₂ transcritical refrigeration system in Istanbul, Turkey, at the Kurtköy-Millennium Carrefour Express. Fig. 1 shows photo of the store in Kurtköy, which has a sales area of 765 m². The retrofitted refrigeration system in the Turkish Kurtköy store entered into operation on 9 May 2012, and is one of four sites operated by the retailer that use 100% natural refrigerants. In more than 30 stores across Europe, Carrefour was already using a hybrid solution such as a cascade system, which combines synthetic refrigerants and CO₂, but the change-over to an installation that operates solely with CO₂ marked a clear shift to natural refrigerants. Carrefour plans to continue to set up new stores across Europe using natural refrigerants.

“Carrefour states that the market penetration of CO₂ commercial refrigeration could be further accelerated if qualified contractors were more widely available to cater for the needs of the booming CO₂ refrigeration market. This is relevant for countries outside the European market and more particularly in Asia and Latin America.” — Jean-Michel Fleury, Director of Assets Carrefour Group.

New System/Installation:
Food refrigeration accounts for two-thirds of the Carrefour Group’s greenhouse gas emissions. The emissions arise from refrigerant leaks, as well as from electricity consumed by refrigeration equipment. To reduce these emissions, Carrefour Turkey is piloting a highly innovative solution - using the natural fluid CO₂ for both refrigerators and freezers at the Kurtköy store. The technology used in Turkey is new to that part of the world, and is only the fourth time it has been used by the Carrefour Group. CO₂ is being used as the alternative to the original HFC refrigerant R-404A. R-404A, with a GWP of 3,922, is an HFC refrigerant, a colorless, odourless mixture which is used as a replacement for R-22, a refrigerant which is being phased out under the Montreal Protocol.

The new Kurtköy’s CO₂ installation has the following dimensions:

- There are 13 showcases for positive temperature products, and two for negative temperature products, which equates to 33 meters of refrigeration displays.
- Compressor racks are used to provide cooling for these showcases at negative and positive temperatures. The capacity of the positive rack compressors is 40 kW, and negative rack compressors 4 kW.

The technical specifications for the compressor racks include:
- The compressor rack for medium temperature applications is composed of four Bitzer compressors with a total refrigeration capacity of 67.44 kW, and a coefficient of performance (COP) of 1.12. This COP is during the summer when the gas cooler outlet temperature is 45°C, while in winter time the COP is 6.99. The compressor rack for the low temperature side is composed of one Bitzer compressor with a total refrigeration capacity of 4.80 kW, with a COP of 4.58.
- The design using CO₂ is similar to a typical transcritical system. Since the pressure level is higher than 70 bar the piping design requires the use of steel pipes throughout. A transcritical CO₂ system operates in transcritical mode whenever the refrigerant is above 31°C. The condenser becomes a gas cooler at temperatures above 31°C and the CO₂ leaving the evaporator is supercritical, a state where vapour cannot condense and one cannot distinguish liquid from vapour.
- Where the pressure level is less than 45 bar, the design is like that for any traditional refrigerant. The system also has a solution for decreasing the ambient temperature by using the ChillBooster™ adiabatic air cooling system. The ChillBooster™ is manufactured by CREA (Italy).
- Fig. 3 is a schematic for the ChillBooster™ system used for high ambient conditions. The system works on cooling the air to a lower temperature going over the coils by evaporative cooling. ChillBooster™ atomises water into very fine droplets that evaporate spontaneously, cooling the air. The coil is thus cooled by a flow of colder air and droplets of water, allowing more favourable operating conditions and thus increasing the cooling capacity of the system.

ChillBooster™ can be used as an extra cooling step only on high temperature days. The droplets of water are evaporated by absorbing heat from the air and, as a consequence, it can decrease the air inlet temperature by up to 15°C to help the system run in optimal conditions (see Fig. 3). This system works best in dry climates, but it is still possible to give reasonable results in higher humidity areas. The system works everywhere except in areas that have both a high temperature and high moisture content simultaneously.

Fig. 1 The CarrefourSA Express Kurtköy, Turkey
Fig. 2 The CO₂ compressor rack
Fig. 3 Schematic of the ChillBooster™ System
Cost and Economic Considerations:
In addition to its excellent technical performance, the CO₂ transcritical installation also offers very significant economic benefits. The Kurtköy hypermarket should not only reduce its overall annual energy bills by 7%, but it should also be able to reduce the amount spent on refrigerants, which is crucially important given that the price of synthetic gas is increasing.

Performance:
The system has been operating in Kurtköy, Turkey where the annual average temperature varies from 0.5° C to 25.7° C. In only 12 months of operation, the technology has significantly reduced the environmental impact of the store. The CO₂ used in the refrigeration system is around 3,922 times less potent in terms of global warming potential than the refrigerant (R-404A) previously used at Kurtköy.

The quantity of CO₂ needed for the refrigeration units is approximately one-third less than the refrigerant charge required by a conventional system.

The performance of the CO₂ system is compared to similar cooling capacity systems operated in roughly similar climatic conditions using R-404A.

The quality of the pipe fittings has been improved and as a result, refrigerant leaks are expected to be reduced by 75%.

The CO₂ solution improves the energy efficiency of the refrigeration units by around 15%, which equally limits CO₂ emissions resulting from electricity consumption.

Advantages of this CO₂ System
• High-GWP refrigerants (which can be a direct contributor to global warming when leaked to the atmosphere) are reduced.
• Total elimination of HFCs from the system.
• High Volumetric capacity - The system can absorb much more heat than an HFC-based system, resulting in reduced compressor and pipe size for the same cooling effect.
• Low HFC refrigerant charge for subcritical systems
• Lower than HFC Refrigerant Costs - CO₂ costs are currently 90% less expensive than traditional refrigerants (US$2.2/kg versus US$24.2/kg for R-404A).
• Reduced Carbon Footprint - CO₂ has a GWP of 1 vs. HFC which has a GWP of 3,922 for R-404A.
• Reduced Carbon Emissions - Because the refrigerant is confined to a machine room, there are fewer braze joints and a significant reduction in potential for leaks in the system.

Disadvantages of transcritical CO₂ System
• Higher investment cost (the components capable of being operated safely in such high pressure applications can be more expensive).
• The COP of the system is reduced when operated in higher ambient conditions.
• CO₂ is heavier than air - importance of good ventilation in case of leaks
• Limited local expertise for service and maintenance in Istanbul. The flash gas leakage causes formation of dry ice on the system.
• Compressor range is very limited (but increasing).

Some of these disadvantages can be overcome with time when systems become more prevalent and through improved training of technicians.

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### Sobeys Commercial Refrigeration, Canada

**Project Background:**
Sobeys owns or franchises more than 1,300 stores all across Canada under different retail banners. In the province of Quebec, Sobeys operates under the IGA brand. In February 2010, the new IGA Cookshire store opened. The new supermarket is a state-of-the-art one, having been built to LEED (Leadership in Energy and Environmental Design) specification with environmental considerations throughout the building.

**Refrigerant Used:**
CO₂ transcritical refrigerant systems

**Refrigeration, Canada**

**Name of the Store/facility:**
Sobeys, IGA Cookshire

**Location:**
35 rue Principale Est, Cookshire, Québec J0B 1M0, Canada

**Contact information:**
Rod Peterson, National Procurement Manager, Rod.Peterson@sobeys.com
David Smith, VP of Sustainability, David.Smith@sobeys.com

**Type of Facility:**
Supermarket, Store Area = 1,950 m², Grocery and Food Retailer, Store has LEED certification.

**New System/Installation:**
The transcritical CO₂ refrigeration system, which has become the new national standard for refrigerant systems at Sobeys, is a low GWP (Global Warming Potential) transcritical CO₂ system. It will be included in all new builds and will be considered for retrofits where feasible based on the store size and scope of the retrofit. Within these systems CO₂ levels are monitored for leakage; however, because CO₂ is a natural gas, these systems do not pose the same risk to the environment (due to leakage) as traditional HFC systems.

The average Sobeys supermarket refrigeration system contains 1,130–1,360 kg of HCFC refrigerant R-22. HCFC refrigerants have an ODP above zero and also significant GWPs of 1,810–4,657 and are therefore responsible for a significant portion of a typical supermarket’s direct carbon footprint due to leakages. The common HFC replacement option for R-22 is R-507 and R-404A. Refrigerant R-507 has a GWP of 3,985, where a 1 kg leak of R-507 is equivalent to 3,985 kg of CO₂ emissions. Average rates of leakage of these refrigerants are between 10% and 30% per store each year, and almost 30% of Sobeys’ stores’ aggregate carbon footprint.

The transcritical CO₂ refrigerant system shown in Fig. 2 uses only CO₂, which has a GWP defined to be 1, as compared to the higher GWP of R-507. The CO₂ systems are energy efficient in comparison with traditional refrigeration systems, and especially with the combination of heat reclaim introduced with them, provide a net reduction in store energy consumption. The intensive reclaiming of waste heat from the refrigeration units can be used to cover almost all the heating needs of the supermarket. A pre-heating water loop is also installed in the supermarket to preheat hot water used within the store.

