



CENTRO  
STUDI  
GALILEO

# INDUSTRIA formazione

special international issue

refrigeration and air conditioning



**ozone protection**



**climate change**



**energy efficiency**

UNDER THE AUSPICES OF THE ITALIAN MINISTRY OF THE ENVIRONMENT

## FOREWORDS

The ozone and climate systems are connected by complex atmospheric feedback systems, and the policy and technology responses to dealing with them can be equally intricate. Some of the technology solutions, for example, that address ozone depletion contribute negatively to climate change. While at the same time, energy-efficient appliances are being improved to tackle environmental threats like global warming. This special publication covers the three interlinked issues: ozone depletion, climate change and energy efficiency, and helps show that today's world is full of interconnected axes, particularly when it comes to the environment and development agenda. The message is clear - While addressing one global environmental challenge, it has become important that we assess the positive and negative impact on other global environmental challenges as well. UNEP strives to reflect this integrated approach in our capacity building work with developing countries under the Bali Strategic Plan, and on-going efforts to meet the goals contained in the Millennium Declaration and the Montreal and Kyoto Protocols. The commitment to achieve environmental goals must be translated into action and that can only be accomplished through effective partnerships. In this area, there has been much good work done by the Montreal Protocol's Multilateral Fund as well as through partnerships. Two examples presented in this magazine – multi-agency, public-private partnerships with UNEP's OzonAction Programme – are directly contributing to ensuring environmental sustainability, one of the Millennium Development Goals. The "Solar Chill" project is helping to reduce child mortality by contributing to vaccine preservation in developing countries, while "Refrigerants, Naturally" is promoting a shift in the point-of-sale cooling technology towards alternative refrigeration technology that protects the Earth's climate and ozone layer. UNEP is proud of these innovative initiatives and pleased to be associated with the Government of Italy and the Centro Studi Galileo in presenting a more integrated vision of ozone, climate and energy efficiency. We hope that this publication gets you thinking about interlinkages in your own work and inspires you to take further action.



**Achim Steiner**

**United Nations Under-Secretary-General**

**Executive Director of the United Nations Environment Programme**



The process under the Montreal Protocol is an important example of global initiatives towards sustainable development: the achievements obtained by the "Montreal Protocol family" in the protection of the ozone layer constitute an important step toward the protection of the environment for present and future generations. The ozone layer protection has so far represented a strong driving force for a global technology innovation in several industrial sectors both in developed and developing countries. Restructuring industrial practices, changing consumers behaviour and trade patterns – involving millions of enterprises and billions of consumer – are remarkable results. Italy is very proud to have played an active role in the successful implementation of the Montreal Protocol. Indeed, we are strongly committed to support the global ozone protection initiative by continuously stimulating technology innovation and promoting industrial and agricultural "ODP free" production. The "lesson learned" with the successful experience of the Montreal Protocol implementation is an important "tool" for the environmental challenges that are to be faced in the coming years. Recent studies underlined that the ozone layer protection is strictly interlinked to other environmental issue such as the climate change and that decisions adopted under the Montreal Protocol could have impacts on global warming. This scientific evidence requires a new global commitment: technologies and products designed to protect the ozone layer should not contribute to the greenhouse effect. Therefore, while it is important to keep on pursuing the technical and financial assistance to developing countries to maintain their compliance with the specific objectives of the Montreal Protocol, the international community should also look at the environment protection with an holistic approach. This publication is meant to be a little step in this direction: analysing the interrelations between different environmental issues, proposing solutions and technologies good for the environment as a whole.



**Corrado Clini**

**Italian Ministry of Environment**

**General Director for Environmental Research and Development**

03/04

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ozone protection  
↕  
climate change  
↕  
energy efficiency



**About the picture on the cover:**  
This image of Achill Island, off the  
most North-Westerly point of  
Ireland, illustrates:

- **Ozone protection**  
the sky: the blue sky contains our  
Earth's ozone shield.
- **Climate change**  
the sea: higher temperatures could  
lead to sea level rise and extreme  
weather events.
- **Energy efficiency**  
the waves: renewable energy  
sources such as waves are waiting  
to be harnessed.



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## Interlinked Challenges, Interlinked Solutions: Ozone Protection and Climate Change

RAJENDRA SHENDE

Head, OzonAction Branch<sup>1</sup>, UNEP DTIE, Paris

**Climate change and ozone layer depletion are two of the most challenging environmental problems facing the global community in the 21<sup>st</sup> century. How are these issues linked?**

Interestingly, the two issues are linked scientifically, technologically and also in terms of their impacts. The increase in surface temperature of the earth due to global warming will result into a colder stratosphere, which may delay the ozone recovery over the polar regions. Furthermore, CFCs, HCFCs and halons controlled under the Montreal Protocol are also greenhouse gases (GHGs) whose global warming potentials (GWPs) are in fact higher than any of the gases controlled under the Kyoto Protocol. Elimination of CFCs, HCFCs and halons will mitigate climate change. Ozone is also a GHG. So, ozone layer recovery will enhance climate change. To complicate the matter further, one of the major substitutes for the CFCs are HFCs which are also GHGs. Hence the elimination of CFCs by HFCs will add to climate change.

