COLD CHAIN TECHNOLOGY BRIEF

REFRIGERATION IN FOOD PRODUCTION AND PROCESSING

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IIR-UN Environment Cold Chain Brief on Refrigeration in Food Production and Processing

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Summary

For consumers, the cold chain is often associated with transport, retail and household refrigerators. But refrigeration is also and widely used in the agri-food industry for the storage of raw materials and final products, as well as for food processing. This brief gives a short overview of refrigeration applications in the industry. The refrigeration technologies in use are briefly presented, according to facility size and temperature requirements, and the problems relating to the use of refrigerants are also discussed. In conclusions, opportunities for sustainable refrigeration are briefly explored.

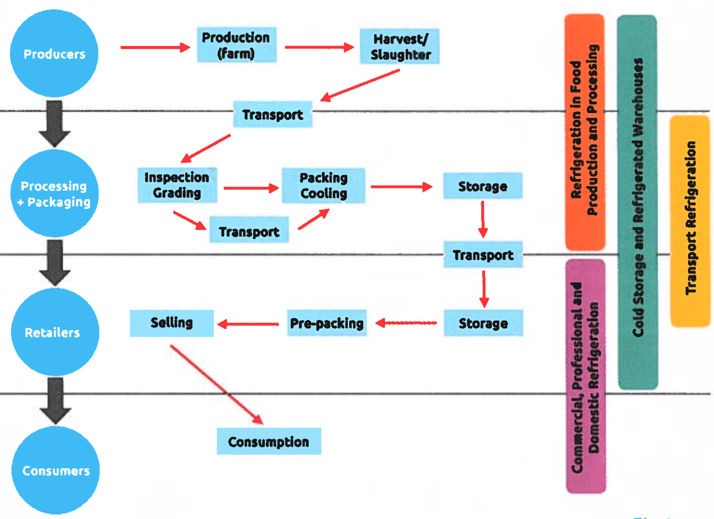
1 Introduction

Some of the food products we eat can be consumed "as is", meaning with minimal processing. For instance, fruits and vegetables can be eaten raw (e.g. apples, oranges, lettuce) or following preparation and, possibly, cooking (e.g. beans, potatoes, yams). In some cases, the preparation and cooking may be done in food processing plants. This is also true for meat products, the difference being that meat is generally consumed cooked (e.g. steaks, stews) or following a specific process (e.g. cooking for ham, grinding for sausages). In all cases, especially those involving processed food, refrigeration is necessary to preserve and maintain the microbial, nutritional and gustative qualities of food.

2 The Cold Chain

The "cold chain" refers to the various stages that a refrigerated product passes through, either until it is removed by a customer in a retail environment or unloaded from a delivery vehicle a few metres from its destination. From the moment a fruit or vegetable is harvested or an animal is slaughtered, the product starts to deteriorate. The deterioration of a product can be slowed by reducing the temperature at which it is stored. In fruits and vegetables, this slows down metabolic processes, which, in turn, slows spoilage. Reduced temperatures slow the growth of potentially harmful bacteria in animal products that are stored at frozen temperatures, allowing them to be shipped all over the world with minimal food safety risks. It is important that suitable temperature control be maintained from as soon as is feasible to as close as possible to consumption. From the raw materials stage to the various distribution storage facilities a commodity passes through, transport refrigeration keeps it at the temperature required to maximise storage life and quality for many days, weeks and months between cold storage facilities.

The Cold Chain



©Diagram : Judith Evans and IIR

Fig. 1

The cold chain is often quite complex, with foods being chilled or frozen on more than one occasion. Worldwide about 400 million tonnes of food are preserved using refrigeration. The overall volume of cold stores (refrigerated warehouses) around the globe is about 600 million m³. The IIR estimates that the total number of refrigeration, air-conditioning and heat pump systems in operation worldwide is roughly 3 billion, including 1.5 billion of domestic refrigerators. 90 million of commercial refrigerated equipment (including condensing units, stand-alone equipment and centralized systems) are operating in the world. There are also 4 million refrigerated road vehicles (vans, trucks, semi-trailers or trailers), 1.2 million refrigerated containers (reefers) and 477,000 supermarkets, with a footprint ranging from 500 to 20,000 m² in operation and where 45% of the electricity consumed is used by refrigeration equipment (IIR, 2015[1]).

[1]IIR, 2015. 29th Note: The Role of Refrigeration in the Global Economy.