**Challenges:**
One of the initial challenges and concerns when installing these systems was that of contractor training and timely access to new components. It was unclear if contractors would be familiar enough to service and work with these systems. This was a particular concern as Sobeys considered scaling up and extending new builds into stores far from the Quebec location of the CO₂ system manufacturer where direct support from the system manufacturer would be much less readily available than during the Quebec pilot phase. However contractors were found to be increasingly embracing this technology and investing in servicing and installation training as these systems become more common. Another challenge was building the company’s plan for the transition to transcritical CO₂ because of the differences in geographical and infrastructural constraints between stores. Furthermore, there are also financial challenges. At this stage, as early adopters, the Sobeys systems are still fairly expensive in capital cost terms compared to future projections, thus the return on investment (ROI) is dependent on the size and nature of the store, whether heat reclaim is already in place, and sometimes whether...
government incentives exist. These systems at Sobeys have a 3-4 year average return on investment. However, as mentioned above, the company expects costs to decrease and installation and infrastructural support to become easier as these systems become more prevalent and efficient. This presents the opportunity to reduce the cost curve.

Emerging out of these challenges and the commitment to this system, many lessons have been learned. For example, in order for the company’s contractors and suppliers to provide the services needed for a new system, they need to be engaged early in the overall process from designing the system through the procurement and installation stages. They need to also understand the advantage of such a system in order for them to develop expertise on these new refrigeration systems, as it does require investment in training and adds complexity to their businesses. It is also important to look ahead, when conducting a business case study on return on investment (ROI), because what may not be feasible today may very well be feasible in the near future as regulations and industry initiatives drive adoption of these systems. Cost forecasts for refrigerant re-charges and energy savings are important considerations in such cases.

Performance:
Sobeys has made a commitment to alternative CO2 refrigeration technology and is very pleased with the results. The installation of these transcritical CO2 refrigerant systems with heat reclamation has not only made financial sense, but clearly makes environmental sense and is in line with Sobeys’ commitment to reduce its CO2 footprint and impact. The approach taken to come up with performance indicators was applied equally to all stores of identical nature. Therefore, the results will be reported per store. The following are the calculated reductions in comparison to a traditional HCFC refrigerant system:

- Carbon dioxide emissions reduced by 62% = 861,920 kg CO2-equivalent per year, per store
- Energy consumption reduced per year by 15% -18%
- Natural gas (heating) consumption reduced per year by 75% - 85%

Note that Sobeys experience with the performance of transcritical CO2 systems is based on all of their stores being located in temperate climates (annual average temperature 0° C to 20° C) in the Northern Hemisphere. Stores located in higher ambient temperature zones would have different design parameters and operating conditions, and therefore these reductions in CO2 emission and in energy consumption will vary.

Cost and Economic Considerations:
The initial capital costs of a transcritical CO2 system are more than traditional HCFC DX systems (approximately 11% increase in capital for refrigeration equipment), however operating costs and energy savings will offset the initial capital cost. The simple payback on a transcritical CO2 system with heat reclaim is less than three years.

Cost savings are a result of lower maintenance (including significantly reduced refrigerant re-charge costs) and energy costs. While it is financially viable to move forward to implement such projects today, Sobeys is proceeding with this technology knowing that the initial capital costs will be rapidly reduced through design, manufacturing and installation efficiencies, and as the Montreal Protocol deadlines for HCFC phase-out approach these systems will become more prevalent and standardised throughout the supply chain.

The following simplified annual financial analysis of a single supermarket assumes that heat reclaim is included as a standard feature, as it helps to drive the reduction in operating costs. Moreover, it is generalised across Canada, where heat, energy, refrigerant, installation and maintenance costs may vary.

Total incremental capital cost for the refrigeration system increased by 11%.
Total installation costs reduced by 0% to 15%.
Maintenance costs reduced by 50% (as experienced across stores in Sobeys Quebec, this would be the average annual refrigeration maintenance costs of a typical IGA store). A large part of the cost reduction would be replacement refrigerant gas from leaks.
Heating cost reduced by 75% to 85%.
Simple payback within three years.

Fig. 2 and 3 are courtesy of Carnot Refrigeration. Fig. 1 is courtesy of www.voirvert.ca

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Brazil

Verdemar Commercial Refrigeration, Brazil

Name of the Store/facility:
Supermercado Verdemar – Nova Lima Store

Location:
Belo Horizonte, Brazil

Contact information:
Carlos Arruda – marketing@superverdemar.com.br

Type of Facility:
Gourmet supermarket, Store Area =1,800 m²,
Small chain fine food and wine retailer.

Refrigerant Used:
CO₂ cascade system with HFC (R-134a) refrigerant as the high side fluid. The new installation uses a cascade system composed of a twin primary system using 75 kg of R-134a (GWP=1430), and a secondary system using 100 kg of CO₂.

Project Background:
The Supermercado Verdemar – Nova Lima Store was opened in 2010, at Nova Lima, Brazil, 10 kilometers from Belo Horizonte, at an altitude of 1,350 meters above sea level. The building has 1,800 m² of store floor and 500 m² of kitchens and cold chambers. Fig.1 shows a photo of the external view of the store.

New System/Installation:
The approach is to use CO₂ as one of the fluids in a cascade system along with an HFC refrigerant (R-134a) as the high temperature fluid. R-134a, is an HFC haloalkane refrigerant with GWP of 1,430. Such systems may have a much lower HFC refrigerant charge, and the global warming potential is reduced compared to a baseline system using only HFC refrigerant.

TECHNICAL DATA:
- Cascade system built inside a large rack that holds most of the working components.
- The Primary dual circuit system is based on R-134a with a load of 136 kg of gas, industrially mounted and piped inside the cooling unit rack in the main rack, using a small volume of gas. This system has zero history of leaks and approximately one-third the amount of GWP as compared to a system using only R-404A or R-507.
- The Secondary system is based on R-744 (CO₂), developed with special high technology parts and components, working on Direct Expansion (DX) or in liquid fluid subsystems.
- The CO₂ subcritical scheme was specially fine-tuned by lowering the condensing temperature of the R-134a primary system to 40° C and raising the evaporation temperature to -8° C, resulting in 71% less energy consumption with a payback period of 19 months. This is achieved by a special patented adiabatic cooling system at the primary condensation circuit allowing a very efficient heat exchange.
- The use of Electronic Expansion Valves were mandatory for better control of the large expansion capacity of CO₂ and to prevent return of liquid to the compressor, as well as keeping stable temperatures at refrigerated points, shorter response time to changes, shorter operation of compressors and lower power consumption.
- Low cost, low power iQ motors (70% energy savings) at the secondary liquid fluid systems, with special larger area evaporators developed by Arneg. The savings are compared to traditional DX HCFC showcases used in the past. It is important to mention that this solution avoids the need for defrosting, hence additional energy savings is achieved.
- High efficiency, progressively activated fans at the condenser, with Electronically Controlled (EC) variable speed DC motors; working on a high-efficiency moist hives adiabatic cooling system, patented by Plotter-Racks Brazilian contractors.
- High-efficiency fans with dual speed ESM³ DC motors in evaporation grids, especially at the production sectors, with energy savings of 36% and a payback period of 14 months, and better ergonomic comfort work conditions.
- Frequency regulated pumps, with energy savings of 19% and a payback period of 21 months.
- Frequency regulated Bitzer compressors, with energy savings of 8% compared to conventional compressors without frequency regulation and a payback period of 23 months.
- Low condensing pressure (30 bar).

This profile installation was then deployed in the two stores opened in 2010 and 2011 and at the main Warehouse in 2012, and has since been adopted as a standard for the chain. So far, the company operates on CO₂ in three out of its eight stores. There are also two new stores in 2013, and plans are in place to convert the older stores to CO₂.

Acknowledgements:

³Energy saving motor
Medium temperature system diagram

Low temperature system diagram

Fig. 3 Medium temperature system diagram

Fig. 4 Low temperature system diagram
to maintain and operate as any other conventional refrigeration system.

**Performance:**
The overall achievement of this installation was a result of investment in training, equipment development and component research. The chosen components behaved as expected, allowing the optimal functioning of technologies to obtain the desired efficiency.

The resulting energy efficiency was 30% better, compared with the previous HCFC conventional systems. The main characteristics of the new CO₂ system are the adaptation of several high technology components in the global assembly such as:

- Intelligent two-speed ESM motors evaporation fans in refrigerated chambers and preparation areas, contributing also to a better ergonomic comfort.
- Progressively activated, variable speed EC motors in special aerodynamic designed ventilators in the condensing unit.
- iQ motors in liquid fluid evaporation grids, with very low energy consumption

The company acknowledges that at present while there is better availability of parts and components in the local market, facilitation of import of special parts and components from official authorities can be an important issue for the adoption of these new technologies. The main items required are R-744 compressors, intermediate heat exchangers, electronic valves and controllers. Fig. 5 shows a photo of the refrigeration system.