The Kyoto Protocol that was signed in 1997 required that emissions of six GHGs be reduced. These six gases

included, among others, HFCs, which are entering into the market in a big way as substitutes for CFCs that deplete the ozone layer. HCFCs, which have small ODP and are controlled under the Montreal Protocol, are also transitional substitutes for CFCs, but they are potent GHGs. They too are entering the market, mainly in the developing countries, with accelerated pace. It appears that while we are setting up the process to resolve the ozone depletion problem, the same process also aggravate climate change.

The description of important linkages between the two issues cannot be completed without indicating the importance of the energy efficiency of appliances that use alternative refrigerants i.e. other than CFCs. In many such appliances, industry has done a remarkable job in improving the energy efficiency in a substantial way. In some cases, due to the use of alternative refrigerants, the energy efficiency has improved by as much as 40%. Such improvements result into an equivalent reduction in the CO<sub>2</sub> emissions arising out of burning of fossil fuels to generate electricity used for running of the appliances. Thus, appliances using alternate refrigerants - needed for the protection of the Ozone Layer - and energy efficient technologies contribute to the mitigation of Climate Change. This could be called a major collateral advantage of the Montreal Protocol. Indeed, these two issues have a real potential to cause global disaster. Though the world has taken appropri-

ate steps to protect the Ozone Layer, in case of Climate Change, deplorably, there have not been concerted and coordinated actions. High level of skin cancers, cataracts, decline in marine food production, fall in plant growth and food production and reduction of the human capability to fight the diseases were predicted consequences of ozone layer depletion. While we cannot say with certainty that all these consequences have been avoided, we can say that we have succeeded in arresting the trend that could have led the world to the catastrophe. The consequence of climate change - an



increase in the Earth's surface temperature - is predicted to have frightening scenarios that are life threatening. Accelerated depletion of natural resources, wide spread of diseases resulting into deaths, inundation of low-lying areas, streams of refugees and unexpected natural calamities.

<sup>1</sup> UNEP's OzonAction Branch is a capacity building programme that assists developing countries and countries with economies in transition to comply with the Montreal Protocol. It has received two awards for innovation and leadership in assisting developing countries, one from USEPA and another from the President of Senegal on behalf of African countries. The Branch also supports the voluntary Refrigerants Naturally initiative, which also received an award from USEPA.

**You have said in some of your speeches that the Montreal Protocol has helped to implement the Kyoto Protocol. What do you mean by that?**

It means that actions taken by countries and companies to comply with the Montreal Protocol have also helped to achieve the objectives of the Kyoto Protocol. Under the Montreal treaty substantial actions are being taken on the ground to stop production and consumption of major global warming gases. To put it in a simple way, many of the substances controlled under the



Montreal Protocol damage the ozone layer and are at the same time potent global warming gases. CFCs have GWPs ranging from about 4000 to 10000 and halons have GWPs of 1700 to 7000.

The world has eliminated nearly 1 million tonnes per annum of CFCs and about 50,000 tonnes per annum of Halons as needed under the Montreal Protocol. A rough calculation shows that the action under the Montreal Protocol has eliminated the emissions equivalent of nearly 8 Giga tonnes of CO<sub>2</sub> annually, which is about 30% of present GHGs emissions. Even if one takes into account the addition of GHGs like HFCs and HCFCs which are introduced in the market as alternatives to CFCs, the impact would not be much different.

This is why we say that the Montreal Protocol is, in a sense, “the world’s first climate protection treaty”. If the Montreal Protocol was not already in place, the Kyoto Protocol would probably have controlled CFCs, HCFCs and Halons as global warming gases.

I would like to draw attention to the power of successful multilateral environmental agreements like the Montreal Protocol. The well-coordinated actions by countries to fulfill the

objectives of that agreement go well beyond expectations. This is because I feel that we always underestimate the potential of the technology change that takes place under the policy initiatives. This is exactly what is happening under the Montreal Protocol. I came to the UN from the private sector. I have always seen that industry responds to any change in the policy regime by innovating technologies that can surpass the objectives of the policy change. Such is the supremacy of the technology responses by the private sector.

