INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

THE ROLE OF REFRIGERATION IN THE GLOBAL ECONOMY

June 2019

38th Informatory Note on Refrigeration Technologies

“ Refrigeration is of paramount importance for mankind and must become a priority for policy makers.”

N° ISSN : *en cours*

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The Role of Refrigeration in the Global Economy

The IIR estimates that the total number of refrigeration, air-conditioning and heat pump systems in operation worldwide is roughly 5 billion. Global annual sales of such equipment amount to roughly 500 billion USD. Over 15 million people are employed worldwide in the refrigeration sector which consumes about 20% of the overall electricity used worldwide.
Statistical data presented in this new Informatory Note highlight the importance of the refrigeration sector which is expected to grow further in the coming years because of increasing cooling needs in numerous fields and global warming.
The refrigeration industry plays a major and increasing role in today's global economy, with significant contributions made in food, health, energy and environmental domains which policy makers need to better take into account.

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Introduction

Refrigeration has become a part of 21st-century life. This "invisible" industry plays a major role in countless sectors ranging from food and air conditioning to healthcare, industry and energy.

Refrigeration is vital for reducing post-harvest losses and in the preservation of food products.

Air conditioning plays a key role in the economic and social development of warmer countries and its use is expanding dramatically - especially in the world's emerging economies - with rising global temperatures.

In the healthcare sector, refrigeration preserves pharmaceuticals and medicines, especially vaccines. New treatments, such as cryosurgery or cryotherapy, were developed thanks to ultra-low temperature technologies.

Refrigeration is employed in numerous industrial processes such as chemicals and plastics. Deprived of refrigeration, data centres - and the internet - would collapse in minutes.

Regarding energy, natural gas can be liquefied through cryocooling, making it easier and cheaper for transportation and storage.

Economically speaking, the importance of refrigeration is paramount, as illustrated by the constant increase in the sales of refrigerating equipment and in the number of refrigeration-related jobs.

However, over 1.1 billion people – mainly in the least developed countries – globally face immediate risks from lack of access to refrigeration that could help address hunger and malnutrition and alleviate the worst of deadly heat waves. [1]

This Informatory Note* summarises basic data illustrating size and reach of the refrigeration sector and its importance for mankind.
It aims to raise policy makers' awareness on the growing importance of refrigeration in order to further encourage its development in a sustainable manner, particularly in the least developed countries.

** This Informatory Note is an update of a first version published by the IIR in November 2015*

The importance of refrigeration

REFRIGERATION ECONOMICS

In order to illustrate the importance of the refrigeration sector, the IIR estimated the number of refrigeration systems in operation worldwide (based on published sources and own estimations as summarised in Table 1.

Based on the above-mentioned figures, the IIR estimates that **the total number of refrigeration, air-conditioning and heat pump systems in operation worldwide is roughly 5 billion,** including 2.6 billion air-conditioning units (stationary and mobile) and 2 billion domestic refrigerators and freezers.

Global annual sales of refrigeration, air-conditioning and heat-pump equipment amount to roughly 500 billion USD [12], which, by way of comparison, represents roughly three quarters of global supermarket sales. [13]

Table 1

Number of refrigeration systems in operation worldwide per application

Applications	Sector	Equipment	Number of units in operation
Refrigeration and food *(see p.7)*	Domestic refrigeration	Refrigerators and freezers	2 billion [2]
	Commercial refrigeration	Commercial refrigeration equipment (including condensing units, stand-alone equipment and supermarket systems)	120 million [3]
	Refrigerated transport	Refrigerated vehicles (vans, trucks, semi-trailers or trailers)	5 million [4]
		Refrigerated containers ("reefers")	1.2 million [5]
	Refrigerated storage	Cold stores	50,000 [6]
Air conditioning *(see p.8)*	Stationary air conditioning	Residential air-conditioning units Commercial air-conditioning units Water chillers	1.1 billion [7] 0.5 billion [7] 40 million [7]
	Mobile air-conditioning systems	Air-conditioned vehicles (passenger cars, commercial vehicles and buses)	1 billion [2]
Refrigeration and health *(see p.9)*	Medicine	Magnetic Resonance Imaging (MRI) machines	50,000 [8]
Refrigeration in industry *(see p.9)*	Liquefied Natural Gas (LNG)	LNG regasification terminals LNG tanker fleet (vessels)	126 [9] 525 [9]
Heat pumps *(see p.10)*		Heat pumps (residential, commercial and industrial equipment, including reversible air-to-air air conditioners)	220 million [10]
Leisure and sports *(see p.10)*		Ice rinks	17,000 [11]