As R-744 is odourless, and its presence at levels greater than 10% is a serious health and safety issue, the company uses sensors and detectors in closed rooms and double release valves located in exterior locations as additional safety measures.

**Cost and Economic Considerations:**
Comparing the cost of the new system with conventional installations in the older stores, the company estimates a capital cost increase of 20%, taking into consideration the rack assembling, compressors, condensers, chillers, heat exchangers, evaporators, valves, piping, electric materials, command and control panels, hand work, start up and operation tests. However, this is offset by the reduced maintenance, operating and energy costs of the new system.

Comparison with older systems:
The payback of this system is less than 30 months. The maintenance cost was reduced by 40%. Energy savings are 30%.

One important aspect is that the energy reduction will be continuous, lowering costs and contributing to environmental benefits.

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Waitrose Commercial Refrigeration, UK

**Name of the Store/facility:**
Waitrose, Bromley South

**Location:**
Bromley, Kent, UK

**Contact information:**
Jim Burnett, jim_burnett@johnlewis.co.uk

**Type of Facility:**
Supermarket, Store Area = 2,170 m², Groceries, Food. Waitrose Limited is an upmarket chain of British supermarkets, forming the food retail division of Britain’s largest employee-owned retailer.

**Refrigerant Used:**
Honeywell Solstice® ze, R-1234ze, HFO-1234ze. This case study has the world’s first HFO chillers.

**Project Background:**
Bromley is near London and the store has a 2,170 m² sales area. The Bromley South store was opened in November 1996 and the plant was typical of systems built around that time. The existing system was R-404A and did not comply with the Waitrose policy of HFC reduction. Waitrose has signed on to the Consumer Goods Forums Resolution to start phasing out HFC refrigerants.

**New System/Installation:**
Waitrose had decided on a water-cooled refrigeration system as these both reduced the refrigerant charges in the branch (as each cabinet is integral) and the potential for leakage due to water being at a lower pressure and systems being of a small individual charge. Jim Burnett of Waitrose said: “We believe the HFO solution shows great promise, as it combines good efficiency with very low global warming potential. This is obviously a highly desirable profile in a refrigerant. If the ongoing monitoring of energy continues to prove successful, we plan to include HFO-based chillers in our choice of refrigeration platforms for stores in the future.”

**Refrigeration, UK**

**CASE STUDY-10**

**CASE STUDY-10 Waitrose Commercial Refrigeration**

**Schematic for the installed compressors**

**Table 1 Specifications for the installed compressor**
All the components have performed as anticipated.
Spare parts for the system are available.
The chillers using this new refrigerant run more efficiently than the hydrocarbon version that is currently used in other stores.
The system uses two 180 kW chillers with a Frascold semi-hermetic compressor supplying chilled water as a condenser medium for the in-store integral cases running on propane (R-290).
A comparison has been done with a same-size store in Canterbury (in south-east England) running identical systems, but using R-290 (propane) instead of HFO-1234ze. The comparison shows a 22% reduction in energy consumption for the HFO system compared to the propane one.
Tests carried out by Frascold with its eight-cylinder reciprocating compressors running on HFO-1234ze indicate a loss of capacity of around 24% compared with R-134a across various application conditions. However, mean power absorbed is almost 27% less, giving an overall COP actually better than R-134a across a range of applications and conditions.

Cost and Economic Considerations:
The capital cost of the new system is currently approximately 10% more than a propane equivalent at the time of installation, but this cost is expected to go down as production is increased and as the operating characteristics and system design requirements become better understood. The cost of maintenance is the same as for hydrocarbon systems.

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Table 2 System specifications and capacity
CASE STUDY-11

Application of Climate-Friendly Commercial Refrigeration Technologies: H-E-B, USA

Name of the Store/facility:
H-E-B at Mueller

Location:
Austin, Texas, United States

Contact information:
Charlie Wernette, wernette.charlie@heb.com

Type of Facility:
Supermarket, Store Area = 7,711 m²

Refrigerant Used:
Propane Self-Contained Cases

Project Background:
H-E-B has been incorporating sustainability measures into their stores for the past 15 years. As part of their environmental strategy for the H-E-B at Mueller sustainable design test store, H-E-B set a goal to reduce energy and potable water consumption by 50% relative to their 2010 baseline. In addition, H-E-B decided to trial the use of climate-friendly refrigerants.

Prior to the opening of their Mueller store, H-E-B had never used a non-fluorinated refrigerant. With the company’s stores located in Texas (United States), and Mexico, H-E-B made a decision not to use a carbon dioxide (CO₂)-based technology, which operates at much higher pressures and therefore is not ideal for use in warmer climates. Inspired by Waitrose—a U.K.-based supermarket chain that began using propane-based refrigeration systems in their stores in 2009—H-E-B approached several equipment manufacturers in the United States about the possibility of implementing a similar type of refrigeration system in their stores. H-E-B ultimately decided to work with Hussmann, and in 2011, the effort to develop self-contained propane units was officially underway. Fig. 1 shows a photo of the store.

New System/Installation:
In total, the H-E-B at Mueller store contains 70 refrigerated cases that have a total cooling capacity of 1,013 MBTUs[^1]. The majority of these cases are self-contained units that use propane (R-290) as the refrigerant. Each condensing unit contains a refrigerant charge size of no more than 150 g, as required by U.S. regulations, adding up to a total of 66.2 kg of propane within the store. The compressors, which pipe the refrigerant directly to the evaporator, are contained within each unit. The vast majority of the propane-refrigerated cases in the store have a door or sliding lid, which minimises energy consumption and allows the refrigerant charge to remain small.

In addition to the propane units, a small number of cases are cooled using a distributed direct expansion refrigeration system. This system, which uses R-404A as the refrigerant, is used to cool select produce cases that are not equipped with a door. These produce cases contain products that are kept wet with an automatic misting system, and therefore cannot be easily equipped with a door. Without a door, it would not have been feasible to keep the refrigerant charge of propane below 150 g; thus, H-E-B reverted to a more traditional refrigeration system to cool these cases.

All of the cases in the store are connected to a water-chilled condenser, which is used to remove heat from the refrigerant after it has removed heat from the refrigerated space. The water-chilled system, which is also used for space cooling and heating, contains 544.3 kg of HFC-134a. It is estimated that roughly 26% of the HFC-134a is used for refrigeration while the rest is used for cooling and heating.

[^1]: Million British Thermal Units
Performance:

Although the store has only been operational for a few months, the refrigeration system so far is operating as expected. While performance data was not available at the time that this case study was developed, it is projected that the carbon footprint of the store will be reduced by 85% relative to a baseline store. Of the 85% reduction, 58% is attributable to reduced energy use while the remaining 27% is attributable to the direct emissions avoided by using propane as the refrigerant.

From a financial perspective, the store cost more upfront but is expected to save money over time. While capital costs were relatively high, the simple, self-contained design eliminated the need to pay a refrigeration contractor to install the system. Due to the simple design, maintenance costs are also expected to be relatively low. Furthermore, cost savings will be realised through a reduced energy bill. H-E-B anticipates a payback on its investment in energy reduction and advanced refrigeration technology design features.

Challenges and Lessons Learned:

H-E-B has identified a variety of benefits associated with its refrigeration system. First, using propane instead of a traditional HFC refrigerant offers enormous environmental benefits. Propane has a global warming potential (GWP) of three, which is significantly lower than the GWP of traditionally used HFC refrigerants, which can be over 3,000. In addition, the simple ‘plug-in’ design, similar to a home refrigerator, is a major benefit.

The simple design allowed H-E-B to plug in the self-contained units and hook them up to the water-cooled condenser rather than having to purchase the display cases and refrigeration racks separately and hire a contractor to install the piping network, connect the system, and charge it with refrigerant and oil.

While H-E-B is very happy with the outcome of the store design, it did not come without some challenges. First, the United States Environmental Protection Agency restriction on charge size of 150 g of propane per unit required H-E-B, with the help of Hussmann, to develop a unique system design to accommodate the refrigerant. To compensate for the limited refrigerant charge, the resulting design uses significantly more compressors than a traditional system, which drives up costs. In addition, it was a challenge to overcome the stigma associated with using a flammable refrigerant. The store was required to install extra leak detection and alarm systems prior to receiving approval from the Austin Fire Department to operate.

Even with the challenges that H-E-B faced, they believe that the benefits of this store outweigh the costs; plans are underway to install the novel technology in other H-E-B stores.