More importantly, the private sector industries using ozone-depleting substances have done amazing work. They have gone beyond the expectations raised under the Montreal Protocol. In the process of eliminating ozone-depleting substances, enterprises have made a technological evolution to improve the energy efficiency of refrigeration and air conditioning equipment. If we add the benefit of the improved energy efficiency, the related elimination of the CO<sub>2</sub> emissions will be far higher than 8 billion tonnes per annum.

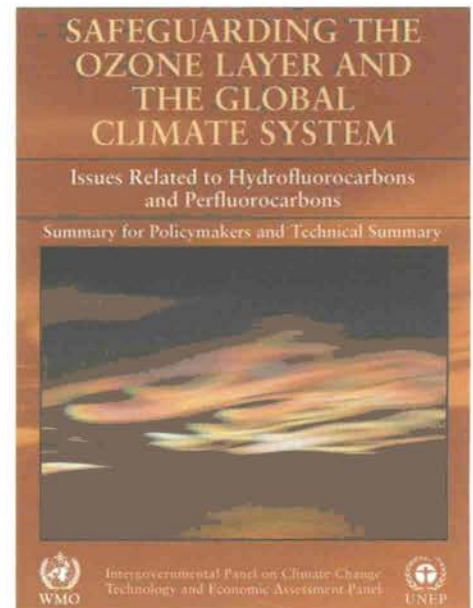
This incredible contribution of the Montreal Protocol to climate change mitigation has not been very well recognized and it deserves more attention.

**You wrote an article recently that has the title “Rich banks and high stocks... but a bleak future for our climate”. What message do you want to convey?**

I wrote that for an article in the IEA’s Heat Pump journal in 2005. I made that statement to draw attention to the very important findings of the IPCC/TEAP Special report on ‘Safeguarding the Ozone Layer and the Global Climate System’. I had the opportunity to be one of the coordinating lead authors. That report indicates the size of the current and future banks of CFCs, HCFCs, and HFCs. Banks are substances that have been produced but not yet released in the atmosphere as they are stored in equipment, stock-piles, captured in foams etc. I was making a play on the words ‘Banks’ and ‘Stocks’. In daily life, a bank is a place where we save our money and stocks mean the options or shares traded in the stock market. When these banks are rich and stocks are high, investors are happy

because they get good returns. But in the case of banks and stocks of CFCs, HCFCs, and HFCs, the situation is alarming and not at all happy for the global environment.

The current banks of CFCs, HCFCs and HFCs are estimated to be equivalent to 21Gt of CO<sub>2</sub>. This is about the same as the amount of CO<sub>2</sub> the entire world emitted in 2002! These stocks will ultimately escape into the atmosphere. I posed a question: Are there major opportunities to redeem this situation? The message in the article stated that “There are!”, but we need concerted efforts, similar to what the world community displayed in implementing the Montreal Protocol. This includes improved containment of substances, reduced charge of substances in the equipment, end-of-cycle recovery and recycling or destruction of substances, increased use of alternative substances with a lower or zero global warming potential, and use of not-in-kind technologies. Of course, recovery, recycling



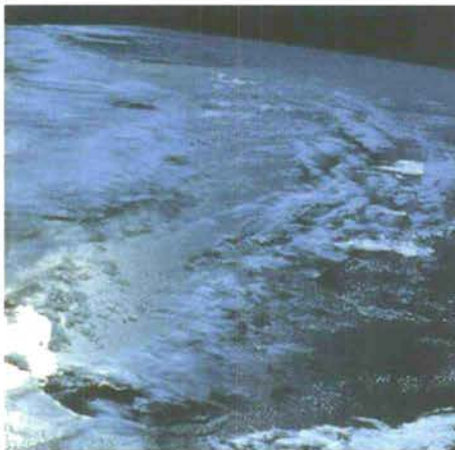
and destruction have associated costs. But environmental benefits could outweigh these costs, and those cost-benefit analyses should be considered.

**What can be done to protect the ozone layer and also mitigate climate change?**

Let me answer that question by giving practical examples: UNEP’s OzonAction has compiled case studies that protect the Ozone Layer and Mitigate climate change. It is

titled as 'Two Challenges: One solution'. But there are number of initiatives that go beyond these case studies:

SolarChill is an innovative global partnership that includes UNEP, UNICEF, WHO, Danish Technological Institute (DTI), Greenpeace, GTZ, Vestfrost, Danfoss and PATH and aims to develop a climate and ozone friendly vaccine cooler. The vaccine cooler is powered by solar energy which will be used in



the compressor of the cooler without using converter and batteries. This product illustrates the utility of the initiative that connects wide-reaching environmental and developmental issues. (see page 17).

Today all the mobile air conditioning systems - "MACs" - in new cars use HFC-134a refrigerants. Enhanced HFC systems can save substantial fuel consumption and also reduce emissions of HFCs. UNEP is working with USEPA, auto manufacturers and EU to benefit developing countries from such technology development. (see page 31).