Fig. 1: Overall cold chain with the different components

3 Overview of Refrigeration of Food Products

Fig.3: Typical precooling facilities for fruit and vegetables (left) and meat products (right)
Fig.4: Typical layouts of a fruit cold storage room (left) and a cold room in a slaughterhouse (right)

An efficient cold chain starts very early in the supply chain: it begins with picking or harvesting for fruits and vegetables, and with slaughtering for meat products. The level of necessity for early refrigeration varies depending on the nature of the food.

3.1. Precooling

3.1.1. Fruits and vegetables

Rapid cooling is necessary to quickly slow the metabolism of these living products and extend their life: the quicker the temperature is reduced, the better the results will be.

Different techniques can be recommended depending of the nature of the product: pulsed air is used for the majority of products, immersion or hydrocooling is used for small fruits (e.g. cherries, berries), and vacuum cooling is used for leafy greens (e.g. lettuce, spinach). Note that for the blast air system, special care has to be taken to make sure the air is evenly distributed inside the pallets and stacks. Therefore, it is recommended to use curtains and/or tarpaulins that force the cold air to pass into the stacks (as shown in Figure 1, on left) and to also apply spacers between layers of the product.

3.1.2. Meat products

Blast air systems are used in order to cool the surfaces of the carcasses, preventing the growth of harmful bacteria and microorganisms. In addition the rapid surface cooling reduces moisture/weight loss. Unless carcasses are electrically stimulated it is recommended that a period of exposure to moderate cold (10 – 12°C) is applied before lowering the temperature down to chilling levels in order to avoid the risk of cold shortening, which can occur when a carcass is exposed too early to a temperature that is too low.

Fig.3

3.1.3. Eggs and dairy products

Even if the shell surface of the egg is necessarily contaminated after spawning (passage through the cloaca of the hen), the interior of the egg remains sterile as long as the shell is not broken or split. For this reason, some countries recommend to keep eggs at room temperature during transport and sale to avoid possible condensation on the surface of the shell due to temperature fluctuations, which would be favourable for the development of germs.

For dairy products, cooling the milk after milking is essential to obtain a quality raw material. This cooling is done in specialized tanks, able to lower the milk to 4°C in less than 2 hours.

3.2. Chilling

After precooling, the food product has to be chilled and maintained at the adequate temperature.

3.2.1. Fruits and vegetables

Chilling can be carried out in specific devices such as chilling tunnels, but it is usually done in classic cold rooms equipped with adequate ventilation (Grolee and Delaunay, 1993[2]), sometimes in modified atmospheres (Leteinturier, 1999[3]).
The chilling and conservation temperatures depend on the sensitivity of the product:

- For high-sensitivity products, (e.g. mangoes, melons, ginger, sweet potatoes, yams) temperatures below 8 - 12°C are not recommended, as they can cause metabolic disturbances that shorten the life of the goods.
- For medium-sensitivity products (e.g. tangerines, green beans, potatoes), it is possible to lower the temperature down to 4 – 6 °C, but not less.
- For low-sensitivity products, a temperature of 2 – 3°C, down to just above the freezing point is recommended.

Non-compliance with these recommendations can lead to injuries, such as surface pitting, discolouration, internal breakdown, failure to ripen, growth inhibition, wilting, loss of flavour, and decay.
Whatever the sensitivity of the product, special care must to be taken to ventilate the core of the pallet or the packaging in order to remove the gases and heat issued from the metabolic processes of the product.
All recommended storage temperatures for fruits and vegetables can be found in the Cold Store Guide (Grolee and Delaunay, 1993[2]) and on Postharvest website[4].

3.2.2. Meat products

After the period of exposure to moderate cold required avoiding cold shortening, a low temperature (below 2°C) is recommended in order to prevent or inhibit the growth of spoilage microorganisms. Depending on the equipment of the slaughterhouse, this low temperature can be achieved in blast chillers or directly in classic cold storage rooms.