REFRIGERATION AND EMPLOYMENT

The socio-economic importance of refrigeration in today's world can be illustrated by means of employment data.

The IIR estimates that over 15 million people are employed worldwide in the refrigeration industry, which means that almost 5 workers out of 1000 have a job linked to the manufacturing, installation, maintenance and servicing of all type of refrigeration equipment.
This ratio is even higher in countries such as Australia, where around 300,000 people (2.5 % of total employment) are employed in over 20,000 businesses operating in the refrigeration sector. [14]

In this field, the need for engineering and technical staff (e.g. installers and mechanics) increases due to the growing demand for refrigerating capacities, along with the unique skills required of refrigeration-related professions.
In the US, employment of mechanics and installers in heating, refrigeration and air conditioning is projected to grow by 15% from 2016 to 2026, much faster than the average for all occupations (7%). [15]

REFRIGERATION AND ENERGY CONSUMPTION

Electricity consumption for refrigeration and air conditioning has been increasing for many years in both developed and developing countries.

The refrigeration sector - including air conditioning - consumes about 20% of the overall electricity used worldwide. This IIR estimation is based on an analysis of fragmentary data about the sectorial electricity consumptions by various areas of the world.

This 20% share highlights the importance of the refrigeration sector, which is expected to grow further in the coming years because of (i) increasing refrigeration demand in numerous sectors, and (ii) global warming.

The IIR estimates that **global electricity demand for refrigeration - including air conditioning - could more than double by 2050.** This assessment is based on IEA "Baseline Scenario" - taking into account the likely effect of current policies and targets - which predicts that electricity needs for space air-conditioning will triple by 2050. [7]
However, continued efforts to improve the energy efficiency of refrigerating equipment may allow to significantly limit this increase in energy consumption, especially in the air-conditioning domain (see page 8. *Air conditioning*).

REFRIGERATION AND ENVIRONMENT

The contribution of refrigeration to the environmental aspect of sustainable development might be illustrated through the indispensable role of refrigeration technologies for maintaining biodiversity by cryopreservation of genetic resources.
Refrigeration technologies are now being considered as a means to capture CO_2 from large power stations and industrial plants thanks to cryogenics; they also enable the liquefaction of CO_2 for underground storage.
However, the adverse environmental effects of refrigeration - and first and foremost its global-warming impact - must also be addressed.
Around 37% of this global-warming impact is due to direct emissions (leakage) of fluorinated refrigerants (CFCs, HCFCs and HFCs), while the remaining 63% are due to indirect emissions originating from the electricity production required to power the systems. [16]
Overall, according to IIR estimations [16], **the refrigeration sector-related emissions account for 4.14 $GtCO_2eq$, representing 7.8% of global GHG emissions.**
Hence, actions implemented by refrigeration stakeholders to fight global warming focus on two objectives:

- reduction in the direct emissions of fluorinated refrigerants to the atmosphere through better containment, refrigerant charge reduction and end-of-life recovery, development of alternative refrigerants with negligible or no climate impact and training/certification of technicians.
- reduction in primary energy use by increasing energy efficiency of refrigerating plants.