Another alliance that illustrates the power of partnerships that can find the solutions to the challenging problems of climate change and ozone layer protection is Refrigerants Naturally. The partnership includes the multinational companies Coca Cola, McDonalds and Unilever and it is supported by UNEP and Greenpeace. The partnership is aimed at the food and drink industry - the so-called "point of sale" end of the market which interacts with the customer - and its equipment suppliers to develop the technologies that use non-ODS and non-GHG gases and at the same time improve the energy efficiency of the equipment. Thousands of such equipment are being deployed by

these companies in their worldwide operations. (see page 38).

There are other initiatives like best practices in the containment of HFCs, their recovery and recycling, and policies to support such actions, which would contribute significantly to protect the ozone layer and mitigate climate change.

**Projections show that the ozone layer should recover at around mid-century if implementation of the Montreal Protocol continues as planned. This considerable success to date is often cited as an example of how the developed and developing world can work together to tackle a seemingly insurmountable challenge. How can the climate protection community learn from the partnerships created under the Montreal Protocol?**

Climate change is happening now. The world is already late in taking action to prevent this change. Fortunately, we can take inspiration from the Montreal Protocol's successes to date to contain the impacts of climate change. The Montreal Protocol demonstrates the beneficial influence of the partnerships between the developed and developing countries, between developing countries themselves - "South-South" cooperation - between companies in different countries and between governments, NGOs and the private sector. Such partnerships that have proven so important to the success of the Montreal Protocol can also foster the technology change needed to mitigate climate change.

What we are learning from the Montreal experience is that global participation and binding commitments can spur the technology innovations of diverse types. The refrigeration and air

conditioning industry is the living example where technological breakthroughs have been unparalleled in the last decade. Such technology innovation makes the earlier cost estimates of the implementation of the Protocol appear to have been grossly overestimated. The enterprises in the developed and developing countries that have complied with the Montreal Protocol have all made significant contributions to the environment, and at the same time utilized this as business opportunity to enhance their profitability, expand their operations and diversify their business. This is an important message for the world community which is hesitating to make a concerted commitment for climate change.

Before the Montreal Protocol, the technology transfer regime from the developed to developing countries was quite restrictive. The time lag in the development and the transfer of technology resulted in an unhealthy situation of developing countries receiving outdated technologies. The implementation of the Montreal Protocol has shown that developing countries can be at the cutting edge of the technology transformation. The Montreal Protocol also ushered in a new era of environmental diplomacy, wherein the scientific assessment of the ozone depletion led to the political negotiations to set global actions, by using a precautionary approach. Every action by every stakeholder - including children - counted. Climate change also needs such actions by all stakeholders. Global environmental issues generally need a long time frame to be solved. Hence, sustained actions from generation to generation are needed. This is another message from the Montreal Protocol.



For 30 years, in collaboration with the major Italian Universities, Centro Studi Galileo has been studying in hundreds of courses and conferences the energy efficiency through solar panels



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**Second Session:** New components and equipment in  
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Results and updates in new systems  
**Third Session:** Open discussion on energy and  
environmental issues:  
new fluids and refrigeration technician training with  
reference to new European regulation  
**Fourth Session:** Regulations and training in  
Europe and U.S.  
**Fifth Session:** new control technologies and the cold chain



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**THE PRESIDENTS AND THE DIRECTORS OF THE MAJOR WORLD INSTITUTES AND ASSOCIATIONS  
IN THE LATEST CENTRO STUDI GALILEO EUROPEAN CONFERENCE.**



From the left: Enrico Buoni, the Director of Centro Studi Galileo and Industria & Formazione; Attila Zoltan, the President of HRACA Association (Budapest); Robert Berckmans and Jean Jacquin, respectively Secretary and President of the Air conditioning and Refrigeration European Association (AREA); Alberto Cavallini, University of Padova, Honorary President (already president in the last two periods) of the International Institute of Refrigeration; Francois Billiard Honorary President of the International Institute of Refrigeration; Ronald Vallort, President of the American Society of Heating, Refrigeration and Air conditioning Engineers; Didier Coulomb, Director of the International Institute of Refrigeration; André Gac, Honorary President of the International Institute of Refrigeration; Rajendra Shende, Head OzoneAction Programme, UNEP; Louis Lucas, Honorary President of the International Institute of Refrigeration and President of the French Association of Refrigeration; Marco Buoni, Secretary of Association of Italian Technicians of Refrigeration.

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## WORKING TOGETHER WITH THE MAJOR EXPERTS TOWARDS “THE FUTURE OF REFRIGERATION”: XII EUROPEAN CONFERENCE



Working together with the major experts towards the future of refrigeration: agreement Centro Studi Galileo – UNEP for training, conference and special issue. On the left Marco Buoni, Secretary Italian Association of Refrigeration Technicians and Rajendra Shende, Head OzonAction Programme – UNEP.

