Sustainable Development: Achievements and Challenges in the Refrigeration Sector

I. INTRODUCTION
The scope of refrigeration is far-reaching. Refrigeration has applications embracing a huge range of fields we all encounter in our daily lives, particularly in the food, health and indoor environment fields. Refrigeration plays an essential role in sustainable development. However, there is a wide gap between industrialized and developing countries in terms of the availability of refrigerating equipment, knowledge and training.

II. THE THREE DIMENSIONS OF SUSTAINABLE DEVELOPMENT
The goals defined by Agenda 21 cover three dimensions: social, economic and environmental.

The impact of the refrigeration and air-conditioning sector on the social dimension has numerous facets. In industrialized countries, the following aspects can be stressed:

- the refrigeration sector generates jobs, particularly in the industrial, commercial and service fields;
- by making it possible to preserve perishable foods at all stages from production to distribution, refrigeration vastly improves food supply to populations;
- thanks to improved food safety, to the development of new equipment and tools in the medical sector (such as MRI, cryosurgery and cryotherapy) this sector promotes health;
- air conditioning makes it possible to create working environments with the desired temperature and humidity levels.

In developing countries, the impact of refrigeration, even if less marked than in industrialized countries, notably due to a lack of equipment and insufficient technology transfer, is nevertheless significant in the following fields:

- in the health field, the role of refrigeration in the immunization of populations against infectious diseases thanks to refrigerators used for vaccine storage can be highlighted and linked to increasing life expectancy. A striking example is the contribution of refrigeration to the eradication of poliomyelitis: in 2000, the number of cases of poliomyelitis occurring worldwide was less than 3500, which is a 99% decrease in comparison with the 350 000 cases registered in 1988;
- air conditioning contributes to social and economic development in hot, humid regions;
- refrigeration technologies have a vital role to play in many spheres, notably in the food field where reduction of post-harvest losses, improved food safety and hygiene, promotion of international trade, and improved food supply to the cities must be considered as top-priority objectives. The same is true in the health field where foodborne diseases caused by pathogenic micro-organisms must be prevented.

From an economic point of view, the following figures summarize and highlight refrigeration’s role: today, there are 700 million to 1000 million household refrigerators, 240 million air-conditioning units, 300 000 000 m$^2$ of cold-storage facilities worldwide. A tentative table showing the annual sales of refrigeration, air-conditioning and heat-pump equipment (which had not been published previously) has been prepared by the IIR and is provided in this report: it shows that total annual sales are around USD 200 billion (average figures for 2000), this being roughly one third of the automobile industry’s annual sales (excluding commercial vehicles). However, the gap between developed and developing countries remains wide. A striking example is the number of domestic refrigerators manufactured annually. In 1996, only 33% of these appliances were for developing-country markets, even though 80% of the global population lived in developing countries.
From an environmental viewpoint, refrigeration-related activities, in a sustainable-developmental framework, have two main components: atmospheric emissions of certain refrigerant gases used in refrigerating plants and the CO₂ emitted in generating the energy required to operate these plants. CFC emissions, and to a lesser extent HCFC emissions, exert ozone-depleting effects. These two refrigerant families also exert global-warming effects. HFCs were developed in order to replace CFCs and HCFCs and have no ozone-depleting potential. However, they have global-warming effects. Via the Montreal Protocol that was adopted in 1987, 177 countries (as of July 31, 2001) committed themselves to measures designed to protect the ozone layer. This protocol calls for the gradual phase-out and total banning of CFCs followed by HCFCs, with a longer time frame for Article-5 (developing) countries. The objective of the Kyoto Protocol, which has yet to be ratified by a sufficiently large number of countries in order to enter into force, is to reduce, in 39 developed countries, emissions of six greenhouse gases by at least 5% between 1990 and 2008 to 2012. HFCs are among these six greenhouse gases. The improvement of the energy efficiency of refrigerating plants is a vital process, since it reduces the main contribution of the refrigeration sector to global warming, that is indirect emissions of CO₂ induced by the production and the consumption of the energy needed to operate the refrigerating plants. Emissions of CO₂ are evaluated as being 80% of the total contribution of the refrigeration sector to global warming. Other indirect impacts should be mentioned such as pollutants (SO₂, nitrous oxide) emissions related to components production and waste products associated with the destruction of refrigerants, oils and the equipment itself.