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Other Sustainability and Energy Efficiency Measures:

H-E-B at Mueller is the seventh green building certified store by the company. H-E-B designed the store with several energy-saving features as well. LED lights are used throughout the store, both inside the cases and for overhead lighting. The roof is fitted with 169 kW of solar panels that provide part of the store's energy needs.

H-E-B at Mueller is also one of the first green buildings in the U.S. to use propane in refrigeration systems. Propane has a global warming potential (GWP) of three, which is significantly lower than the GWP of traditionally used HFC refrigerants, which can be over 3,000. In addition, the simple ‘plug-in’ design, similar to a home refrigerator, is a major benefit.

H-E-B anticipates a payback on its investment in energy reduction and advanced refrigeration technology design features.
Sector Overview
The transport refrigeration sector comprises the equipment, technologies and services used to transport and dispense frozen and fresh foods at the appropriate temperatures. Travel time, ambient temperatures, and risk of spoilage often make temperature-controlled transport necessary. Because some commodities are sensitive to the relative humidity and chemical composition of their surrounding atmosphere, these conditions may also need to be controlled. Today many commodities travel to distant markets intermodally (i.e., by some combination of highway, ocean and railroad).

Vehicles used for temperature-controlled transport are similar in construction and outward appearance to those in general freight service, but have three fundamental differences which are as follows:

1. Insulation that is usually foamed in place.
2. Provisions for conditioned air circulation through and around the cargo.
3. Machinery for cooling/heating.

A brief description of the four main vehicle types is as follows:

**Cargo containers** are usually 2.4 m wide, 2.4 to 2.9 m high and 6.1 or 12.2 m long. They have hinged doors in one end for cargo loading and other access to the interior. The machinery comprises the opposite end, so it must also provide structural rigidity and insulation. Containers have standardized corner fittings to secure them to vessels, railway cars, and highway vehicles.

Railway refrigerator cars are insulated boxcars, usually 15 to 20 m long. They may have a machinery compartment at one end.

Trails range in size from 2.4 to 2.6 m wide, 3.7 to 4.1 m high, and 7.3 to 18.3 m long. Their doors are usually hinged, but they may have insulated roll-up doors if used for multi-stop delivery service. Some include a curb-side door in addition to rear doors. Several interior compartments for different temperatures may be provided by an insulated bulkhead to separate the different zones. Specially designed trailers riding on railway flat cars are quite common. As with ordinary trucks, those built for temperature-controlled duty come in a wide variety of designs and sizes. Their bodies may have insulated hinged or roll-up doors on the sides and rear. Truck bodies also may have several interior compartments for different temperatures, similar to trailers, with an insulated bulkhead separating the different zones. Smaller vehicles may include a refrigeration compressor as an engine-driven accessory.

**Cargo Container and Rail Car Systems**
Refrigerated cargo containers typically have unitary equipment that comprises the entire front wall of the container. The equipment has a vapour compression refrigeration system and uses an external source of electricity for its compressor and fan motors, resistance heaters, and operating controls. It usually uses bottom air delivery. The unit may have a detachable diesel engine/generator set (with integral fuel tank) accompanying it while traveling by land. Rail cars may have field-installed components. A three-phase AC diesel engine-generator set, condensing unit, and refrigerant and electrical operating controls are usually located in a machinery compartment at one end of the car. An evaporator fan coil package, or separately mounted evaporator and fan, is typically adjacent to the machinery compartment but inside the insulated space. Electric heaters in or under the evaporator are used for heating and defrost.

**Self-Powered Truck and Trailer Systems**
The majority of over-the-road transport refrigeration equipment is based on vapour compression technology. Whereas refrigerated cargo containers and railway refrigerator cars are supplied by external electric power, truck and trailer refrigeration units are designed with a range of driving concepts. Units can be self-powered or vehicle powered. The self-powered unit contains its own prime mover and therefore can operate independently on the vehicle. A combustion engine is frequently used as a source of mechanical power. In this case, the engine drives an open-shaft compressor and condenser and evaporator fans/blowers are driven through a belt-and-pulley system. This classical concept of a self-powered refrigeration unit is widely applied on truck and trailer systems. There is only one source of mechanical energy, and cooling capacity can be modulated either by switching the engine on and off, or by shifting engine speed between predetermined high- and low-speed operating modes. Engine speed change also changes the speed of the fans/blowers and therefore affects air circulation over the condenser and inside the refrigerated space.

An optional standby operation is often used in this type of system. An electric motor is integrated into the drive system so that when the vehicle is stationary, the refrigeration system can be operated by electric power, also referred to as shore power.

Another type of self-powered unit propulsion system uses an on-board engine-driven generator that supplies power to an electric compressor and to condenser and evaporator fan/blower motors. The full electric refrigeration unit allows for use of a hermetic or semi-hermetic compressor, thus eliminating potential for shaft seal leakage. The electric-powered components can be controlled independently, turning on and off when needed. Electric supply eliminates belt transmission losses, and the refrigeration unit can be directly connected to shore power when the vehicle is stationary.

Trailer systems typically have unitary equipment that consists of a diesel engine with battery-charging alternator, compressor, condenser and engine radiator associated with fan, evaporator fan with fan, and refrigerant and electrical controls. The refrigeration components, such as the compressor, condenser fan, and evaporator fan, can be mechanically driven from the engine. These components may also be fully electric, with the diesel engine driving a generator, or some combination of mechanical and electric components can be used. Large self-powered truck systems typically have unitary equipment that is similar to trailer equipment.

**Vehicle-Powered Systems**
Vehicle-powered refrigeration units, as the name suggests, draw power from the vehicle’s propulsion system. This type of system is typically applied to small trucks and vans used for local delivery of refrigerated products. For this type of system, the compressor can be mechanically driven, typically through a belt and pulley, from the engine, with all other refrigeration components driven electrically off the vehicle battery. As with self-powered trucks, a condenser and evaporator fan-coil package is installed at the front top over an opening to accommodate the evaporator and its fan(s), and top air delivery is generally used. An all-electric vehicle-powered truck system, is powered by an electric alternator that is driven by a belt either from the engine crankshaft or the engine power take-off (PTO). Electrical power is wired to the refrigeration unit, which allows use of a hermetic or semi-hermetic compressor and electric fan motors.

**Multi-temperature Systems**
Trucks and trailers with multiple interior compartments operating at different temperatures require a multi-temperature refrigeration unit. A moveable insulated bulkhead typically separates the different compartments, and remote parallel evaporators are connected to the main refrigeration unit, which is connected to the front wall.

The expected lifetime for all transport is between 10 and 15 years, and between 20 and 25 years for equipment aboard ships. Refrigerant charge size ranges from 4.5 to 7.5 kg for road vehicles, railcars, and intermodal containers and from 100 to 500 kg for conventional equipment aboard ships.

Historically, HCFC-22 was used for transport refrigeration applications which were converted to HCFCs in the 1990s—primarily to R-404A, R-507A, R-410A, R-407C, and HCFC-134a. Currently, significant research on zero- and lower-GWP refrigerants has focused on “natural” or non-fluorinated, chemicals such as CO₂, NH₃, and Liquid Nitrogen (LN₂).
To compile the case studies, research was conducted to generate a list of potential case studies for consideration taking into account all of the currently available zero- and lower-GWP refrigerants in transportation refrigeration applications. Some criteria such as geographic location, refrigerant used and available information of the proposed applications were taken into consideration when selecting the case studies. However obtaining appropriate and relevant case studies in the transportation refrigeration sector was something of a challenge. Included below are three case studies with CO₂ and LN₂ refrigerants with innovative technologies and systems in the field of transportation refrigeration. The intention is in the future to collate further case studies from other transportation sectors as well as examples of other lower-GWP refrigerants and advanced technological inventions, systems and strategies.

These chosen case studies take into account energy efficiency benefits of alternatives, as well as cost, safety, availability, maintainability, life expectancy and other sustainable and environmental considerations. Robust technical information was collected in the chosen case studies based on data provided by the source. These case studies also provide a detailed analysis for the system components, methodologies, and controls technology to optimise energy efficiency and continually update with new developments.

The technologies presented in these case studies are only some examples of the many available options for zero- and lower-GWP substances, taking into account all design criteria, such as system performance, environmental impact, and cost analysis. The cases presented here focus on CO₂ and LN₂ refrigerants. All these refrigerants still have many challenges that should be considered in the design such as their flammability, toxicity, lower efficiencies in some cases, and cost. Balancing the safety, energy efficiency, cost, and environmental impact of refrigerants using a consistent and comprehensive methodology across all refrigerants and system types is essential in assessing alternatives. Good design is also important for reducing refrigerant emissions and preventing refrigerant loss during installation, operation and maintenance, decommissioning and end-of-life disposal.