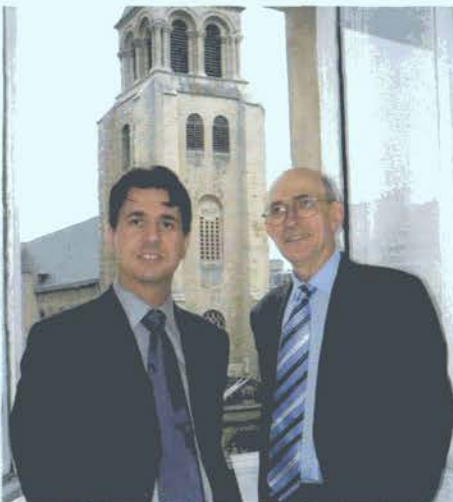
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Office of the United Nations in Paris: from the left Rajendra Shende, Head OzonAction Programme UNEP, Marco Buoni, Secretary Italian Association of Refrigeration Technicians, Enrico Buoni, Director of Centro Studi Galileo, Jim Curlin, Information Manager UNEP.



The XII European Conference about the latest technology in refrigeration and air-conditioning with particular reference to the energy issues will be organized by CSG-ATF and by the United Nations Environmental Programme-UNEP on the 8<sup>th</sup>-9<sup>th</sup> June 2007 in the Politecnico of Milan.



**LOUIS LUCAS**  
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**DIDIER COULOMB**  
IIR Director:  
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**ALBERTO CAVALLINI**  
IIR Honorary President:  
*XII European Conference General Chairman*



**ROBERT BERCKMANS**  
AREA Secretary:  
*Qualification of the refrigeration technicians (page 27)*



**REX BOYNTON**  
NATE Secretary:  
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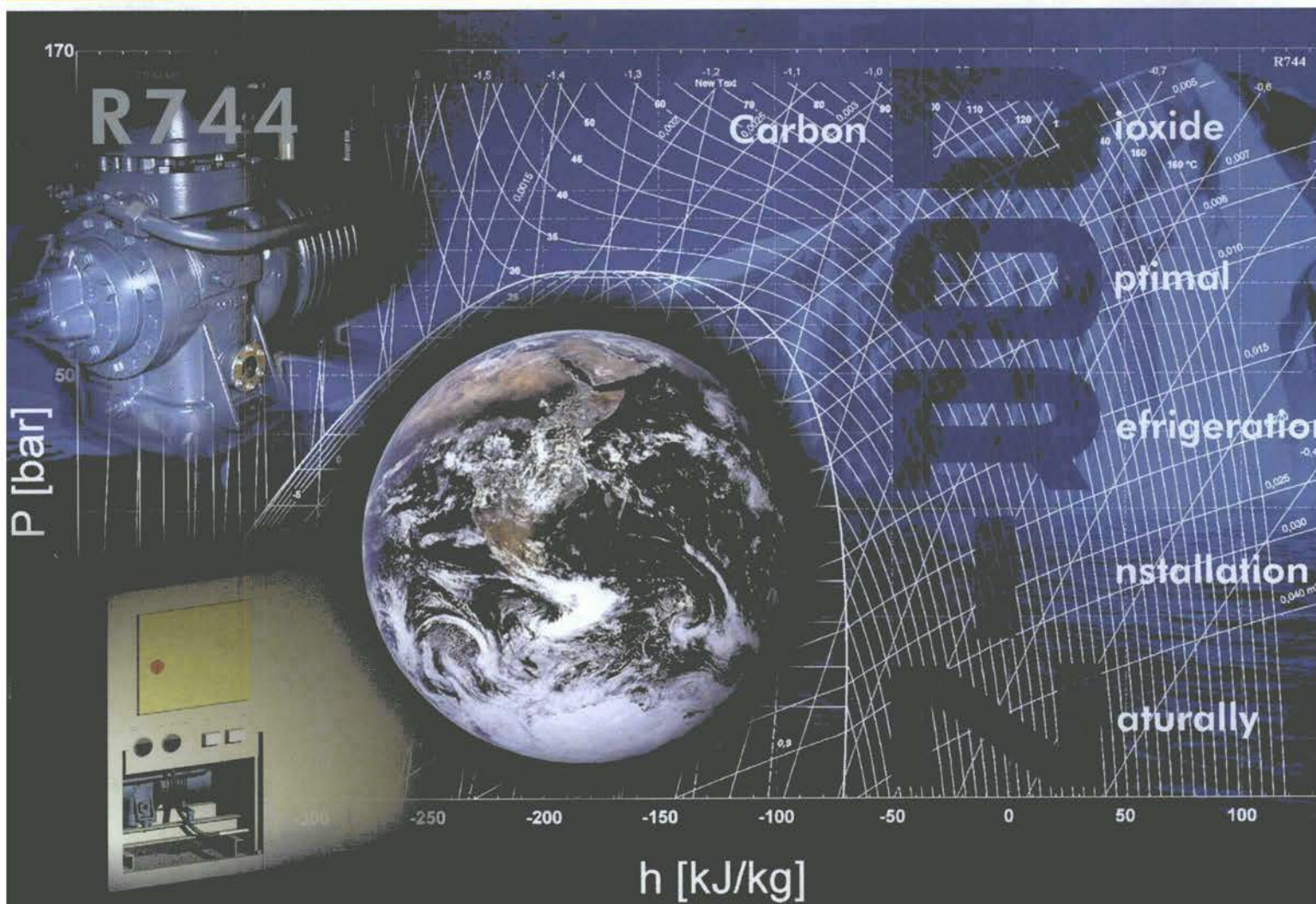