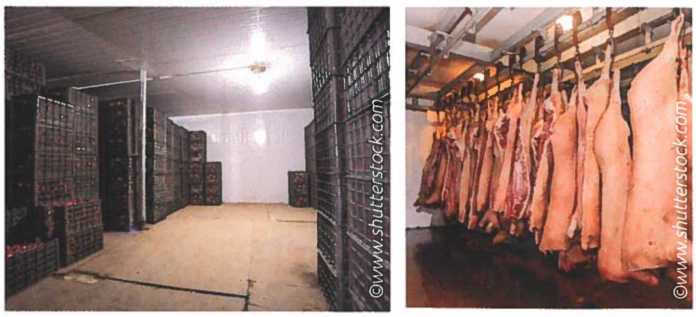


Fig.4

[2] Grolee, J. and Delaunay, J., (1993). Cold Store Guide. 3rd IIR edition, International Institute of Refrigeration (IIR), Paris, 204 p.
[3] Leteinturier, J., 1999. Preservation of fruit, vegetable and plant-derived products using refrigeration. Bull. IIF-IIR, 1999, vol. 79, 12 p.
[4] http://postharvest.ucdavis.edu/

Fig.5: Typical frozen food products
Fig.6: Superchilled salmon (up) and supercooled garlic cloves (down)

3.2.3. Eggs and dairy products

For dairy products, a rigorous preservation of the cold chain is necessary to preserve the sanitary and organoleptic quality of the product until its consumption or its transformation. The conservation of processed dairy products (cheese, yoghurts, fermented milks, ...) has to be done at adequate temperature (4-6°C) in order to avoid the development of spoliage or pathogenic germs.
For eggs, conservation at higher temperature (8 – 10°C) could be adequate while the shell remains unbroken or unsplit. Nevertheless, the adoption of lower temperature permits to increase the shelf lives up to some months. Therefore, lower temperatures are recommended (4 - 6°C).
For both, these temperatures are maintained in classical cold storage rooms.

3.3. Freezing

Freezing is a process that consists in lowering the temperature of a product below its solidification point. Lowering the temperature of food products reduces the rate that chemical reactions occur. Freezing stops the metabolism of the fruit and vegetable products, and as long as the product remains frozen, it allows for very long storage durations.

In most cases, this process takes place in specific equipment designed to provide low temperatures and high air velocities (typically -35°C to -45°C and 3 to 7 m s-1) in order to ensure rapid freezing of the product. Following that, the product is stored at low temperature, (below -18°C) as required by international standards (FAO, 2008[5]).

Fig.5

3.4. Supercooling and superchilling

New processes for food storage have recently appeared in the cold chain. These processes are supercooling (lowering down the temperature of a food product just below its freezing point, but without ice formation) and superchilling (partial freezing of a food at a temperature just below its freezing point). These techniques have been adapted to animal products such as salmon and pork, and extend the shelf life of the product considerably (Kaale, 2011[6]). However, difficulty in defining and maintaining the adequate temperatures for these processes limits their uses to high-technology industries and refrigerated transporters.

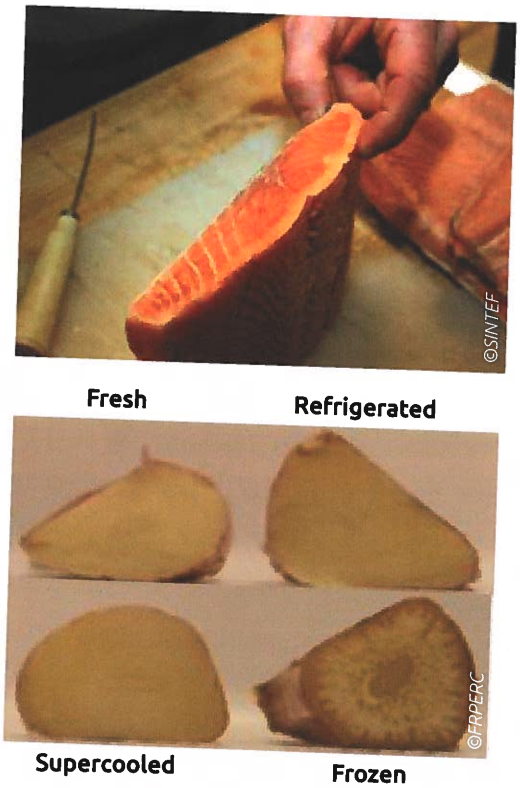


Fig.6

3.5. Other food processes that require refrigeration

While refrigeration is generally known as an essential part of the food chain (preservation and storage), it is also used in many other industrial food processes that deliver high-quality products. The following is a non-exhaustive list of these processes:

- Crystallisation of fat for the texturisation of butter, margarines and some soft cheeses.
- Cryoseparation of undesirable components; such as tartaric acid in white wines and champagne.
- Cryoconcentration of components, as is done with fruit juices
- Lyophilisation (freeze-drying) of goods and drinks, most commonly coffee.

