World tendencies and priorities in development of low-temperature engineering

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The International Institute of Refrigeration (IIR) is an independent intergovernmental science and technology based organization which promotes knowledge of refrigeration and associated technologies that improve quality of life in a cost-effective and environmentally sustainable manner including:

— food quality and safety from farm to consumer;
— comfort in homes and commercial buildings;
— health products and services;
— low temperature technology and liquefied gas technology;
— energy efficiency;
— use of non-ozone-depleting and low global warming refrigerants in a safe manner.

It comprises 60 member countries (both developed and developing) including of course Russian, 500 experts and 600 corporate and private members: private companies (refrigeration equipment, public services, food and pharmaceutical sectors), consultants, academics, students... It was founded in 1908. The Head office is in Paris. The information services are the refrigeration portal with 90 000 references, the publication of Journals, Books, Informatory Notes, Statements, the organisation of Conferences and Working Parties...

1. Increasing needs of Refrigeration

1.1. Refrigeration is necessary to mankind. Why?

- Temperature is a magnitude and a key variable in physics, chemistry and biology.
- It characterizes the state of matter and liquid, solid and gaseous phases. It thus drives to materials applications.
- It is vital to all living beings and each living being (bacteria, plant, animal) has a temperature range within which it can live (more or less optimally: metabolism slowdown — or even arrest, hibernation...).

Consequence: exerting an effect on temperatures equals exerting an effect on nature.

Man wants to tame nature and has to tame refrigeration

- The temperature governs whether a living being can survive or not.
- And whether pathogens can develop, survive or not.
  - To ensure that foodstuffs are healthy, to prevent the growth of pathogens, foodstuffs are chilled or frozen.

Refrigeration is everywhere:

— cryogenics (petrochemical refining, steel industry, space industry, nuclear fusion...);
— medicine and health products (cryosurgery, anaesthesia, scanners, vaccines...);
— air conditioning (buildings, data centres...);
— food industry and the cold chain;
— energy sector (including heat pumps, LNG, hydrogen...);
— environment (including carbon capture and storage), public works, leisure activities.

1.2. The increasing needs in developing and emerging countries

- 1600 deaths/year in the USA are due to pathogens, at least partly associated with temperature control and many more in «developing» countries. According to a WHO report (2008) refrigeration and improved hygiene have reduced stomach cancer by 89% in men and 92% in women since 1930 in the USA. Another estimation: about 3 millions deaths/year related to refrigeration Worldwide.
- There is an increase in the global population, particularly in Africa and South Asia (9–10 billion in 2050, 8 in developing countries).
- 70% (50% now) will be in urban areas (doubling in developing countries) and it will increase the need for cold chains, because of longer distances between the production and the commercialization and because of increasingly westernized models (meat, ...).
- 1 billion people are undernourished; 23% of food losses are caused by a lack of refrigeration (vs 9% in

developed countries).
- There are needs for better health everywhere (good cold chain, air conditioning), particularly because of an ageing population.

This increase in emerging and developing countries will increase the impact on the environment.

2. Energy and environmental challenges

2.1. Refrigeration is a major energy consumer

Refrigeration including air conditioning represents 15% of global electricity consumption. And it will increase (The Netherlands: 18%...). Refrigeration issues are clearly linked with electricity issues, which are:
- Global warming because of CO_2 emissions (electricity production depending on fossil fuels): we need to take into account the TEWI (Total Equivalent Warming Impact), and the LCCP (Life Cycle Climate Performance) of the refrigerating equipment (the IIR recently built a Working Party to measure it).
- The price of electricity will increase (new sources of energy have higher costs).
- There is a lack of power infrastructures, particularly in developing countries.
- Overall system solutions (district cooling, trigeneration...) should certainly be developed.
- Heat Pumps are considered as a renewable energy in the European Union, but provided that they have a sufficient Coefficient of Performance because of their electricity consumption.
- There are and there will be new regulations on energy and on buildings in Europe and the USA, with new constraints on energy and thus new constraints on refrigeration systems.
- Changing a system because of refrigerant issues must take into account potential reductions in energy consumption.

2.2. The impact of refrigerants on the environment
- Vapour-compression systems will remain predominant in the short and medium term and thus we will need more refrigerants in the future.
- Because of their impact on the stratospheric ozone layer; Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) are included in the Montreal Protocol and each country (developed and developing countries) had to build phase-out plans. That issue will thus soon be behind us except the bank issue (refrigerants in existing equipment to be destroyed in the future).
- There are alternative refrigerants:
  — hydrofluorocarbons (HFCs), including Hydrofluoroolefins (HFOs) have no impact on the ozone layer but an impact on global warming (they are included in the Rio Convention and the Kyoto Protocol);
  — natural refrigerants (ammonia, CO_2, hydrocarbons, water, air) have a very low impact on global warming;
  — mixtures, combinations (cascades, secondary fluids) are being developed in order to meet the various uses.