It is important to underline the positive environmental contribution of the recent implementation of the Kigali Amendment to the Montreal Protocol - supported by the refrigeration industry -, which plans a gradual reduction of HFC production and consumption worldwide.
Without the Kigali Amendment, the HFC emissions from the refrigeration sector would rise to between 3 and 4 $GtCO_2eq$ [16] in 2050. However, according to IIR estimates, thanks to the implementation of the Kigali Amendment, the HFC emissions will only amount to approximately 0.7 $GtCO_2eq$ in

2050, after a peak around 1.5 $GtCO_2eq$ at the end of the 2020s. Based on these estimates, the Kigali Amendment is expected to prevent a substantial increase in average temperatures up to 0.3 °C by 2100. [17] This result must be put into perspective with the Paris Agreement, whose objective is to limit the rise in global average temperature to well below 2 °C above pre-industrial levels.

Role and applications of refrigeration

REFRIGERATION AND FOOD

Refrigeration is crucial for the food sector because it ensures optimal preservation of perishable foodstuffs and provides consumers with safe and wholesome products.
However, the food cold chain is still insufficiently developed, especially in developing countries. Global food production comprises roughly one third of perishable products requiring refrigeration..
A striking example is India, whose percentage of cold chain logistics in perishable food logistics is less than 22% for fruits and vegetables and 34% for meat, well below the approximately 95% in Europe and the US. [17]

This results in huge food losses. **According to the IIR, the lack of a cold chain causes significant global food losses: up to almost 20% of the global food supply.** [18]

The FAO estimates that global gross agricultural output will have to increase globally by 50% from 2012 to 2050 under BAU scenario [19] and refrigeration has a vital role to play in this context. **Refrigeration can also make a significant contribution to addressing the issue of undernourishment** considering 821 million people, approximately one in nine people in the world, were undernourished in 2017 [19], especially in the least developed countries.

Continuous and ubiquitous refrigeration is necessary throughout the perishable food chain, from production to consumers.

In supermarkets, between 30% and 60% of the electric energy consumed is used by refrigeration equipment supplying cold to the display cabinets and the cold rooms for chilled and frozen food storage. [20][21]
It is inconceivable that small shops, restaurants, bars, and hotels could function without refrigeration equipment.

About 2 billion domestic refrigerators and freezers are in service worldwide. [2] Based on the number of refrigerated appliances installed and their electricity consumption, the IIR estimates that domestic refrigerators and freezers consume almost 4% of global electricity.
However, energy efficiency in refrigerators has been increasing constantly, as highlighted by the constant qualitative evolution of the energy labels. For example, in the USA, the annual average electricity consumption was divided by 4 between 1974 and 2015, while the equivalent volume increased by 20%. [22]

Refrigerated food processing, cold storage, refrigerated transport and distribution are less visible for the customer, but are key elements of the cold chain.

Currently, there are around 5 million refrigerated vehicles in service worldwide, including vans, trucks, semi-trailers or trailers. [4] Moreover, the global refrigerated transport market is expected to grow strongly in the coming years (+30% between 2018 and 2022). [23]

Furthermore, the volume dedicated to cold storage in the world accounts for 616 million m^3 in 2018 - representing around 50,000 cold stores - with an increase of 34% over 2012. [6]

The continuous advancement in freezing technologies permitted the fast development of new food markets such as frozen foods and ice creams. Convenient and ready meals, currently the dominant segment of the global frozen food market, responds to the changing and busy lifestyles of many people, especially in urban areas. In addition, numerous studies show that frozen fruits and vegetables have nutritional qualities that are globally equivalent to those of fresh products, and often contain more vitamins than fresh products kept for several days. [24,25]
Annual consumption per capita of frozen food is about 50 kg in countries such as the USA, Ireland, UK, Sweden and Germany. [26]
Valued at USD 219.9 billion in 2018, the global frozen food market is expected to grow by almost 30% by 2023 and reach USD 282.5 billion. [27]

AIR CONDITIONING

Air conditioning is an essential part of the refrigeration sector. Its use is increasing for both human comfort and health (see page 9 *Refrigeration and health*), and industrial processes (Information Technology, biotechnologies, etc.; see page 9 *Refrigeration in industry, transportation and energy sectors*).