[5] *Food and Agriculture Organization of the United Nations (FAO), 2008. Code of Practice for the Processing and Handling of Quick Frozen Foods CAC/RCP 8-1976.*
[6] *Kaale, L. D., 2011. Superchilling of food: A review. Journal of Food Engineering. Volume 107, Issue 2, December 2011, Pages 141–146.*

4 Industrial Refrigeration and Food Processing

Refrigeration is widely used in facilities for the storage and the processing of foods. The refrigeration systems and the cold distribution loops used in facilities operate according to the required temperatures and capacities.

4.1. Small facilities

Refrigeration is generally ensured by classic single-stage direct expansion systems. Piston/reciprocating compressors are widely used, and the refrigeration is produced by the refrigerant itself. These systems offer advantages since they are simple, reliable, the least expensive, and easy to implement and maintain.

4.2. Larger facilities

Research in high energy efficiency refrigeration technologies has led to the development of other adapted technologies, although they are more expensive in terms of investment and maintenance.

- For chilling, single-stage systems with flooded evaporators are recommended. The use of a secondary refrigerant (a coolant such as propylene glycol) for cooling distribution dramatically reduces the use of the primary refrigerant.
- For freezing, two-stage refrigeration systems (often with a screw and/or piston compressor in series) with flooded evaporators are often used and recommended.
- For chilling and freezing, screw compressors are often used because of their high ratio refrigeration capacity / overall dimension, even if large piston compressors can easily do the job.

Fig.7

Fig.8

5 Current Refrigerants Used and Potential Alternatives

Refrigerants used for cooling production depend on the size of the facility and the required temperature.

5.1. Small facilities

Non-flammable refrigerants with low toxicity are widely used, such as those belonging to the family of hydrofluorocarbons (HFCs). Due to their high Global Warming Potential (GWP), EU and international regulations on climate change (Kigali amendment) require countries to progressively reduce or phase out their use (IIR, 2015[7]), (EU F_gas regulation, 2014[8])

Alternatives to HFCs could include the use of low-GWP refrigerants and/or blends of refrigerants adapted to the required temperature. These blends are tailored to offer the best compromise between environmental impact, safety, and energetic performances. On the other hand, the majority of these blends have very high glide. For some applications, this particularity may cause some problems and require specific care.

Other possible alternatives that are beginning to be developed in small facilities include (RealAlternatives, 2015[9]):

- The use of hydrofluoroolefins (HFOs), a family of refrigerants with a very low GWP. The availability, current cost, and mild flammability behaviour of these refrigerants limit their widespread use. In addition, the long-term accumulation of their decomposition residuals in the environment must be checked and studied.
- The use of hydrocarbons (e.g. Isobutane, Propane) is possible, but only for very low refrigerant charges, due to their high flammability.
- The use of carbon dioxide is developing. While the intrinsic performances of this refrigerant are lower than those achieved with other fluids, the low environmental impact as well as the progress made in the designing of CO_2 loops makes this a potentially sustainable alternative, especially in temperate climates (IIR, 2000[10]).

[7] *IIR 26th Informatory note Note, 2015. Overview of Regulations Restricting HFC Use, Focus on the EU F-Gas Regulation, January 2015.*
[8] *F-gas Regulation n° 517/2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 - 16 April 2014.*
[9] *RealAlternatives, (2015). IIR – IoR Life European project. Available at: http://www.realalternatives.eu*
[10] *IIR 15th Informatory Note, 2000. Carbon dioxide as a Refrigerant , February 2000.*

Fig.7: Typical refrigeration units in a small-sized facility (left) and a medium-sized facility (right)
Fig.8: Typical refrigeration unit in a large-sized facility

5.2. Large facilities

As a rule, ammonia is generally used. Despite certain characteristics of this refrigerant, (e.g. toxicity) it can be used in large cooling production loops for a long time without any other constraints than those imposed by their toxicity. The adoption of specific design and maintenance regulations can reduce risks and create safer facilities (Pearson, 2008[11]).

For freezing, the use of two-stage systems with liquid-vapour separation vessels and screw compressors remains a standard.