The following table summarizes the impact of the main refrigerants on the ozone layer (Ozone Depleting Potential = ODP) and on climate change (Global Warming Potential = GWP). Even if CFCs have a very high ODP and GWP, HCFCs and HFCs have similar impacts.

Family of refrigerants	Main refrigerants	ODP	GWP
CFCs	CFC 11	1	4 750
	CFC 12	1	10 900
	Others	0.4…1	6 000…15 000
HCFCs	HCFC 22	0,05	1 810
	Others	0,020…0,070	70…2 400
HFCs	HFC 134a	0	1 430
	HFC 404A	0	3 900
	HFC 407C	0	1 800
	HFC 410A	0	2 100
	HFC 32	0	720
	HFC 1234yf	0	4
	Others	0	4…4 500 (except HFC 23 = 14 800)
Natural Refrigerants	HC 290	0	20
	HC 600a	0	20
	HC1270	0	20
	R717 (ammonia)	0	~ 0
	R744 (Carbon dioxide)	0	1
	Air, water	0	~ 0

CFCs and HCFCs are mainly replaced by HFCs, which generally have a high GWP.

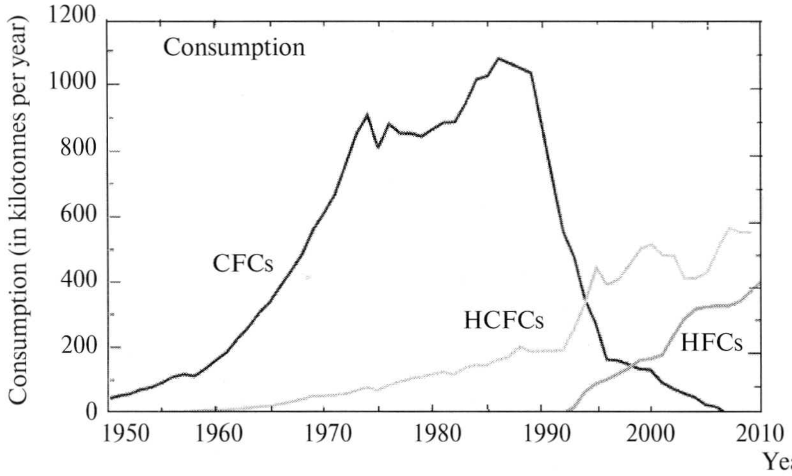

Fig. 1. Global of ozone depleting CFCs and HCFCs. The phasing in of HFCs as replacements for CFCs is evident from the decrease in CFC usage concomitant with the increasing usage of HFCs.
Use of HCFCs also increased with the decreasing use of CFCs. HCFCs are being replaced in part by HFCs as the 2007 Adjustment to the Montreal Protocol on HCFCs continues to be implemented.
Thus, HFCs are increasing primarily because they are replacing CFCs and HCFCs. (Source UNEP)

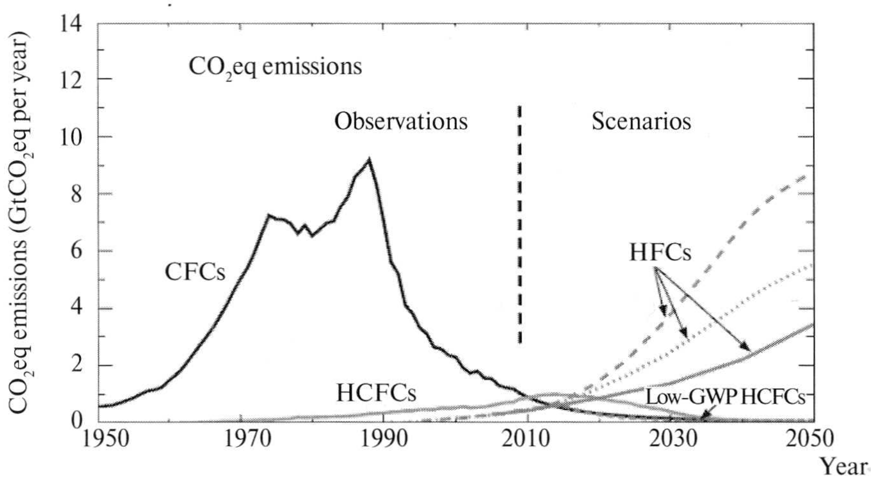

Fig. 2. Trends in CO2eq emissions of CFCs, HCFCs and HFCs since 1950 and projected to 2050.
The HFC emissions scenarios are from Velders et al. (2009) and Gschrey et al. (2011). The low-GWP HFC line represents the equivalent HFC emissions for a scenario where the current mix of emissions (with an average lifetime of HFCs of 15 years and an average GWP of 1600) was replaced by a mix of low GWP HFCs (with an average lifetime of less than 2 months or GWPs less than 20). Source UNEP