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<th>REFRIGERANT</th>
<th>APPLICATIONS</th>
<th>CHALLENGES</th>
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<tbody>
<tr>
<td>CO₂ (R-744)</td>
<td>Limited use in refrigerated ships and road applications; used in some small intermodal containers and boxes; requires external mechanical refrigeration system to generate.</td>
<td>Safety Risks, High Operating Pressure; Requires: Good Engineering Design and extensive Training and Education.</td>
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<tr>
<td>NH₃ (R-717)</td>
<td>Limited application in indirect and cascade systems on new refrigerated ships; specifically in ships that carry professional crew only (no passengers) and those with relatively high refrigeration capacity (e.g., fishing ships). Under evaluation for use in refrigerated railcars, rail and ships.</td>
<td>Toxicity, Slight Flammability; Requires: Good Engineering Design, Standards and Safety Regulations.</td>
</tr>
<tr>
<td>HCs (e.g. isobutane, propane)</td>
<td>Under evaluation for use in road or rail transport refrigeration (in secondary loop systems; used in compression systems (including hermetic/semi-hermetic compressors) likely to be enabled in road transport if/when refrigeration equipment becomes electrified.</td>
<td>High Flammability, Liability Concerns; Requires: Safety Code Restrictions, Safety Devices, Standards and Service Procedures, Training and Education.</td>
</tr>
<tr>
<td>HFOs (e.g. HFO-1234yf, blends)</td>
<td>Under consideration for use across transport refrigeration modes beyond 2014, Intermodal containers, Rail, Road, Ships.</td>
<td>Slight Flammability; Requires: Research and Development, Alternative Refrigerant Technologies.</td>
</tr>
<tr>
<td>Liquid Nitrogen (LN₂)</td>
<td>Limited use in cryogenic refrigerated units.</td>
<td>Safety Risks, Requires: Good Engineering Design and extensive Training and Education.</td>
</tr>
</tbody>
</table>
**CASE STUDY-1**

**ASKO, Norway**

Name of the Facility:
ASKO, Norway

Location:
Norway

Contact information:
Name: Dr. Dermott Crombie
Email: dermott_crombie@thermoking.com
Designation: Vice President, Strategic Initiatives, Climate Solutions

Transport Category:
Road transport

Refrigerant Used:
Liquid CO2/R-744

Project Background:
Urbanisation is a global phenomenon. Today, in the EU, 70% of the population lives in cities⁹, and this percentage will continue to increase. Major urban centres are working to improve the quality of life for their inhabitants. One measure of success is the extent to which lifespan can be extended.

Contributing factors would include road safety, exercise, air quality, noise, and diet. On this last point, it is worth noting that prior to the invention of transport refrigeration (1938) people in the developed world ate fresh food, in season, grown within 100 miles of where they lived. Outside of those parameters, people ate dried, salted or pickled food. Today, people in the developed world eat almost any type of fresh perishable food, any day of the year. Strawberries at Christmas, kiwis from half way around the world, are all taken for granted. A varied and fresh diet has contributed greatly to the health of the general public.

This study outlines a product which provides near-silent, zero-emissions refrigeration, ideal for distribution of perishables both day and night in busy urban locations.

ASKO is a major retailer in Norway. With 3,300 employees, and a turnover of over 50 billion Kr in 2014, ASKO includes 13 regional ASKO companies, central warehouses and a cross docking terminal at Vestby in Akershus, plus 8 Storcash outlets. Storcash is the largest cash & carry wholesale for businesses. With 600 trucks on the road each day, ASKO is also one of the largest transport companies in Norway.

**New System/Installation:**
The challenge of delivering perishables to large urban centres with minimal environmental impact is addressed in this case study. Traditionally, refrigerated trucks, running on diesel fuel, used an additional diesel-powered refrigeration system, operating with hydrofluorocarbon (HFC) refrigerants, to make regular deliveries to city supermarkets. The novel cryogenic system discussed here can operate on a traditional diesel truck, or on an electric vehicle. The system operates without utilizing HFCs, requires no diesel engine, thus avoiding other emissions, including particulates (PM), and does so almost silently (59 dBA or lower).

United Nations World Urbanisation Prospects: The 2014 Revision, Highlights

The system utilises waste CO₂ (carbon dioxide), typically from fertilizer, ammonia production processes or more and more from biological processes such as the conversion of biogas into Natural Gas. The energy used to refrigerate the cargo has to originate somewhere. In this case, the energy for liquefying the CO₂ comes from the national electricity power grid. Other cryogens such as LN₂ (liquid nitrogen) were considered but were rejected for reasons we will discuss later.

Reduced Carbon Footprint
CryoTech uses liquid carbon dioxide (CO₂ or R-744), sourced from recycled waste gas. R-744 is a waste by-product of industrial processes which avoids a cumulative global warming effect. Liquefaction of R-744 generates significantly less emissions than nitrogen or fossil fuels. Fig. 2 shows a source path of liquid CO₂.

The liquid CO₂ is stored in a cryogen tank, fitted on the vehicle. The system utilises a liquid CO₂-fed evaporator coil in the load space to remove heat from the cargo. The liquid CO₂ does not enter the cargo space. A fan system is powered by the vehicle’s electrical system. Earlier systems used the cryogen to power the fan system as well, but this configuration was less effective because the fan system only ran when cooling was required. The latest system has air circulation independent of cooling demand, which leads to a better control of the cargo climate, and better utilisation of the cryogen in the tank. Fig. 1 shows a schematic diagram of the refrigeration system.
CASE STUDY 1: ASKO, Norway

Multi-compartment:

Inner city supermarkets carry a wide range of perishables, which need to be transported at a variety of temperatures. To minimise the number of vehicles delivering, Thermo King has developed the Cryo product range to include up to three independent temperature compartments in one vehicle. Thus, one vehicle can deliver fresh, chilled, and frozen food in one delivery, thereby reducing traffic volumes.

CO₂ Storage:

CO₂ is stored in a large tank, either at a public filling station, Thermo King Dealer facility, or at the customer’s distribution centre. Liquid CO₂ is ‘refueled’ as needed, typically on a daily basis. Fig. 4 shows a photo of the CO₂ tank.

Noise:

Noise has been identified as a key element in quality of the environment. Fig. 5 gives an indication of sound pressure level of various systems and equipment.

Choice of Cryogen:

Thermo King looked at several cryogens including CO₂ and LN₂. Liquefied air is sometimes mentioned, but in practice the 21% O₂ contained in liquefied air is removed and sold separately, leaving ‘liquefied air’ cryogen as LN₂. LN₂ has a much lower cryogen temperature, being stored at degrees -190°C, whereas liquid CO₂ is stored at degrees -57°C. In this respect, LN₂ presents more of a safety challenge than R744. Additionally, liquid CO₂ has higher refrigeration capacity per stored litre of cryogen, meaning the cryogen tank can go farther on CO₂ than on LN₂.

Finally, the carbon footprints of LN₂ & liquid CO₂ are compared below with a traditional diesel system as a reference. Fig. 3 shows an annual average CO₂ Emissions from Truck Unit Operation.
Fig. 6 chart illustrates the dramatic noise difference when compared to traditional diesel refrigeration units.

Due to the very low noise levels of the system, they are suitable for delivering at night. Doing so allows a shift from busy daytime traffic to times when traffic is much lighter, again saving on distribution time and fuel used.

Performance:
A major factor in shelf life of perishables is in maintaining their correct temperature. Fast recovery of the correct temperature after the doors have been opened multiple times is key to cargo quality. In this respect, the Cryotech system outperforms the traditional refrigeration system, as it has fewer constraints on cooling capacity. Fig. 7 shows the pull down comparison of Cryotech unit and Conventional Refrigeration Unit.

Shelf Life and Reduced Waste:
Both fresh and frozen products can suffer significant temperature fluctuations every time a door is opened. Such spoilage can account for 0.25% of a retailer’s annual turnover. With its market leading temperature recovery, Cryotech ensures steady product temperature even on the most demanding distribution routes at high ambient temperatures. Fig. 8 shows a comparison of shelf life and reduced waste between Cryotech unit and Traditional Refrigeration unit.

Cost and Economic Considerations:
The capital cost of the new system is currently higher than the traditional diesel powered system, as it involves installing a cryogen storage system at the depot. However, running costs are lower resulting in an overall savings of around 7% in overall costs.

Case studies have shown that city distribution during rush hours take, on average 14% more time. Cryotech allows you to access restricted areas at any time during the day or night, due to its very low noise levels. Avoiding heavy traffic with faster distribution runs saves time and cuts fleet operating costs by up to 7%. Fig. 9 shows a distribution pattern and savings with Cryotech units.

Disclaimer:
The information presented here is provided by Thermo King. The accuracy of the content and figures is the responsibility of the company and these have not been verified by the CCAC or UNEP.
As governments and environmental advocacy organizations are considering regulations around HFC refrigerants due to concerns about global warming potential, the desire for natural refrigerants as a solution is needed for sustainable refrigerated transport. For the introduction of our NaturaLINE® unit, the world’s first natural refrigerant Container unit, we decided to use Carbon dioxide CO₂ (R744) based on the same criteria of Global Warming Potential (GWP), cost, efficiency, capacity and availability.