**DENIS CLODIC**  
Deputy Director Ecole des Mines de Paris:  
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## Editorial

# Working together with the major experts towards “the future of refrigeration”: XII European Conference

The world evolves and technology with it, every person needs to adjust adequately to the changing world, and to do that every person needs to be informed of the changes. Today information is much more important than in the past. We get that from many sources, from the internet, from the media etc.. but this is very generic, not specific information. The operators who want or have to contribute to solving environmental issues need to go into further depth. Thanks to the training courses, seminars and European Conferences that Centro Studi Galileo have done since 1975 in the field of refrigeration, air conditioning and heating and new technology, it is possible in the main Italian Universities (Università La Sapienza Roma, Università Milano, Palermo, Sannio, Ancona, Genova, Bari, Perugia, CNR Padova, Politecnico Milano and Torino) and in the other training sites of the Centro Studi Galileo to follow and learn about the new trends in technology, new refrigerants, new way of saving energy and preservation the environment. For 3 generations technicians have attended the courses and more than 2 thousand HVACR (Heating, Ventilation, Air Conditioning and Refrigeration) operators every year come to our standard courses (listed in [www.centrogalileo.it](http://www.centrogalileo.it)) or to the courses we do specifically for each company which asks for a tailored training course. All the most important companies of the world have asked Centro Studi Galileo for training about refrigeration or air conditioning. (To mention a few: Coca Cola, Nato, Royal Air Force, Banca d'Italia, and many more... see more [www.centrogalileo.it](http://www.centrogalileo.it)). With respect to the target of spreading information of Environment and Energy preservation, United Nations and Centro Studi Galileo have concluded in recent months numerous agreements for training, European conferences, and this special number with worldwide distribution of the “Special International Issue”.



In particular **Centro Studi Galileo** and the **United Nations Environment Programme (UNEP)** are cooperating to strengthen the knowledge and skills of refrigeration technicians in new technologies in refrigeration and air conditioning related to energy, the environment (**new refrigerants**) and climate change. The cooperation is structured around 3 points:

- 1) **Training:** organising courses between us specifically for developing countries.
- 2) **Information:** producing a special issue of the magazine *Industria & Formazione* to be delivered to 190 Countries and to the Italian and mainly foreign operators in the field.
- 3) **XII European Conference:** organizing the 8<sup>th</sup>-9<sup>th</sup> June 2007 Politecnico di Milano.

Those agreements allow us to increase the international activity of Centro Studi Galileo and at the same time to increase the service, knowledge and the

information already given to its members, training attendants and all the thousands of companies connected with CSG. The United Nations chose Centro Studi Galileo from among the other European Institutes and organizations: this reflects its links with the Italian Association for the refrigeration technicians - ATF, their magazine with its long experience in this field, its high quality of training and conferences. At the international and Italian level and to provide a good service to the ATF members, many agreements have been made with the most important refrigeration and air conditioning institutes and associations. Thanks to that many interviews have been conducted with some of the most important directors and presidents of various associations of the world, which have also provided papers for this international magazine. Among the international associations that collaborate with Centro Studi Galileo and the **Associazione dei Tecnici Italiani del Freddo (Association of Italian Technicians of Refrigeration)** are the:

- International Institute of Refrigeration IIR (an intergovernmental organization that brings together 61 countries, which represent 80% of the global population),
- AREA (Air Conditioning and Refrigeration European Association),
- AFF (French Association of Refrigeration),
- AICVF (the French Association of Engineers of the Air conditioning, Ventilation and Refrigeration),
- NATE USA (North American Technician Excellence),

These associations/institutes are the most important in the refrigeration and air conditioning field and most of them have contributed to this special international issue.