HFCs are mainly used in refrigeration and air conditioning

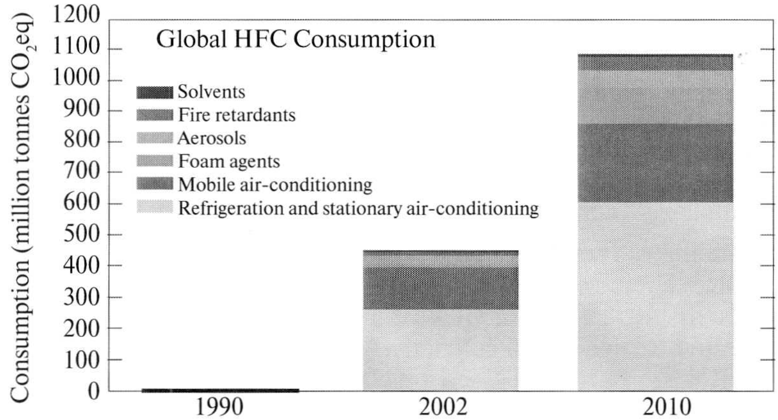

Fig. 3. Estimated global consumption of HFCs by various sectors, expressed in CO_2 equivalent, for 1990, 2002 and 2010 (TEAP 2005, EPA 2010a). HFCs are predominantly used for the same industrial uses as the CFCs and HCFCs which are subject to phase-out under the Montreal Protocol. The rapid growth in HFCs after 1990 is also clearly evident. (Source UNEP)

HFCs currently represent less than 1% of CO_2 eq emissions. In 2050, they will represent 7% to 45% (more likely 7%) of CO_2 equivalent emissions. HFCs emissions in 2050 could offset the achievements of the Montreal Protocol related to the phase-out of CFCs.

Hence, discussions are held at an international level (Montreal Protocol and Kyoto Protocol meetings) on the future of HFCs: replacing HCFCs with HFCs could be a real threat to climate.

At the contrary, HFCs are short-living substances compared to CO_2. Thus phasing down HFCs would have short-time results and USA, Canada, Mexico, Sweden, Ghana, Bangladesh launched a new initiative beginning of 2012.

Previously, North America (USA, Canada, Mexico) and Islands (Mauritius, Micronesia) proposed several times since 2008 during the Montreal and the Kyoto Protocol United Nations meetings to phase down (15% of previous emissions in 2033 and 2043 for developed vs developing countries) the consumption and production of HFCs, in all countries. The amounts would be weighted according to their Global Warming Potential. Most countries progressively agreed. However, there is currently an opposition of India, China, Brazil and Gulf countries.

Other initiatives recently took place:

- The European F-gas regulation and the Mobile Air Conditioning (MAC) directive
- Taxes and bans on HFCs in certain countries (Scandinavia, Australia...)

This decision is linked to other decisions regarding global warming. The new time schedule is 2015 for a new agreement on this issue.

3. How to reduce the impact on global warming?

3.1. Various solutions

— There are other technologies: absorption, adsorption, solar refrigeration, magnetic refrigeration, thermoelectric cooling, cryogenics (nitrogen, CO_2) but they still require technological improvements (cost, energy efficiency, capacity). Thus, they are today only niche technologies.

— Reducing leakage. Because of important variability within similar equipment working in similar conditions, there are margins for progress. For instance, leakage in the European Union which were 30% in the 1980s now are 5% and less.

The review of the F-gas regulation in the European Union will strengthen the controls on leakage. Training is the most important difficulty. However, reducing leakage has clear advantages in terms of savings and safety.

— Reducing the refrigerant charge. It is both an issue of safety and of reduction of Greenhouse gases emissions. There are thus research and development for all refrigerants on secondary refrigerants or on microchannels...

— Choosing a low-GWP refrigerant:

What is a low-GWP refrigerant? This question could be a delicate regulation issue, at least at an international level. We need a sector-by-sector approach, including high ambient-temperature conditions. «Low» or «moderate» GWP.