Hot areas and zones with high air humidity underwent remarkable economic development due to the introduction and expansion of air-conditioning technologies over the past 60 to 70 years.

Several independent studies reported that high ambient temperature and poor quality of indoor air have a significant influence on students' cognitive learning and the productivity of office workers. [28,29] A study carried out on over 10 million US high school students shows that without air conditioning, each 0.5 °C increase in school year temperature reduces the amount learned that year by one percent. [30,31]

Inappropriate ambient temperatures impair work efficiency and may cause economic losses.

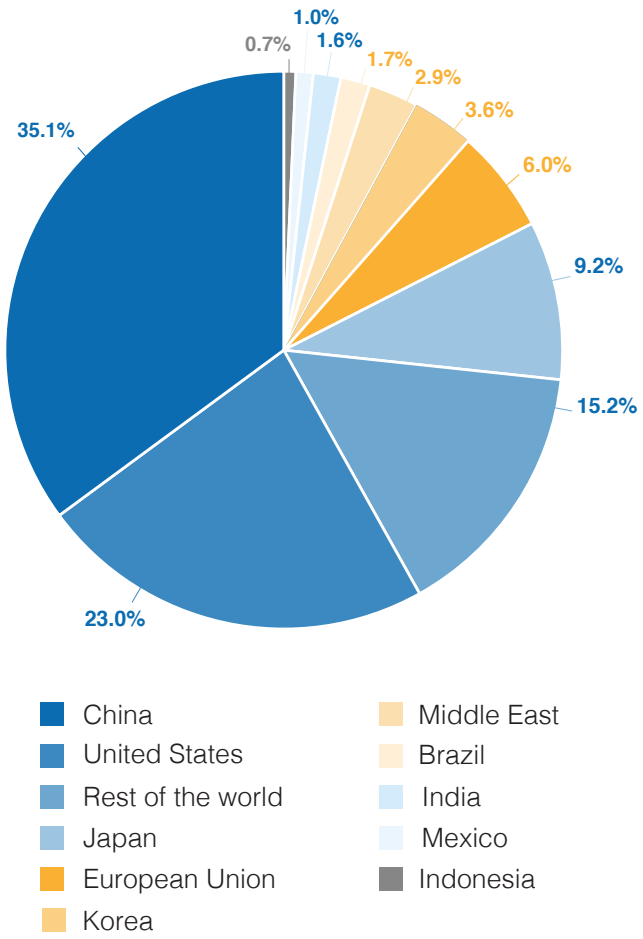
Globally, the International Labour Organization points out that even in a scenario of effective climate change mitigation, temperature increases resulting from climate change will lead to the loss of the equivalent of 72 million full-time jobs by 2030 due to heat stress. Developing countries and the most vulnerable population groups - particularly migrants, people in poverty, and indigenous and tribal peoples - are most exposed to these impacts. [32]

Air-conditioning is responsible for over 8% of global electricity consumption, according to IIR estimations. This ratio varies widely from one country to another, depending on the local climate and the development level. Household ownership of ACs varies enormously across countries, from around 4% in India and less than 10% in Europe, 60% in China to over 90% in the United States and Japan, and close to 100% in a few Middle Eastern countries. [7]

Air-conditioning is expanding dramatically, especially in the world's emerging economies and this trend is expected to increase since of the 2.8 billion people living in the hottest parts of the world, only 8% currently possess air conditioners. [7]

Figure 1

Stock of air conditioners by country/region, end 2016



Total capacity = 11675 GW (1.6 billion units) [7]

Furthermore, air conditioning is expected to play an increasing role in the context of climate change and the associated increase of ambient temperatures. According to IEA « Baseline Scenario », which takes into account the likely effect of current policies and targets, global energy needs for space cooling will triple by 2050. [7] Most of this projected growth in energy use comes from the emerging economies, with India, China and Indonesia alone contributing half. [7]

Associated CO_2 emissions are expected to almost double by 2050. However, potential exists to curb this strong increase in energy demand and CO_2 emissions. IEA states that the average energy efficiency of air conditioners sold today is one third of best available technology. It presents an « Efficient Cooling Scenario » based on much stronger policy action resulting in much tighter minimum energy

performance standards (MEPS) for air-conditioning equipment, in all countries. The implementation of these policies would allow to cut down by three the energy needs increase of the "Baseline Scenario". [7]

These figures highlight the critical need for determined policy action regarding energy efficiency in order to ensure sustainability of air conditioning.