**Project Background:**
Carrier Transicold helps improve transport and shipping of temperature controlled cargoes with a complete line of equipment and services for refrigerated transport and cold chain visibility. For more than 40 years, Carrier Transicold has been an industry leader, providing customers around the world with the most sustainable container refrigeration systems and generator sets, direct-drive and diesel truck units, and trailer refrigeration systems. Carrier Transicold is a part of UTC Climate, Controls & Security, a unit of United Technologies Corp. (NYSE:UTX), a leading provider to the aerospace and building systems industries worldwide.

Carrier’s NaturalLINE® system underwent extensive field trials beginning in 2013 and through the end of 2014. These trials were conducted on a global basis with a number of customers, including container shipping lines as well as supermarket retailers testing the system for over the road use. Cargo transported range from frozen goods such as ice cream, carried at -22 degrees Celsius, to perishable goods such as bananas carried at 13 degrees Celsius. The trials represented over 120 shipments in total and accumulated more than 28,000 operating hours. The ambient temperatures experienced during these trials are representative of what container units normally experience, with ranges between -40 degrees Celsius to 50 degrees Celsius.

Environmental and efficiency concerns have been central to container refrigeration use and design for the last few decades. Advances in components and controls have delivered efficiency improvements along with refrigerant changes from ozone depleting CFC-12 to non-ozone depleting HFC-134a in the mid 1990’s. At a typical rating point of -18°C/38 deg. C the Coefficient of Performance (COP) has improved from 0.7 with a HCFC-12 system to 1.2 with the latest Carrier design using HFC-134a which is shown in the Bar Chart in Fig. 3.

**Original System:**
Container refrigeration units are mobile systems designed to fit into a refrigerated ISO container, typically 20 or 40 feet in length, that travel intermodal for transport on ships, rail and over the road. They typically consist of a basic vapour compression system utilizing a compressor, expansion device, evaporator (coil with fan & motor) and condenser (coil with fan & motor). Container refrigeration units can be configured with either reciprocating or scroll compression technology depending on customer preferences. The compressor can typically make up more than 50 percent of the total system energy consumption, during part-load operation, while the air circulating fans contribute another 12-15 percent. However, how these components are arranged, designed and controlled play a significant role in the overall efficiency of the unit. Fig. 2 shows a typical container refrigeration application.

**New System/Installation:**
For container shipping, CO₂ is the only refrigerant that offers a GWP of one, avoids harmful direct emissions, has zero ozone-depletion potential and is classified as non-toxic and non-flammable. Further, as an A1 refrigerant (no flame propagation, low toxicity), requires no disposal, is cost effective, available world-wide, and has excellent heat transfer and heat reclaim properties. Finally, CO₂ refrigerant is protected against phase-outs, taxes and F-gas regulations.

The challenge to create a system for transport refrigeration that meets the energy consumption levels of today’s efficient HFC machines is significant. In order for CO₂ to work as a viable refrigerant it must meet the demands of energy efficiency, cooling capacity, power consumption and pull-down that are expected in a container refrigeration unit today. To do that, we had...
to develop components and systems that can better control capacity and temperature using CO₂.

Carrier’s NaturaLINE system utilizes a variety of new technologies to meet this challenge and provide a solution for today’s needs. These include:

- A multi-stage, exclusive, reciprocating compressor design that maximized capacity while minimizing power consumption
- A variable speed drive that is custom-designed to electronically adjust the compressor speed to provide required cooling capacity
- A gas cooler coil that was designed to wrap around the fan to maximize heat-transfer surface area for greater efficiency
- A flash tank added to the design to manage the flow and phase change of the refrigerant
- Two-speed fans for both the evaporator and gas cooler for greater energy saving performance
- Advanced software controls to manage the unique system and provide optimized performance
- A Zero GWP polyurethane (methyl formate) foam blowing agent is used for high insulation without contributing to GWP

The result is a system that offers high overall performance with efficiencies comparable to the highest selling unit available, as well as part-load, perishable performance efficiency greater than the highest selling unit available, as well as part-load, perishable set-points. A comparison against similar to HFC-134a units, but with superior efficiency at part-load perishable set-points. A comparison against HFC-134a can be seen in Fig. 5.

Performance:
The capacity and efficiency of Carrier’s NaturaLINE unit is comparable to Carrier’s HFC units available today including the best-selling Carrier PrimeLINE™ unit. Specific capacity figures for typical rating points of a 380°C ambient and 60Hz power are:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>R744 Capacity</th>
<th>R134a Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2°C</td>
<td>9400 W</td>
<td>6000 W</td>
</tr>
<tr>
<td>-18°C</td>
<td>6000 W</td>
<td>4400 W</td>
</tr>
<tr>
<td>-29°C</td>
<td>4400 W</td>
<td></td>
</tr>
</tbody>
</table>

The average energy usage for the NaturaLINE unit is similar to HFC-134a units, but with superior efficiency at part-load perishable set-points. A comparison against HFC-134a can be seen in Fig. 5.

Cost and Economic Considerations:
The operational cost of the NaturaLINE unit will be comparable to existing HFC systems with respect to energy costs. Other costs associated with maintenance may be less as restrictions on HFC refrigerants and the cost of the higher GWP refrigerants rise either due to supply or taxation effects. Upfront costs will be more, but this is offset by potential operating savings as well as potential risks associated with fleet obsolescence brought about by F-gas regulations that could be enacted in the future.

Disclaimer:
The information presented here is provided by Carrier Corporation. The accuracy of the content and figures is the responsibility of the company and these have not been verified by the CCAC or UNEP.
and second due to leakages of refrigerants. According to sources of CO2 emissions: one due to diesel combustion (motor transport (trucks and trailers)), there are two approaches to cryogenic refrigerated units design: direct cryogenic refrigerated units where LN2 is released into the load space for cooling and indirect cryogenic refrigerated units that use a heat exchanger with LN2 or L-CO2 to cool air circulated in the load space. However, due to these disadvantages and government regulations on CO2 emissions, industry is actively searching for viable alternatives to diesel technologies by development of more fuel efficient diesel engines and hybrid systems.

Hybrid-diesel units consist of a full-capacity diesel engine combined with an electric standby unit, which is used to maintain temperature when the truck/trailer is stationary and has access to a 3-phase electric outlet. An electric standby unit adds more weight to the truck, is stationary and has access to a 3-phase electric outlet. 

Due to these disadvantages and government regulations on CO2 emissions, industry is actively searching for viable alternatives to diesel technologies by development of more fuel efficient diesel engines and hybrid systems.

Hybrid-diesel units consist of a full-capacity diesel engine combined with an electric standby unit, which is used to maintain temperature when the truck/trailer is stationary and has access to a 3-phase electric outlet. An electric standby unit adds more weight to the truck and are 10% more expensive than diesel units.

Efforts to solve problems that could not be solved by improving diesel systems and the creation of hybrid systems has led to the creation of cryogenic refrigerated units that use cryogenic technologies with liquid nitrogen (LN2) or liquid carbon dioxide (L-CO2).

There are two approaches to cryogenic refrigerated units design: direct cryogenic refrigerated units where LN2 is released into the load space for cooling and indirect cryogenic refrigerated units that use a heat exchanger with LN2 or L-CO2 to cool air circulated in the load space. 

LN2 is an inert gas, constituting the largest part of the atmosphere so is harmless, however in direct refrigeration units, there is risk if operators enter an oxygen-free load space and hence require various safety measures to guard against personnel entering or being trapped in an area where oxygen is low or nonexistent.

Safety concerns regarding the absence of reliable safety system for N2 direct cryogenic refrigerated units was one of the reasons for well-known gas supplier Linde Gas Company to develop N2 indirect cryogenic refrigerated units for truck and trailer use. This system uses LN2 in a closed system as the coolant. Another advantage for such systems comparing to conventional diesel systems has led to the creation of cryogenic refrigerated units for food transport has shown that it is feasible to use N2 direct cryogenic refrigerated units for food transport refrigeration for both rigid vehicles and trailers at zero GHG emissions at its operation.

**New System/Installation.**

The natureFridge technology suggests a “total loss”: refrigerants technology as an alternative to mechanical refrigeration where after use the refrigerant is released to the atmosphere, hence the term “total loss”.

LN2 is an industrial non-toxic gas, which does not produce direct CO2 emissions at its release to the atmosphere. There are only indirect CO2 emissions due to electricity consumption at LN2 production (different for different countries). Table 1 presents comparison of the CO2 emissions for modern mechanical system and any direct or indirect LN2 system.

NatureFridge technology provides refrigeration within the trucks’- trailers’ cargo space by means of a system consisting of a mounted storage tank, evaporator with sprayer above the cargo space and a thermostatically operated control system to inject N2 as required. The operating control system is connected with temperature sensors, positioned in the interior space to be refrigerated. By means of appropriate control valves the LN2 flows to sprayer which allows N2 to be injected into the cargo space as a gas.