III. MEANS OF IMPLEMENTATION: STRATEGIES, ACHIEVEMENTS AND LIMITS
Among refrigeration stakeholders’ recent achievements within the framework of sustainable development, the most significant is the industry’s landmark contribution to the implementation of the Montreal Protocol on the substances that deplete the ozone layer. The refrigeration industry, over a decade, has completely changed the refrigerants from CFCs and HCFCs to ozone-friendly substances to protect the global environment. This contributed to lowering the chlorine concentration in the stratosphere and reducing ozone layer depletion that threatened life on Earth. Industries also took the opportunity of changing over to second generation and more energy-efficient technology over the last 10 years. Refrigeration is one of the unique sectors that witnessed complete technology overhaul that was environmentally friendly. This has been made possible through co-operation between developing and developed countries through the Montreal Protocol, through funding of new technology by the Multilateral Fund, and through international co-operation between organizations such as the IIR, UNDP, UNEP, UNIDO, the World Bank, WHO and many others. The refrigeration sector is now gearing up to face another environmental challenge of the next millennium: global warming. In order to combat global warming, the main strategies are reductions in energy consumption, reductions in refrigerant emissions, research and development on new refrigerants and not-in-kind (NIK) technologies, new developments in the cold chain and new developments in air conditioning and heating systems. The environmental benefits of the strategies implemented have to be evaluated using an assessment that takes into account the overall environmental impact throughout the life cycle of the refrigeration system. Thus, concerning the greenhouse effect, Life Cycle Climate Performance (LCCP), which is a measure of total greenhouse emissions (throughout the life cycle) is no doubt the most objective criterion.

In industrialized countries, initiatives aimed at reducing energy consumption have led to measures that cover all phases in the life cycle of refrigerating equipment:

- during the design phase: initiatives enabling refrigerating system and component performance to be enhanced;
- during installation and commissioning: application of stringent plant acceptance procedures taking into account measurement of the energy consumption of a plant;
- during maintenance and servicing: application of stringent operating procedures.

Standardization provides a means of obtaining objective benchmark performances of equipment. Quality procedures are increasingly including training followed by proficiency-based certification of technicians and installers. This process needs to be more widely applied and the harmonization of standards also needs to be expanded. Several figures provide striking evidence of achievements in the field of energy savings. The coefficients of performance (COPs) of refrigerating equipment are constantly being enhanced but much remains to be done in this field.

Emissions-reducing initiatives are applied throughout the life cycle of a plant:

- during the design and manufacturing phases, manufacturers’ Research and Development (R&D) departments focus on optimizing plant tightness and reducing the refrigerant charge and the length of piping used in the circuits in order to reduce emissions and to facilitate maintenance and servicing during plant operation;
- during installation of the plant, stringent qualitative procedures are applied to an increasing extent, particularly with regard to containment of the refrigerant;
- during maintenance and servicing, the emphasis is on plant tightness thanks to regular controls and systematic refrigerant recovery whenever maintenance or repairs are performed. Thanks to training of installers, owners and operators in the handling of new refrigerants and raising of their awareness of the environmental dimension, considerable progress has been achieved, but much remains to be done;
- during disposal of equipment, recovery of the refrigerant, and recycling or reclaiming whenever possible (or destruction if this is not possible).

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In terms of achievements, the impact of CFCs, HCFCs and HFCs on ozone depletion and global warming has decreased in a striking manner, as demonstrated by several indicators: decreased production of these refrigerants (weighted according to their respective impacts on these 2 phenomena) starting in 1988 and 1989, and the diminishing percentage of these refrigerants in total greenhouse-gas emissions.

The refrigeration sector’s initiatives in the field of NIK technologies and alternative refrigerants (new HFC refrigerants and alternative refrigerants to fluorocarbons) are also an important breakthrough since they lead to reduced adverse effects on the environment.

Among non-HFC refrigerants developed to replace fluorocarbon refrigerants, the focus is above all on ammonia, hydrocarbons and carbon dioxide (CO₂). In the field of NIK technologies that provide suitable alternatives to vapour compression, key research focuses include advanced absorption and adsorption technology, solar refrigeration, desiccant cooling, air cycles, the Stirling cycle, thermoelectric cooling, etc.