All those associations and institutes will participate to the **XII European Conference that will be held in Milan on the 8<sup>th</sup>-9<sup>th</sup> June 2007 organized by United Nations Environment Programme - UNEP, Centro Studi Galileo and Associazione dei Tecnici del Freddo about the future of the Technological Innovations in Air Conditioning and Refrigeration, with particular reference to energy optimization, new refrigerants, new regulations.**

**Marco Buoni**

*Secretary Associazione dei Tecnici italiani del Freddo - ATF*

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## Refrigeration: the Challenges associated with Sustainable Development

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*The International Institute of Refrigeration (IIR) is an intergovernmental organization. It brings together 61 countries, which represent 80% of the global population (developed countries, developing countries and countries in transition). The IIR's mission is to promote and disseminate knowledge of refrigeration technology and all its applications. Refrigeration is not only useful for humanity (air conditioning, industrial processes...), but is even vital in several of its applications (food, health...). It is also used in many advanced technologies (space industry, information technology, superconductivity...). Moreover, its use is increasing regularly and will continue to increase in the future. Thus, more than 1 billion domestic refrigerators are currently in operation worldwide, which corresponds to a doubling of the production between 1990 and 2002.*

*However, refrigeration is partially responsible for stratospheric ozone depletion and global warming, because of the release of certain refrigerants used and the energy consumption of refrigerating equipment. The seeking of suitable ways to address the impact of refrigeration on the environment without impeding growth in the sector is the IIR's role.*

### THE ROLE OF THE REFRIGERANTS

Most existing refrigerating equipment is based on the compression and expansion of a refrigerant. The efficiency of the system and its application at the desired refrigerating temperature are closely related to the thermo physical properties of the refrigerant in question. Many different refrigerants have been and are still used worldwide, and meet the needs dictated by various applications, and the investment and operating costs differ.

Because of their thermophysical properties and ease of use, chlorofluorocarbons (CFCs) were the most widely used refrigerants up until the 1980s. However, it was demonstrated that CFCs were contributing to the depletion of the stratospheric ozone layer and global warming (being greenhouse gases), where containment and recovery following use are not addressed correctly. Refrigerant leakage of up to 15% per year in commercial refrigeration plants is by no means rare, and leakage varies greatly from one system to another.

It clearly shows the necessity to consider differently the sectors of application:

- commercial refrigeration and mobile air conditioning: an effort on the reduction of leakages, (good practices and use of secondary fluids) and the replacement of refrigerants are clearly necessary and possible (see hereafter).
- stationary air conditioning and other

uses : even if the same efforts can be conducted, we have to first consider the consumption of energy (global energy system of a building..) regarding its role in global warming.

CFCs have been gradually replaced by hydro chlorofluorocarbons (HCFCs) that have less impact on ozone depletion and global warming.

CFCs and HCFCs will be phased out within the framework of the Montreal Protocol: CFCs have already been banned in non-Article 5 countries, i.e. developed countries and most transition countries and will be banned in developing countries as of 2010. HCFCs will be banned in 2030 and 2040 respectively, but Europe (European regulation 2037-2000) has decided a ban by 2015 at the latest, and perhaps as of 2012. The USA, Canada, Japan, Australia will also abandon HCFCs before the date of 2030. With the entry into force of the Kyoto Protocol, the phase-out schedules will undoubtedly become more stringent. However, most refrigerating equipment in developing countries runs on CFCs or HCFCs. Replacement with other refrigerants require more investment. CFC's are then going to be replaced almost only by HCFC's in developing countries.

These other refrigerants include hydrofluorocarbons (HFCs), which have only a global-warming impact, and natural refrigerants (ammonia, CO<sub>2</sub>, hydrocarbons), with negligible or no impact on global warming.

Technologies other than refrigerant-compression technology can also be

used but still need further developments: magnetic refrigeration, absorption/adsorption, solar refrigeration.... Whatever option is adopted, it will involve investment in containment and safety, improved maintenance and higher qualification levels of practitioners. These changes will only be of value if they are linked to energy savings.

