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NEW SUSTAINABILITY OBJECTIVES FOR THE REFRIGERATION INDUSTRY

The refrigeration industry has found itself caught up in environmental problems because of the use of certain types of refrigerating fluids which have considerable impact on the ozone layer and contribute to the phenomenon of global warming.
The Montreal and Kyoto protocols, adopted from the point of view of sustainable development, set the objective of gradually reducing, and eventually banning, the use of certain environmentally hazardous substances, including those in use for decades as refrigerating fluids.
In this work we trace the move towards environmental sustainability in the refrigeration sector, analyse the initiatives undertaken and examine the most promising technological developments.

Introduction.

The refrigeration industry is a flourishing sector of the economy and has contributed to the notable improvement of man's living conditions. The contribution of refrigeration affects numerous aspects of everyday life, from foodstuffs, thanks to the conservation of food supplies, to the medical and pharmaceutical fields.
On an economic and social level the size, value and contribution of the refrigeration industry can be summarised as follows:

- worldwide, the whole industry employs about two million people, with an annual turnover in sales of refrigerating units estimated to be in the region of 200 billion US Dollars;
- in the food industry refrigeration allows the conservation of perishable foods at all stages of processing, from production to consumption, and thus helps to reduce losses after harvesting and to supply consumers with healthy and safe foodstuffs. The value

of foodstuffs preserved and distributed in the refrigerating industry is estimated at 1,200 billion US Dollars;
- air-conditioning helps the socio-economic development of regions with hot and humid climates and creates working environments that provide an ideal temperature and level of humidity for the physical well-being of workers and for productivity;
- numerous sectors such as: industry (chemicals, foodstuffs), heating (heat pumps), health (cryotherapy, surgery), biodiversity (cryobiology), energy (natural liquefied gases, superconductivity) need refrigeration technology.

Despite its numerous advantages, refrigeration technology is involved in or held responsible for serious environmental problems, principally linked to two factors:

- *the presence of refrigerating fluids which damage the environment:* the direct emissions of greenhouse effect refrigerating gases (CFC, HCFC and HFC) present in refrigerating plants and in isolation materials account for about 20% of global warming; the percentage varies greatly from sector to sector, but these emissions are essentially due to leaks during maintenance, inadequate confinement in the plants or improper disposal;
- *the indirect emission of carbon dioxide (CO_2) deriving from the energy needed to make the refrigerating plants operate:* indirect emissions of carbon dioxide (CO_2), due to the production of components and the operating of refrigerating units contribute about 80% of global warming. In fact, refrigeration, air-conditioning and heat pumps consume about 15% of the electricity produced worldwide.

For many years chlorofluorocarbons (CFCs) and, in more recent times, hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs)[1] have dominated the debate on the refrigeration and air-

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[1] As regards HFCs, countries such as Austria, Denmark and Switzerland have drawn up national regulations with the aim of abolishing HFCs. It must be remembered, however, that

conditioning industries [8]. Over the years legislation has imposed strict environmental constraints on the refrigeration sector, forcing it to search for innovative solutions which are more efficient from an economic and environmental point of view.

From the Montreal Protocol onwards the refrigeration industry has introduced a series of measures to limit emissions of substances that damage the ozone layer into the atmosphere. The total elimination of CFCs in the short term is proving to be difficult, however, due to the enormous quantities of these refrigerating fluids still present in domestic refrigerators and other appliances, which will reach the end of their useful life in the next few years, and due to the presence of CFC supplies probably fed by illegal imports[2].

The need to redefine the objectives set by the Montreal Protocol was satisfied by the new European Regulation n° 2037/2000 of 29 June 2000 on substances that deplete the ozone layer, published on 29 September 2000 in the Official Gazette (L244/1) of the European Parliament [9].

The new European Regulation on this subject aims to close the loopholes left by previous legislation and, at the same time, hopes to put an end to the illegal market which is encouraged by the confusion of the previous Regulation on the flow of CFCs among Member States. Substantially, the actions taken by the refrigerating industry in its move towards sustainability regard:

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of these countries only Switzerland does not belong to the EU and so for the others it is necessary to consider the opinion of the other member states.

[2] In recent years, as a direct consequence of the restrictions put into place by the Montreal Protocol, there has been a growth in the lucrative illegal trade in CFCs.

From 1995 onwards, enormous quantities of CFCs have been traded in the EU, mainly destined for use in car air-conditioners, but also for other cooling purposes.

According to recent studies, about 30 thousand tons of CFCs are traded illegally every year between developed and developing countries. In 1996, the illegal trade in CFCs generated a turnover of about 300 million dollars a year; this amount has grown and continues to grow dramatically, so much so that the illegal sale of CFCs is now second only to cocaine trafficking. It is estimated that in Italy, in the period 1995/97, about 5,000 tons of CFCs entered the country illegally. Since European manufacturers have not been allowed to produce CFCs since 1995, the main illegal suppliers of CFCs are now developing countries, which were not subject to the prohibition according to art. 5 of the EU Regulation n° 3093/94 on substances which damage the ozone layer, now repealed, such as India and China, which sell products in Europe and the United States, and countries with an economy in transition, such as Russia.