HFCs can be used, but only as a possible intermediate step. Moving directly to «very low» GWP.

HFCs (150 is the maximum allowed in the MAC directive in Europe and could be an international reference in the near future; HFOs would be the main «very-low» GWP HFCs) and of course to natural refrigerants are a better option where possible (efficiency...)

3.2. Key elements to take into account when choosing a low-GWP refrigerant

— No very low-GWP refrigerant is perfect:

They all present safety risks and drawbacks: flammability, toxicity, corrosion, pressure. They all need adaptation of the equipment even if HFOs and to a lesser extent HCs are more similar to HFCs than others.

— Fair comparisons (outdoor temperature, type of equipment, suitable oils...) concerning efficiency are rare. Many technical developments took place in recent years on CO_2, on HCs and even on ammonia; thus improvements in the future are probable.

There is at the contrary no real experience with very low-GWP HFCs: they are still not on the market, except in mobile air conditioning in Europe since the end of 2011 and experimental studies on supermarkets... The first results published generally show relatively similar efficiency.

— Safety regulations:

- They are a barrier to ammonia; but ammonia is still recognized as the most efficient refrigerant; regulations can change (e. g. in France) but trained technicians are needed.
- They are also a barrier to hydrocarbons; but HCs are a really good solution for low charges; regulations can change (e. g. USA) and barriers could be relatively similar for very low-GWP HFCs (even if their flammability is very low).

— Adaptation to warm climates.

There are still few recent examples: HFOs are not commercialized and natural refrigerant technical development is mostly in Europe and Eastern Asia. However, CO_2 seems to be less efficient than current HFCs. HCs are a real and potential solution (e. g. Australia, India, China) for many applications in the future. Experiments with ammonia-CO_2 cascades are underway. However, a market needs to be developed.

— Industrial strategies:

- Refrigerant manufacturers would like only one worldwide market and they are lobbying in order to include HFCs in the Montreal Protocol.

E. g.: for mobile air conditioning, a European market is being developed for HFO 1234yf; it could soon also be a market in North America and they would have afterwards a worldwide market.

Refrigerant manufacturers are developing similar products for other uses: foams, commercial refrigeration, stationary air conditioning.

But they need time to produce and commercialize them.

- Equipment manufacturers: they are producing an increasing amount of equipment running on natural refrigerants because of huge demand in Europe and Eastern Asia.

Thus, prices of equipment will decrease (currently, 10–20% higher than current equipment, but lower running costs)

- Installers: they resist change, because of a lack of expertise and training.

Thus, working with them and funding training when implementing an HCFC phase-out plan is necessary.

— Refrigerant prices:

There will be shortages:

- Shortage of HCFCs because of phase out in developed countries (already in force) and because of manufacturer's forecasts.
- Shortage of HFCs produced by very-low-GWP HFC manufacturers because they need to convert their plants.

Their price thus will increase. The development of very-low-GWP HFCs (HFOs) was expensive: their price will be higher than those of HCFCs and HFCs. In addition there is less current competition within refrigerant manufacturers.

Natural refrigerants: they are very cheap; they need higher investment costs but lower running costs.

— Types of equipment

- For relatively new equipment: drop-in solutions with HFCs are the best option. Reducing leakage thanks to a better maintenance and training is possible.
- For old equipment: replacement solutions, taking into account energy consumption and solutions with natural refrigerants where possible (safety constraints, regulations, quality of maintenance) and low charge are the best option, even if the investment cost is higher.
- There is no universal solution: refrigerant properties are different.

Conclusion: What should the future be?

- Current HFC consumption and production will decrease in the medium term because of international regulations, the example of the European Union and worldwide strategies of refrigerant manufacturers.
- Very-low-GWP HFCs will be developed, but progressively (they are currently not on the market), and at higher prices at least at the beginning.
- Natural refrigerants are already a solution for various applications, including in warm climates. Countries like China are more and more interested and ready to manufacture equipment.
- A sectorial approach is needed in a strategic national plan.
- Numerous current technical developments on very-low-GWP refrigerants, on more efficient equipment and on new technologies are underway.

Administrations, companies, universities need an updated information

The IIF can help you

— thanks to its new portal;

— through its database Fridoc (the most complete refrigeration database);

— through its publications (the International Journal of Refrigeration, the best impact factor in its field; the Newsletter, books, guides....);

— through its reference documents (eg the International Dictionary of Refrigeration including russian...);

— through its network of experts;

— through its participation in international decisions;

— through its conferences, congresses, research projects and working parties on these issues.

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