**Analysis of the natureFridge units for refrigerated food transport.**

Food transport has shown that it is feasible to use N2 direct cryogenic refrigerated units for food transport refrigeration for both rigid vehicles and trailers at zero GHG emissions at its operation.

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More in depth the system lays together five operational subsystems (see Fig.1):

- Supply subsystem: it allows the possibility to install one to two tanks for the liquid nitrogen storing, which can be filled both from a supply track and a stationary supply tank.
- Control subsystem:
- Power subsystem:
- Cooling subsystem, which is equipped with:
- Safety subsystem, with multiple controls to minimize nitrogen asphyxiation risks

### Table 1 CO₂ emissions for diesel (without leakage included) and natureFridge systems

<table>
<thead>
<tr>
<th>Subsystem Description</th>
<th>LN₂ or diesel consumption (litre per hour)</th>
<th>MECHANICAL SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply subsystem</td>
<td>15</td>
<td>1.8</td>
</tr>
<tr>
<td>CO₂ emissions (kg/h)</td>
<td>4.80 at emission factor 0.32 kg CO₂ eq/l according to electricity consumption at LN₂ production in USA</td>
<td>6.15</td>
</tr>
<tr>
<td>CO₂ saving</td>
<td>24%</td>
<td></td>
</tr>
<tr>
<td>CO₂ emissions (kg/h)</td>
<td>0.96 at emission factor 0.064 kg CO₂ eq/l according to electricity consumption at LN₂ production in France</td>
<td>6.15</td>
</tr>
<tr>
<td>CO₂ saving</td>
<td>85%</td>
<td></td>
</tr>
</tbody>
</table>

According to http://large.stanford.edu/publications/coal/references/docs/sae98.pdf

<table>
<thead>
<tr>
<th>Subsystem Description</th>
<th>LN₂ or diesel consumption (litre per hour)</th>
<th>MECHANICAL SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply subsystem</td>
<td>26.17</td>
<td>2.79</td>
</tr>
<tr>
<td>CO₂ emissions (kg/h)</td>
<td>3.16 at emission factor of 0.21 kg CO₂ eq/l according to 0.465 kwh/l electricity consumption at LN₂ production</td>
<td>6.15</td>
</tr>
<tr>
<td>CO₂ saving</td>
<td>56%</td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Subsystem Description</th>
<th>LN₂ or diesel consumption (litre per year)</th>
<th>MECHANICAL SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply subsystem</td>
<td>89,467</td>
<td>14,470</td>
</tr>
<tr>
<td>CO₂ emissions (kg/h)</td>
<td>11.4 at emission factor 0.32 kg CO₂ eq/l according to electricity consumption at LN₂ production in USA</td>
<td>19.04</td>
</tr>
<tr>
<td>CO₂ saving</td>
<td>88%</td>
<td></td>
</tr>
<tr>
<td>CO₂ emissions (kg/h)</td>
<td>2.34 at emission factor 0.064 kg CO₂ eq/l according to electricity consumption at LN₂ production in France</td>
<td>19.04</td>
</tr>
<tr>
<td>CO₂ saving</td>
<td>90%</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 CO₂ emissions for diesel (without leakage included) and natureFridge systems
There is an oxygen sensor located in the track-trailer to measure oxygen levels in the confined space. When the LN₂ system is operational and the oxygen concentration in the trailer is below 18% (by volume) and if the track-trailer door is opened, the safety gate shown in Figure 1 will not be permitted to be opened and an audible siren will be activated and remain on to warn and prevent any personnel from entering the trailer.

Upon detection of the door opening and presence of low oxygen levels within the track-trailer, the following alarms are initiated:

1. Audio Oxygen alarm: An audible siren alerts the operator that it is unsafe to access the track-trailer. The audible alarm will stop once the O₂ levels are normal (safe for entry).
2. Visual Alarm: A red sign alerts the operator that it is unsafe to access the track-trailer. The sign will turn green once O₂ levels are normal (safe for entry).

An emergency stop switch is also provided, inside the track-trailer. A person trapped inside the track-trailer, when the door is accidently closed and LN₂ injection is activated can push the lighted emergency stop switch and stop the flow of nitrogen into the compartment. Activation of the emergency switch will also alert the driver, through a flashing red LED outside the track-trailer. A person trapped inside the track-trailer, and if the track-trailer door is opened, the safety gate will also alert the driver, through a flashing red LED outside the track-trailer.

There is a LED panel in the front end of the track-trailer. Driver, through a flashing red LED outside the track-trailer.

There is a LED panel in the front end of the track-trailer. A person trapped inside the track-trailer, an audible siren will be activated and remain on to warn and prevent any personnel from entering the trailer.

There is a LED visible from the driver’s position to indicate health/status of the nitrogen cooling system.

Performance:
Technical information based on data collected on the new system is presented in Table 2 below.

Table 2 – natureFridge refrigeration system Vs diesel powered mechanical refrigeration system

<table>
<thead>
<tr>
<th>NATUREFRIDGE SYSTEM</th>
<th>MECHANICAL SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NOISE LEVEL DURING OPERATION</strong></td>
<td><strong>NOISE LEVEL DURING OPERATION</strong></td>
</tr>
<tr>
<td>No Noise (&lt;20 dB)</td>
<td>Significant noise generation (&gt;70 dB)</td>
</tr>
<tr>
<td>PEK certified since 2016, Noise level less than 58 dB required for night time operation.</td>
<td>Result in restrictions of the system usage in cities at night (Noise ban at urban areas: 10:00 p.m. – 6:00 a.m.).</td>
</tr>
<tr>
<td><strong>N₂ OR DIESEL CONSUMPTION DURING OPERATION, L/H</strong></td>
<td></td>
</tr>
<tr>
<td>Continuous Run</td>
<td>24</td>
</tr>
<tr>
<td>Cycle Run</td>
<td>15</td>
</tr>
<tr>
<td>Economy</td>
<td>5.5</td>
</tr>
<tr>
<td><strong>MAINTENANCE</strong></td>
<td></td>
</tr>
<tr>
<td>No moving parts therefore no regular service, only check procedure once in 12 month.</td>
<td>Diesel refrigeration unit is complex system which requires constant service, engine service, compressor service, filter, pump changes, oil changes and refrigerant recharge.</td>
</tr>
<tr>
<td>Self-test is performed by the electronics regularly and in case of any failure sends signals (driver light, sound, display, by email to fleet manager.)</td>
<td></td>
</tr>
<tr>
<td><strong>GHS EMISSIONS</strong></td>
<td></td>
</tr>
<tr>
<td>No any GHS emissions during operation</td>
<td>Releases 2.94 kg CO₂ per each liter of diesel fuel including extraction, refining, transport and combustion.</td>
</tr>
<tr>
<td>During LN₂ production only electricity is consumed. In the majority of cases consumed LN₂ is by product of the air liquefaction process at LO₂ and argon production.</td>
<td>Refrigerant leakage can add 5.1 tonnes eq CO₂/y to the total CO₂ emissions resulting in 3.35 kg CO₂ per each liter of diesel fuel.</td>
</tr>
<tr>
<td>In some cases when LN₂ demand is much higher than LN₂ amount received as by product it is necessary to take into account foot print at electricity consumption for LN₂ production (indirect CO₂ emission per kWh is different in different countries).</td>
<td></td>
</tr>
<tr>
<td><strong>CO₂ emission (kg per hour)</strong></td>
<td></td>
</tr>
<tr>
<td>3.74</td>
<td>2.34</td>
</tr>
<tr>
<td>12.36</td>
<td>6.35</td>
</tr>
<tr>
<td><strong>CO₂ emission, kg per year</strong></td>
<td></td>
</tr>
<tr>
<td>8976</td>
<td>5616</td>
</tr>
<tr>
<td>29964</td>
<td>15240</td>
</tr>
<tr>
<td><strong>Cooling capacity, cool down time and temperature fluctuations after door opening</strong></td>
<td></td>
</tr>
<tr>
<td>Limited cooling capacity in principal by adding more sprayers</td>
<td>Limited cooling capacity</td>
</tr>
<tr>
<td>Cool down to -20°C from 30°C in ambient in less than 30 minutes</td>
<td>Cool down to -20°C from 30°C in ambient from 90 to 180 minutes</td>
</tr>
<tr>
<td>Maintain a consistent temperature (-20°C) throughout the trailer for more than 15 hours without top freezing and &quot;hot spots&quot; in the rear section of the trailers.</td>
<td>Large fluctuations in temperature</td>
</tr>
<tr>
<td>No defrosting procedure</td>
<td>Need defrosting every 6 hours when below freezing, consuming fuel for defrosting.</td>
</tr>
<tr>
<td>Ice frosting leads to decreasing cooling efficiency and as the result no consistent temperature in the box. Large fluctuations in temperature require systems to work harder to retain temperature consuming additional amount of fuel</td>
<td></td>
</tr>
<tr>
<td><strong>Downtime</strong></td>
<td></td>
</tr>
<tr>
<td>Less downtimes</td>
<td>Lower system efficiency, reliability and durability (expected lifetime: 7 years and less)</td>
</tr>
<tr>
<td>Higher system efficiency, reliability and durability (expected lifetime: virtually not limited)</td>
<td>Lower system efficiency, reliability and durability (expected lifetime: 7 years and less)</td>
</tr>
<tr>
<td>Inert, food-safe nature of N₂ ensures high food safety, less spoilage and dry up with natureFridge</td>
<td>Inert, food-safe nature of N₂ ensures high food safety, less spoilage and dry up with natureFridge</td>
</tr>
<tr>
<td>Safe cryogenic filling and easy operation. Less danger in the case of accident as LN₂ is not flammable and nonexplosive as pressure in the fuel tank is low.</td>
<td>Safe cryogenic filling and easy operation. Less danger in the case of accident as LN₂ is not flammable and nonexplosive as pressure in the fuel tank is low.</td>
</tr>
<tr>
<td>Greater flexibility with multi-temperature zones of natureFridge – possibility to transport several low-volume goods in one trip saving transportation costs.</td>
<td>Greater flexibility with multi-temperature zones of natureFridge – possibility to transport several low-volume goods in one trip saving transportation costs.</td>
</tr>
</tbody>
</table>