- the use of refrigerating fluids that do not cause irreversible damage on the ozone layer;
- research and the adoption of high energy efficiency technology, in order to reduce CO_2 emissions;
- the adoption of a life cycle view, from the planning phase to the installation, maintenance and operation of the refrigerating plant, in order to carry out a measurement of the overall reduction of global warming, operating in accordance with the so-called Life Cycle Climate Performing (LCCP).

Substantially, the strategies introduced to reduce the environmental impact of the refrigeration sector regard:

- the choice of alternative refrigerating fluids instead of traditional ones;
- the optimisation of refrigerating technology (steam compression) and orientation towards alternative technology (absorption-adsorption, solar refrigeration).

The aim is that of achieving advantages from the energy, economic and environmental points of view simultaneously [5].

New refrigerating fluids.

The steam compression cycle, which has dominated the refrigerating industry for many years, needs to be made more sustainable. The choice of refrigerating fluid and the adoption of the most efficient one is the best way of analysing the life cycle of a refrigeration plant and of applying the best alternative solution with regard to LCCP.

The restrictions on the use of CFCs and HCFCs as refrigerants has brought about the need for the refrigerating sector to search for alternative refrigerating fluids with characteristics of environmental sustainability and economic-technical efficiency [7].

HFCs represent the best solution from an economic point of view, since they are closely compatible with existing plants. The growing awareness that even HFCs do not represent the ecologically most efficient solution and that, consequently, they are destined to be phased out has moved the attention of the sector towards other refrigerants with characteristics that can satisfy the ecological and regulatory requirements.

The following table shows the new refrigerants which are alternatives to the family of fluorocarbons:

Refrigerants	Sectors of use	Advantages	Disadvantages
Ammonia	Currently used in the industrial and commercial sectors as well as in air-conditioning	0 ODP 0 GWP new design technology for refrigeration plants allows the creation of plants that need a low quantity of refrigerant	Highly toxic and must be handled with care Cannot be efficiently used in low capacity appliances and with thermostatic expansion valves
Hydrocarbons	Home refrigeration Heat pumps Commercial appliances	0 ODP insignificant GWP Excellent thermodynamic properties and good mixability with low cost mineral oil.	Highly inflammable
Carbon dioxide	Air-conditioning in cars Refrigeration counters	Energy saving	Low critical point Needs high levels of pressure compared with other refrigerants
Water	Economically viable for use with refrigeration power values between 500 and 5000 KW	Non-toxic Non-inflammable Ecological	Needs low levels of pressure Not very good cost-benefit relationship
Air	Air-conditioning in aeroplanes	Non-toxic Ecological	Not very cheap

Source: our elaboration

Studies of the opportunity of using carbon dioxide as a refrigerant began in 1994. This possible use is considered positively, even though it presents design problems for new compressors and exchangers because of the very high pressure levels. It is thought that carbon dioxide could be used for air-conditioning in vehicles. In 2006 German car manufacturers will use carbon dioxide as a refrigerant in car air-conditioners and by 2008 they will develop heat pumps to be used both for air-conditioning and heating in cars, with the aim of achieving considerable energy savings. Since it is forecast that in 2010 about 50% of HFC emissions will be caused by vehicle air-conditioning (Ecofys Energy and Environment Report 2001), the use of carbon dioxide in this sector is an important fact [3].
Carbon dioxide can also easily be used in industrial refrigeration.

This table summarises the main objectives and limitations divided according to sector of use:

Sector of use of refrigeration	Principal changes
Home refrigeration	Before the elimination of CFCs the main refrigerant was CFC12. The most widely used new refrigerant has become HFC134a. New alternatives are being created with mixtures of propane and butane. As regards expanding agents CFC 11 has been replaced by cyclopentane. The expanding agent has a mass about four times that of the refrigerant; this means that new isolation technology allows the reduction of the quantity of refrigerant and thus saves energy. It is foreseen that annual energy consumption can be certified and the efficiency of domestic refrigerators can be improved by about 50 % compared to the past.
Commercial refrigeration	CFC12 is still used in some cases, although there is a move towards HFC 134a and HFC 404° or the use of hydrocarbons. Experiments have been made using carbon dioxide as a refrigerant.
Storage	After the abolition of CFCs in the Montreal Protocol and the phasing out of HCFCs, the main tendency is that of using ammonia.
Industrial refrigeration	The most widely used refrigerant is ammonia.
Air-conditioning and heat pumps	Use of HCFC22 continues, although, as it is to be phased out, HFC 410A and HFC 407C are the main candidates as replacements. There is also a move towards hydrocarbons. Research is concentrating on carbon dioxide, although the adoption of this refrigerant requires new designs for air-conditioner components. Significant progress is being made in adsorption technology.
Air conditioners (water chiller)	This field is still dominated by steam compression technology, which mainly uses HCFC and HFC refrigerating fluids. Absorption technology using steam, natural gas and heat produced from waste is under study in some Asian countries but neglected elsewhere.
Transport	The most widely used refrigerating fluids after the abandonment of CFCs and HCFCs are HFC 404A and HFC 134a.
Vehicle air-conditioning	The general rule is taht of the use of HFC, although the tendency is towards carbon dioxide

Source:our elaboration

New refrigeration technology.