Given the low GWP of ammonia, adoption of this refrigerant is often the best option. When it comes to reducing the hazards related to this refrigerant, some approaches have been used for a long time, while others have been in development recently:

- For chilling, the use of a cooling distribution loop based on a secondary refrigerant (a coolant such as propylene glycol) is a technology that has existed for a long time. It significantly reduces the quantity of ammonia present in the system, and therefore dramatically improves the safety of the facility.

- For freezing, the use of two-stage cascade systems with, for instance, HFC-R134a or ammonia in the high-temperature stage and CO_2 in the low-temperature stage also reduces the ammonia charge.

- The progress made in designing CO_2 loops has increased the use of full CO_2 systems, especially for freezing and low-temperature warehouses.

Table 1: Summary of current and alternatives refrigerants

Refrigeration in Food Production and Processing		
Types of facilities	**Current higher GWP refrigerants (GWP kg.CO_2)**	**Alternative lower GWP refrigerants (GWP kg•CO_2)**
Small	HFC-134a (1360), HCFC-22 (1810), HFC-404A (3920), HFC-407C (1920)	R-744 (1), HC (1.8 – 20), HFO-1234 yf and ze (<1-2), Low GWP blends HFC-HFO (< 1300)
Large	R-717 (0), HFC-404A (3920), HFC-507A (3990), HFC-134a (1300)	R-717 (0); R-744 (1)

[11]Pearson, A, 2008. *IIR guide on Ammonia as a Refrigerant. 3rd IIR edition, International Institute of Refrigeration (IIR), Paris, p.88.*

Fig.9: Typical two-stage liquid-vapour separator systems used for industrial refrigeration
Fig.10: Typical industrial refrigeration facilities based on secondary refrigerant loop system (up) and two-stage ammonia-CO_2 system (down)

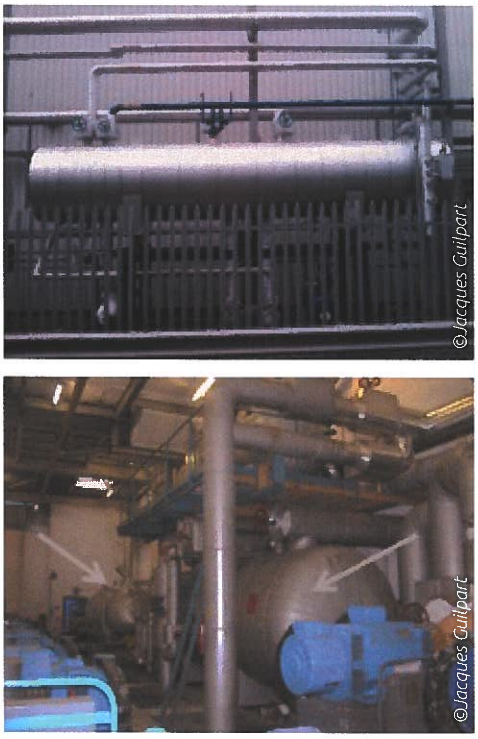


Fig.9

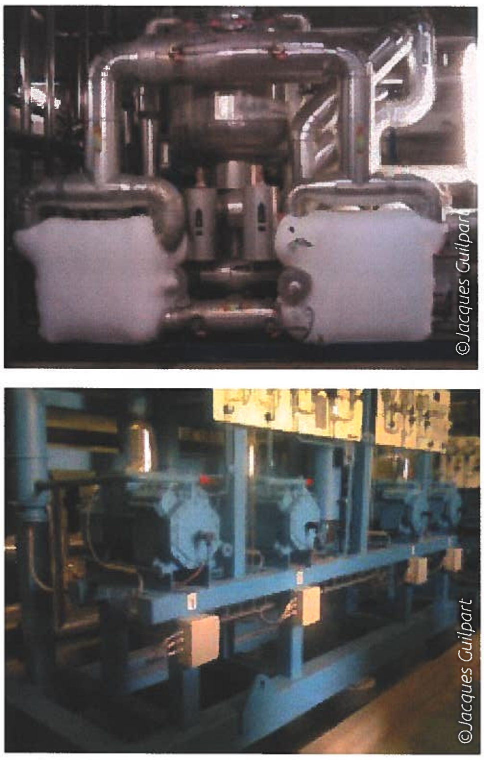


Fig.10

6 Development Perspectives and Challenges

Thanks to their performance, compactness and reliability, compression–expansion systems with phase-change refrigerants have been used for more than a century, and they will probably continue to be used for a long time.