New developments in the cold chain can be highlighted: increasing importance is now attached to cleanability in order to prevent contamination of foods, flexibility of equipment, regulation of ambient conditions, traceability of foods, consumer information and interface management.

New developments in air conditioning and heating systems can also be stressed. Indoor air quality (IAQ) and its relationship with occupant comfort, health and productivity has received increased attention in recent years. New developments related to ventilation, source control, humidity management and filtration/air cleaning have been achieved. Energy efficiency is becoming increasingly important within the sustainable building approach, and several developments such as “low-temperature heating” and “high-temperature cooling” are taking place.

Developing countries joined the industrialized countries in the last decade to phase-out ozone depleting substances. In developing countries, among positive activities that have been implemented in order to respond to the challenges of sustainable development are:

- the financial and technical resources that were made available through the Multilateral Fund of the Montreal Protocol were leveraged to transfer ozone-friendly technologies to the developing countries. Of USD 1.3 billion spent by the fund so far, nearly 60% is used for refrigeration sector.
- through the collaborative efforts such as UNEP’s OzonAction Programme and IIR’s worldwide network of experts, Refrigerant Management Plans (RMPs) have been set up in many countries. Each RMP involves an initial diagnostic phase that is an essential prerequisite to actions and training initiatives designed to achieve sustainable development, implementation of training programmes addressing refrigeration technicians’ and custom officers’ needs.

However, the development of the refrigeration sector in developing countries has limits that should be emphasized:

- education for refrigeration technicians in good practices and installers is not available to all;
- insufficient maintenance, causing high leakage of refrigerant and other plant anomalies;
- regeneration and refrigerant destruction plants are too few and scattered.

A per-sector approach (domestic refrigeration, commercial refrigeration, cold storage, industrial refrigeration, unitary air conditioning, water chillers, transport, mobile air conditioning) makes it possible to identify the actions implemented, in each sector, in order to meet the defined objectives: emissions reductions, energy-efficiency measures, development of new technologies and new refrigerants, retroconversion of plants in order to use new refrigerants.

IV. CHALLENGES

Sustainable-development-driven challenges confronting the refrigeration sector in years to come will be numerous; they include the addressing of issues that require sustainable solutions (covered in Part II) and the expanding of actions that have already been implemented (focused on in Part III).

**Industrialized countries**

Most specialists are of the opinion that vapour-compression systems are likely to be the dominating trend over the next 20 years. The challenge to be met is to develop vapour-compression systems that are environmentally friendly, energy-efficient, robust and sustainable, cost-effective and safe for users. Bearing in mind these challenges, here are some objective challenges for the next 20 years, with 2000 as baseline year:

- to reduce energy consumption by 30% to 50%);
- to halve refrigerant leakage;
- to improve LCCP (Life-Cycle Climate Performance) by 30% to 50%;
to reduce the refrigerant charge by 30% to 50%.

However, defining quantitative objectives is useful only if reliable benchmarks are defined and validated. Some technologies and applications using vapour-compression systems have an important role to play in order to meet these objectives, for example:

- sustainable building: sustainable building can only be achieved if energy efficiency is taken into account right from the outset of the building design process;
- mobile air conditioning: it is forecast that in 2010 emissions of refrigerants from vehicle air-conditioning equipment in Europe will represent about 50% of all refrigerant emissions. In order to reduce CO$_2$ emissions, means of reducing fuel consumption related to air conditioning should also be given serious consideration. This area represents one of the biggest future challenges in the sector under consideration;
- heat pumps are an efficient tool to reduce CO$_2$ emissions: the potential for reducing these emissions is about 6% of the total worldwide CO$_2$ emissions of 22 000 mt/y. With future technologies, a share of up to 16% seems possible in residential, commercial and industrial applications.

This report also explores promising refrigeration technologies and applications using non-vapour-compression technology that will undoubtedly also play important roles in ensuring sustainable development:

- absorption and adsorption cooling systems, which quite often are fuel-fired, are a practical means of providing both commercial and industrial cooling without imposing a major drain on a developing electric infrastructure and therefore a major drain on the limited developmental capital available to most developing countries. Absorption-based air conditioning, in the form of large absorption chillers for major commercial-building or industrial applications, is the most widespread application of these technologies today. Low energy efficiency is still the major drawback of this technology. Further development and simplifications are needed in order to enable this technology to be more widely applied;
- solar refrigeration is technology that should be given priority when choosing sustainable development options in developing countries. The growing demand for ice for the conservation and transportation of perishable products, the development of cold storage for food storage, the freezing of fresh and cooked products, space air conditioning, among other refrigeration applications, are only a sample of the potential applications of this technology. The establishment of the infrastructure required for the production of solar refrigeration units and the setting up of educational programmes and training in the operation and maintenance of solar plants as well as in the design and instrumentation aspects are priority actions;
- desiccant technology includes a broad spectrum of systems providing cooling, dehumidification, and ventilation in order to control the quality of the indoor environment in the industrial and commercial sectors. But many production and technical issues still have to be addressed;
- trigeneration (combined power production, heating and cooling) has considerable benefits from an energy standpoint. It makes it possible to totally or partially utilize the heat rejected to ambient as waste heat generated during electrical power production and use part of it in refrigerating applications. The development of high-performance absorption plants will enhance the benefits of trigeneration plants;
- cryogenics is a field encompassing all refrigeration technology used to achieve temperatures below 120 K (-150°C) down to 4.2 K, and has paved the way to a huge range of sustainable-development-promoting applications. Superconductivity is one of the most promising cryogenic technologies. Cryomedicine and its cryosurgical component are making and will continue to make a valuable contribution to sustainable development;
- many other technologies that will promote sustainable development are being developed or are the focus of research projects, notably air-cycle and Stirling-cycle refrigeration, and thermoelectric cooling.

**Priority actions to implement in developing countries**

- reduction of post-harvest losses: Perishable foodstuffs represent 31% of the total volume of foods consumed in developing countries. In developing countries, only 1/5th of perishable foodstuffs is refrigerated, meaning that high losses are incurred following harvest, slaughter, fishing, milking, then during transportation and finally during sale. Refrigeration is one of the most effective tools enabling loss reduction to be achieved. However, economic aspects should be dealt with;
- development of cold chains
  Ensuring both food quality and safety to 5 billion inhabitants of developing countries thanks to the setting up of effective cold chains is a major challenge for the refrigeration sector;
- technology transfer
  One avenue for enhancing developing country initiatives is through the sharing of developed-country industrial technology, know-how and information, including standards and certification programmes;
- strengthening of structures
  It is important to define a ministry in charge of handling refrigeration policy at national level. Trade organizations and associations play an indispensable role in federating refrigeration stakeholders. A state-approved, neutral, authoritative national refrigeration association is also necessary. An interministerial and interprofessional
organization such as a national refrigeration council can play an important role in defining refrigeration plans that include inventories of existing equipment and a long-term developmental plan;

- data collection
  A precise inventory of the needs of developing countries is an essential preliminary step in order to facilitate the design of focused programmes and activities in the various fields concerned: structures, technologies, training.

In industrialized countries as well as in developing countries, education is the cornerstone of development in all aspects of refrigeration: design, installation, running and maintenance of refrigerating equipment.

In conclusion, the major challenges to be met by the refrigeration sector can be summarized as follows:

**Industrialized countries**

- to address the environmental impact of refrigerating systems by using the LCCP concept and standardizing its calculation and to promote application of this concept among all stakeholders;
- to consider the whole system and not just the refrigerant;
- to design equipment with a reduced refrigerating capacity as far as practicable, for instance by attaching great importance to well-calculated and efficient insulation;
- to bear in mind that the primary goal of a refrigerating plant is to make it possible to supply high-quality foodstuffs or to ensure high indoor air quality;
- to give top priority to proper maintenance: such practice reduces leakage and improves energy efficiency;
- to recover, recycle, regenerate or destroy, following standardized procedures, refrigerants, lubricants and materials used in refrigerating plants;
- to further improve energy efficiency and performance;
- to use the capabilities of heat-pump technologies for reducing energy consumption by utilizing renewable energy sources and waste heat.

**Developing countries**

- to make refrigeration available in developing countries, particularly in the least developed countries, for food preservation, industry and air-conditioning purposes;
- to set as a rule that developing countries have the same rights to refrigeration technology as developed countries;
- to take advantage of current technological achievements in order to enable “leap-frogging” to environmentally friendly, reliable, robust and cost-effective practices through promotion of technology transfer and increased training and education;
- to avoid dumping old polluting, high-energy-consuming technology in developing countries, even if initial costs appear to be attractively low.