An alternative solution to that of identifying alternative refrigerants for the traditional steam compression refrigerating cycle is that of moving towards new refrigerating technology which exploits the principle of absorption-adsorption [2].

Absorption-adsorption refrigerating technology can easily be used in the commercial and industrial sectors without creating an increased demand for power. These systems can use different kinds of traditional fuels (oil, natural gas, coal…) or alternative ones (biomass, fuel derived from refuse-RDF…) and, for this reason, present great potential for areas in which it is necessary to reduce power consumption.

This technology still encounters resistance from the market, which continues to prefer traditional refrigeration methods for economic reasons; it may, however, represent the future objective of the refrigeration sector [10].

Recent innovations in the field of absorption exploit solar energy. This technology makes use of solar energy collectors of the *vacuum* or *concentration* type[3] in order to reach high temperatures. Reflectors are used to concentrate the sunrays and to gradually reduce the surface of the absorber, increasing efficiency at high temperatures and reducing heat loss [6].

Vacuum collectors are mainly used for moderate temperatures, between 50 and 90°C. Heat loss is minimal because the sunrays are channelled in a vacuum.

In the field of air-conditioning a form of solar refrigeration has been developed which exploits bromide and lithium water solutions that function along with solar collectors at a temperature of 75-100°C in order to obtain cold water at a temperature of 8-10°C; in order to reach lower temperatures (-10/-30°C) a water-ammonia solution is used at a temperature of 120-160°C.

Thanks to its simplicity, easy use and low costs, solar refrigeration could be used efficiently in the future also in non-industrial refrigeration. In particular, it could be a great opportunity for Less Developed Countries (LDCs) where, currently, solar refrigeration is used in the medical field for the storage of vaccines[1].

The environmental credibility of this technology is linked to the use of a renewable energy source which eliminates the effects of using fossil fuels [4].

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[3] There are numerous ways of collecting solar energy: flat glass collectors or without glass; perforated panel collectors without glass; return passage collectors; concentration collectors; air collectors; integrated collectors; solar furnaces; liquid circulation collectors; parabolic reflector collectors; parabolic cylinder reflector collectors; fixed concentration and vacuum collectors.

Glass collectors exist in the form of liquid circulation or air collectors and are convenient for uses at moderate temperatures between 30 and 70°C. Liquid circulation collectors are commonly used to heat water in houses or swimming-pools. Air collectors are used for drying produce in warehouses.

Other forms of "sustainable" refrigeration technology which are under development are summarised in the table below.

Technology	**Characteristics**	**Uses**	**Limitations on use**
Desiccant cooling	Chemical desiccants (titanium silicate) are used to absorb the humidity in the air and to cool it	Cooling, dehumidification and ventilation of interiors	High levels of air humidity
Trigeneration	Uses the excess heat created by cogeneration for cooling purposes. Water-lithium bromide absorption units are used; in industrial refrigeration the water-ammonia combination is used	Air-conditioning and industrial refrigeration	Requires heat and electricity together in order to function
Cryogenics	Includes refrigeration technology used to reach temperatures below 120K. Exploitation of superconductivity and cryomedicine	Mainly in the medical field	Promising applications which need further study and experimentation
Air cycle	Masses of pressurised air are used	Air-conditioning in jets and some high-speed trains	Low level of efficiency and high costs
Stirling cycle refrigeration	Functions by compressing and expanding a gas at a high temperature	Refrigeration at low temperatures	Difficult to use in large refrigeration plants. Niche applications
Thermoelectric cooling	Exploits the Peltier effect which involves the absorption of heat produced by the electricity supply passing between different metal joints: alloys or semiconductors	Small refrigerators for food and drink	Further studies and experimentation needed
Wind refrigeration	Exploits wind power	Production of ice in areas where electricity supply is limited	Limited applications

Conclusions.

The refrigeration sector is continually moving towards the adoption of strategies that combine economic and environmental efficiency.

The strategies that have been adopted affect the entire life cycle of the product and are aimed at solving the numerous environmental problems affecting the sector.

Much remains to be done, however, both as regards the development of better technology and as regards closing the gap between developed countries and developing ones. The considerable difference between developing and developed countries is above all a question of access to technology. It is important to try to reduce this gap because the lack of access to this technology, or worse still the use of obsolete technology, has an environmental impact which in part thwarts the efforts made in moving towards new technology with reduced environmental impact, since pollution knows no boundaries.

In order to obtain overall benefits from the environmental management of the refrigeration sector, the objectives of the sector over the next few years are:

- reduction of energy consumption from 30 to 50%
- reduction by half of leaks of refrigerating fluids
- promotion of initiatives to reduce emissions of greenhouse gases
- improvement of alternative technology
- education and training of all those who play a part in the life cycle at any stage, so as to guarantee the best possible application of new discoveries.

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