Fig 2: represents natureFridge unit delivered for Nisa UK Company
CASE STUDY-3 EcoFridge Production Company Ltd

Cost and Economic Considerations:

As shown in Table 3, total expenses per year for natureFridge system in comparison with diesel unit are lower even at today’s decreasing diesel fuel prices not saying about 7 years diesel unit lifetime. Comparison was made for different modes of operation: continues run and periodic (cycle) run with intervals for natureFridge system; continues run and run in economy mode at economy fuel consumption for improved mechanical system.

### Table 3 – Cost estimation for natureFridge system and Mechanical System

<table>
<thead>
<tr>
<th></th>
<th>natureFridge System</th>
<th>Mechanical System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OPERATION COST</td>
<td></td>
</tr>
<tr>
<td></td>
<td>continues run</td>
<td>cycle run</td>
</tr>
<tr>
<td>N₂ or diesel consumption (liter per hour)</td>
<td>24</td>
<td>15</td>
</tr>
<tr>
<td>N₂ or diesel Cost (per liter)</td>
<td>$0.11*</td>
<td>$0.11</td>
</tr>
<tr>
<td>N₂ or diesel Cost (per hour)</td>
<td>$2.64</td>
<td>$1.65</td>
</tr>
<tr>
<td>Total N₂ or diesel cost per year (2400 operating hours)</td>
<td>$6,336</td>
<td>$5,960</td>
</tr>
<tr>
<td></td>
<td>MAINTENANCE COST</td>
<td></td>
</tr>
<tr>
<td>Maintenance cost per hour***</td>
<td>$0.2</td>
<td>$0.2</td>
</tr>
<tr>
<td>Total maintenance cost per year</td>
<td>$540</td>
<td>$480</td>
</tr>
<tr>
<td>Total expenses per year</td>
<td>$6,816</td>
<td>$4,440</td>
</tr>
</tbody>
</table>

*Estimation was done for the prices in UK: 0.11 USD/L for nitrogen = 0.11x0.63 =0.07£/L 0.1 £/kg for CO₂ (http://www.grimsby.ac.uk/documents/defra/tms-casestudy.pdf)

**Estimation was done for the average prices for red diesel in UK in 2015 =0, 8 USD https://www.boilerjuice.com/red-diesel-prices/

***According to UK customer data scheduled service check of the natureFridge system is carried out twice per year (6000 operating hours per year) for about 3 hours each and costs 0.05 $ per hour of check. No maintenance is needed for natureFridge.

As shown in Table 4, fuel expenses for N₂ direct cryogenic refrigerated unit for rigid is 3-4 times cheaper than for N₂ indirect rigid cryogenic refrigerated unit and about 2 times cheaper than CO₂ indirect rigid cryogenic refrigerated unit, due to better refrigeration efficiency of the direct cooling method applied in natureFridge system in comparison with indirect heat exchanger cooling method and also due to better N₂ refrigeration efficiency in comparison with CO₂ refrigeration efficiency.

### Table 4 – Cost estimation for natureFridge direct cryogenic system, indirect CO₂ system and indirect N₂ system

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Average CO₂ or N₂ consumption Chilled, L/h</th>
<th>Average CO₂ or N₂ consumption Frozen, L/h</th>
<th>Average CO₂ or N₂ cost* Chilled, £/h</th>
<th>Average CO₂ or N₂ cost* Frozen, £/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect CO₂</td>
<td>12.74</td>
<td>36.47</td>
<td>1.03</td>
<td>2.95</td>
</tr>
<tr>
<td>Indirect N₂</td>
<td>40.50</td>
<td>60.70</td>
<td>3.15</td>
<td>4.55</td>
</tr>
<tr>
<td>Direct N₂ natureFridge</td>
<td>11.00</td>
<td>18.00</td>
<td>0.77</td>
<td>1.28</td>
</tr>
</tbody>
</table>

Disclaimer:
The information presented here is provided by EcoFridge Production Company Ltd. The accuracy of the content and figures is the responsibility of the company and these have not been verified by the CCAC or UNEP.

* Estimation was done for the prices in UK: 0.11 USD/L for nitrogen = 0.11x0.63 =0.07£/L 0.1 £/kg for CO₂ (http://www.grimsby.ac.uk/documents/defra/tms-casestudy.pdf)

** Estimation was done for the average prices for red diesel in UK in 2015 =0, 8 USD https://www.boilerjuice.com/red-diesel-prices/

*** According to UK customer data scheduled service check of the natureFridge system is carried out twice per year (6000 operating hours per year) for about 3 hours each and costs 0.05 $ per hour of check. No maintenance is needed for natureFridge.
A note on GWP values used in this booklet

The GWP values included in the case studies in this booklet were provided by the enterprises that drafted the case studies. These have not been modified or standardised to the most recent values as it would have corresponding effects on the various calculations included in the case study.

Calculation of global warming potential (GWP) values of refrigerants is a complex issue. For the great majority of refrigerants there are a number of different values of GWP which could potentially be quoted for a specific refrigerant. This is due to a number of reasons. Firstly, these is variety of sources from which these values can be obtained; a commonly used source being the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC). Secondly, the GWP values can be periodically updated based on the most recent research (however it should be noted that for reporting purposes, it can be necessary to use a particular version of GWP values, even if newer values are available). Thirdly, GWP values are calculated over different time horizons. Typically GWP values are quoted over a 100 year time horizon, although 20 and 500 year integrated values are also commonly provided.

The table below provides an easy reference to the various values quoted in the case studies and those provided by IPCC Assessment Reports for all the refrigerants included in this compilation.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HFC-134a</td>
<td>1430</td>
<td>1300</td>
<td>1430</td>
<td>1300</td>
</tr>
<tr>
<td>HCFC-22</td>
<td>1780</td>
<td>1500</td>
<td>1810</td>
<td>1760</td>
</tr>
<tr>
<td>HFC-404A</td>
<td>3900, 3922</td>
<td>3260</td>
<td>3922</td>
<td>3900*</td>
</tr>
<tr>
<td>HFC-507A</td>
<td>3985</td>
<td>3300</td>
<td>3985</td>
<td>4000*</td>
</tr>
<tr>
<td>HFO-1234ze</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>&lt;1*</td>
</tr>
<tr>
<td>R-449A (OpteonTM XP40)</td>
<td>1397</td>
<td>-</td>
<td>-</td>
<td>1300*</td>
</tr>
<tr>
<td>R-450A (Solstice® N13)</td>
<td>547</td>
<td>-</td>
<td>-</td>
<td>550*</td>
</tr>
</tbody>
</table>

* As quoted in the TEAP March 2016: Decision XXVII/4 Task Force Report - Further Information on Alternatives to Ozone-Depleting Substances

The GWP values of ammonia (R-717) carbon dioxide (R-744, CO₂) and propane (R-290) are 0, 1 and 5 respectively.
This booklet presents a series of case studies on lower-GWP energy efficient alternatives and technologies in the commercial and transport refrigeration sectors. It is an information resource intended to assist relevant decision makers, especially those in developing countries, in selecting the most appropriate climate-friendly alternatives. The publication provides an update to the first compilation of case studies which was published by UNEP DTIE OzonAction/CCAC in 2014. It provides a number of new commercial refrigeration case studies and case studies from the transport refrigeration sector, including alternatives not previously considered. All the case studies from the first compilation are maintained.

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