6.1. Technical challenges

The real challenge is to develop and use refrigerants with high energetic performances, low environmental impacts and low hazard potentials (e.g. for flammability, toxicity). While a large variety of refrigerant blends are on the market, a "universal" refrigerant has yet to be discovered, and will probably never be discovered.

Alternative technologies, such as absorption and adsorption systems, have been developed in the past and continue to be the subject of research. At present, these systems have very high inertias and remain difficult to control in facilities that have large refrigeration loads. Investment in these systems is also higher compared to conventional systems, and there are few technicians qualified to provide maintenance for them.

6.2. Related driving policies

Refrigeration and Air Conditioning Industry witnessed considerable development and modernization in the last 3 decades partly as result to the international environmental policies where many refrigerants that have been used efficiently for decades, are held responsible to the Ozone Layer Depletion as well as Global Warming. The phase-out of ozone depleting substances (ODSs), under the Montreal Protocol, triggered significant changes in the industry moving towards alternative refrigerants and technologies that has zero-ODP (Ozone Depletion Potential).

In October 2016, the Kigali Amendment to the Montreal Protocol brought another dimension to the mandate of the Montreal Protocol by adding the control of production and consumption of hydrofluorocarbons (HFCs) under its mandate which will have major contribution towards the fight against climate change. Control of HFCs production and consumption will add to the climate benefits already achieved by the Montreal Protocol through the phase-out of ODSs including CFCs and HCFCs. The emissions of HFCs are also listed within the group of GHGs (Greenhouse Gases) under the Climate related conventions i.e. Paris Agreement and previously the Kyoto Protocol. However, actions to specifically control HFCs emissions within the climate regime are not yet set except for reporting requirements under the UNFCCC (UN Framework Convention on Climate Change).

The refrigerant climate impact of refrigeration equipment depends on direct and indirect effects. The direct effect is from its GWP (Global Warming Potential) and amount of a refrigerant emitted to the atmosphere (either from a leak, accident, or from improper handling or disposal). The indirect effect is associated with the energy consumed during the operation of equipment which, over its lifetime, occurs as a result of the CO_2 (CH_4 to lesser extend) produced by fossil fuel power plants, and is commonly greater than the direct effect. Minimizing direct and indirect impacts, of all types of refrigerants, emissions should be addressed through improved design, better field commissioning and maintenance practices, sound decommissioning procedures and enforcement to local relevant standards and regulations.

There are several principal organisations developing standards related to the refrigeration and air-conditioning sector. The UNEP International Standards in Refrigeration and Air-Conditioning booklet (UNEP, 2014[12]) summarises the main international standardisation organisations and provides some examples of national and regional standards organisations.

The cold chain sector is one of the most important but overlooked business segments in terms of being addressed in a holistic approach. This is because it crosscuts with different economic, social and technical areas i.e. food industry, health, refrigeration, transportation, tourism, etc. The norms and directions for cold chain technology selection that has less environmental impact, energy efficient operation and affordable economics is scattered amongst different groups and entities within the same country. In September 2015, International Community adopted the 2030 Sustainable Development Goals (SDGs) stipulating Goal #2 «Zero Hunger» as the second global goal which needs to be achieved by 2030. This automatically means the urgent need to efficiently manage the portfolios of «Food Security» & "Food Waste" which depends on the cold chain capabilities. While this goal can be noted as the main goal with direct relation to cold chain, other goals are also connected to the cold chain business i.e. Goal #3: Health and Wellbeing, Goal # 9: Industry Innovation and Infrastructure, Goal # 12 Responsible Consumption and Production as well as Goal #13: Climate Action. Therefore, the integrated.

[12] *UNEP, 2014. International Standards in Refrigeration and Air-Conditioning. An introduction to their role in the context of the HCFC phase-out in developing countries.*

7 Conclusions

Industrial refrigeration is the first step in the cold chain where food is processed and stored before transport, retail and consumption. The refrigeration sector faces several challenges relative to reliability, performance (reducing energy consumption), environmental impact (promoting the use of refrigerants with low Global Warming Potentials and taking safety issues into account), regulations and economic concerns. Solutions for providing sustainable industrial refrigeration systems depend on the size of the facility and on the required temperature levels. These solutions do exist, and they must be implemented. Only then may we continue to provide our world with safe, high-quality food and contribute to its development and welfare.