Mobile air conditioning is expanding at a comparable pace since almost all new vehicles currently sold are air-conditioned. There are currently about 1 billion mobile air-conditioning units in vehicles and buses worldwide. [2]

REFRIGERATION AND HEALTH

Refrigeration has a direct impact on human health through preservation of foods and pharmaceuticals, as well as through new low-temperature therapeutic techniques.

Refrigeration inhibits the development of bacteria and toxic pathogens therefore preventing foodborne diseases. Refrigeration dramatically reduces the need for chemical preservatives in food. Since 1930, thanks to cold-chain enabled food preservation, a 90% decrease in the number of stomach cancer cases was noticed, according to a study by the WHO. [33]

Heat-sensitive health products, kept at a controlled temperature (particularly between 2 °C and 8 °C), experienced a tremendous market extension all over the world. From 2011 to 2017, the number of heat-sensitive healthcare products increased by 45%: 1 out of 2 medicines on the market is heat-sensitive. [34]

Concerning vaccines, a particularly striking example is the role of refrigeration in the eradication of poliomyelitis. In 2018, the number of cases of poliomyelitis occurring worldwide was 33, i.e. over ten thousand times fewer than the 350,000 cases registered in 1988. [35]

Cryosurgery is an easy-to-use and relatively inexpensive technique which requires only fairly basic equipment. Cryoablation is used as a clinical treatment. Its ability to cure skin cancer, for example, is proven to have a success rate for 99% of patients. [36] It also showed a 99.4% success rate in the treatment of women with low-risk breast cancers. [37]
Whole-body cryotherapy consists in exposing a patient to extreme cold (-80 to -160 °C) for a short time (2 to 4 minutes) in a specialised cold chamber. Preliminary studies suggest that this technique induces significant physiological and psychological benefits. Little known a few years ago, this therapy is currently attracting keen interest.

Superconductivity - a phenomenon enabled by cryogenic technologies - is at the heart of Magnetic Resonance Imaging (MRI) scanners, helping to give doctors an unprecedented view of structures deeply within the human body. Most MRI machines use superconducting magnets to maintain strong, stable magnetic fields. MRI has a wide range of applications in medical diagnostics, with over 50,000 MRI scanners in use worldwide. [8]

Finally, the health benefits of air conditioning should be emphasised. A study suggests that the mortality impact of days with a mean temperature exceeding 27 °C has declined by about 75% over the course of the 20th century in the United States, with almost the entire decline occurring after 1960; the diffusion of residential air conditioning explains essentially this decline. [38]

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REFRIGERATION IN INDUSTRY, TRANSPORTATION AND ENERGY SECTORS

Refrigeration is vital for the food (see page 7 *Refrigeration and food*)**, chemical, plastic, steel and building industries, etc. Other advanced industries, such as electronic-data processing or biotechnologies could not operate without refrigeration.**

Air separation by cryogenic distillation is a mature technology and the only feasible means currently available for mass production of air products such as oxygen and nitrogen. [39] The consumption of high-purity oxygen by steel, medical, and chemical industries amounts to 1.2 million tons per day. [40]

Refrigeration has a major influence in the high-tech sectors, including Information Technology (IT). While data centres are responsible for about 2% of global electricity consumption [41], between 30% and 55% of this consumption is used for cooling IT equipment. [42] Since the average power density of data centres is expected to be multiplied by 8 by 2025 [43], implementation of advanced efficient cooling technologies is essential.

New energy-related sectors such as gas liquefaction are rapidly growing. World trade in liquefied natural gas (LNG) more than tripled since 2000, growing to 316.5 million tonnes of LNG in 2018, which constitutes 10.7% of global gas consumption. [9] LNG accounts for almost 90% of the projected growth in long-distance gas trade to 2040. [44] LNG starts to be used as clean fuel for ship propulsion, particularly in closed seas (Baltic ferries). [45]

Although liquid hydrogen remains a fuel of choice for rocket propulsion, it will certainly appear in the more conventional transport distribution chain, namely electric vehicles powered by fuel cells.

The International Thermonuclear Experimental Reactor (ITER), currently under construction, is a large magnetic device for plasma confinement aimed at demonstrating the feasibility of controlled thermonuclear fusion for electricity production. The machine uses very large superconducting magnets cooled at liquid helium temperature and cryopumps cooled by liquid nitrogen. [46]

HEAT PUMPS

Heat pumps are devices that use the refrigeration cycle for both heating and cooling. They have a unique role in the energy system of the future. No other technology can simultaneously provide for net primary energy savings, economic benefits to the users and reduced climate impact.

In heating mode, heat pumps are very energy-efficient since for each kW of electricity consumed, about 3 to 4kW of thermal energy is generated.

In Europe, operating heat pumps save about 1% of the total CO_2 emissions today. [47] According to IEA, nearly 8% of global emissions could be saved by heat pumps, especially in the building's sector. [48]

REFRIGERATION IN SCIENCE

Refrigeration is at the heart of major scientific projects of strategic nature essentially as an ancillary technique to superconductivity.

Nuclear magnetic resonance (NMR) is a powerful analytical technique requiring high magnetic fields. Such magnetic fields are produced by superconducting magnets cooled by liquid and sometimes superfluid helium. NMR has found a variety of applications in many disciplines of scientific research, medicine, and various industries.

The CERN's Large Hadron Collider (LHC) - the world's largest and most powerful particle accelerator - uses a 27-kilometre ring of superconducting magnets maintained at -271.3 °C through superfluid helium to reach the high energies needed to test fundamental theories of particle physics. The discovery of the Higgs boson in July 2012 is the first major result of LHC research. [49] The Future Circular Collider (FCC), the next-generation facility currently under consideration, is intended to produce magnetic fields nearly twice as strong as the LHC, and accelerate particles to unprecedented energies of 100 tera-electron volts, about 7 times higher than the LHC. [50]

LEISURE AND SPORTS

Ice rinks (about 17,000 worldwide [11]), artificial ski runs, bobsleigh, luge and skeleton tracks become more and more popular.

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IIR recommendations

The issues of food safety, health, energy and the environment make it quite clear that refrigeration is of paramount importance for mankind and must become a priority for governments in the sectors of industry, education and research.

It is necessary to advance training and qualification of staff in the refrigeration sector, but also to incite more young people to turn to promising refrigeration-related careers offering long-term perspectives.
No effort should be spared to help developing countries reach refrigeration capacities necessary to preserve food safety and human health. Investments in infrastructures should also be made in order to implement the adequate equipment.
Improving the energy efficiency of refrigeration plants is a key issue and must remain a constant concern for the refrigeration industry. This involves further research and development in innovative efficient refrigeration technologies and in different renewable energy sources (solar, wind, geothermal, biogas, etc.), offering smart alternatives to the electrical grid when powering refrigeration plants. This also involves the generalisation of policy measures to encourage consumers to purchase increasingly efficient refrigeration equipment.
The amount of high-Global Warming Potential (GWP) refrigerant emissions from refrigerating plants must be reduced through leakage control, charge reduction, end-of-life recovery and use of alternative natural or synthetic low-GWP refrigerants.

Refrigeration-related research and development must be further stimulated and actively supported by national and international authorities, funding agencies, public and private industries in order to improve health, well-being, energy and environmental sustainability around the world.

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