## THE ENERGY CONSUMPTION

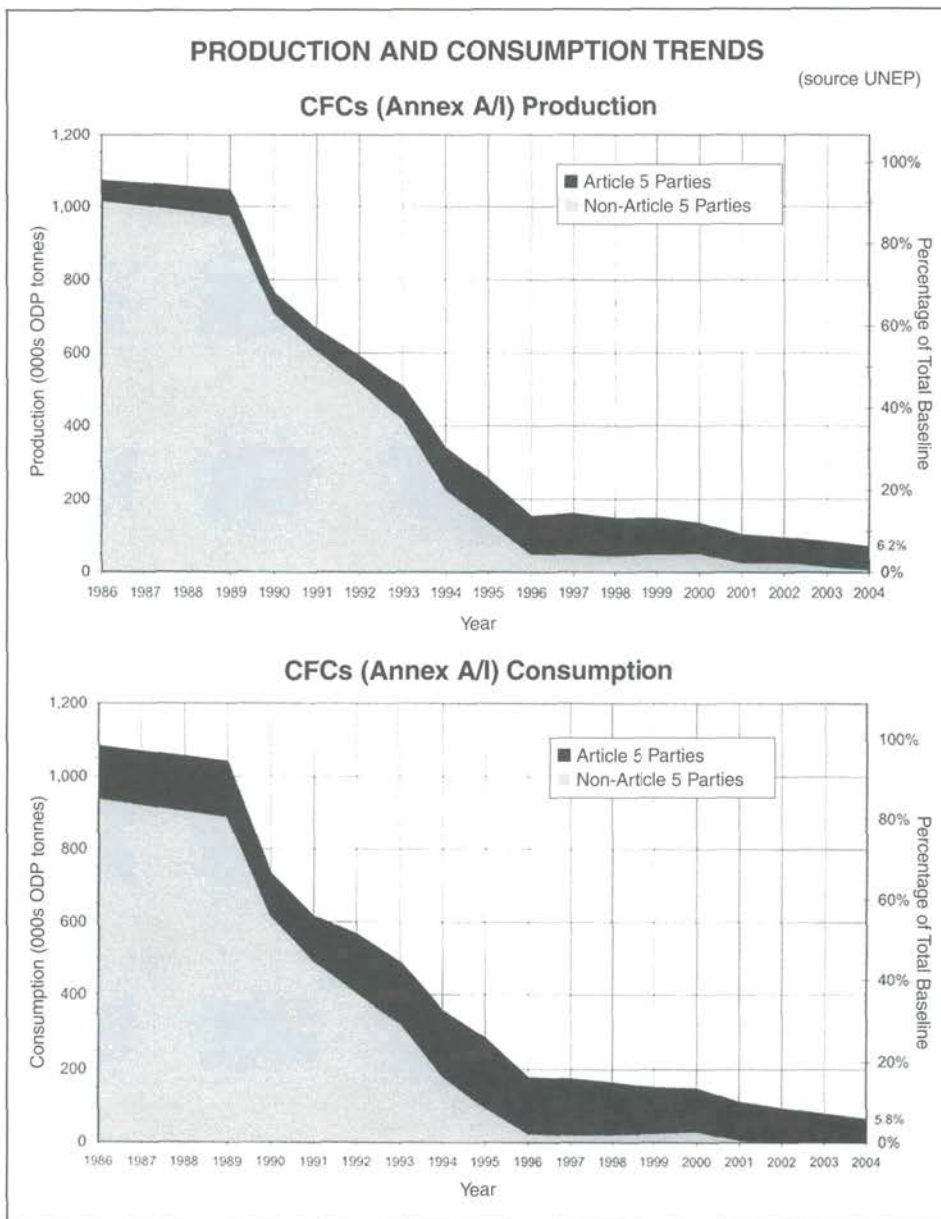
Eighty percent of the global-warming impact of refrigeration plants is due to energy consumption, not to refrigerant leakage. Refrigeration consumes about 15% of all electricity consumed worldwide, and the latter is mostly produced using fossil fuels (coal, oil and gas). Reducing the energy consumption of refrigerating equipment must become a key environmental priority throughout the sector. Energy costs will continue to rise in the future because of dwindling oil reserves.

The energy consumption is a global problem. It concerns all the applications of refrigeration and we therefore have to focus our efforts on that. But it would not be enough efficient if we do not consider the whole systems where we live.

The transport sector is one of the main energy users and consequently one of the main responsible of the production of greenhouse gases, essentially CO<sub>2</sub>. Regulations on this sector will be implemented. The refrigerated transport clearly depends on the development of the different kinds of transport and mobile air conditioning on the conception of the vehicles.

The energy consumption of the buildings is the other main sector with the industry. The impact on global warming from the domestic refrigeration and the air-conditioning depends on the kind of energy we use (electricity produced by fossil fuels or not) and on the conception of the building (ventilation, heating,...). The concept of sustainable or green buildings has appeared: energy-efficient-design, construction, maintenance. Global solutions like heat pumps are encouraged.

Moreover, the education of the people, its awareness on energy consumption is one of the key issues to permit energy savings and then a less important global warming impact.



## THE ACTIONS

Much work has already been undertaken to reduce the impact due to emissions, in particular following the Montreal Protocol on ozone depletion. The refrigeration community and the IIR proved their efficiency in this context. But much still remains to be done, particularly in the area of fluid containment.

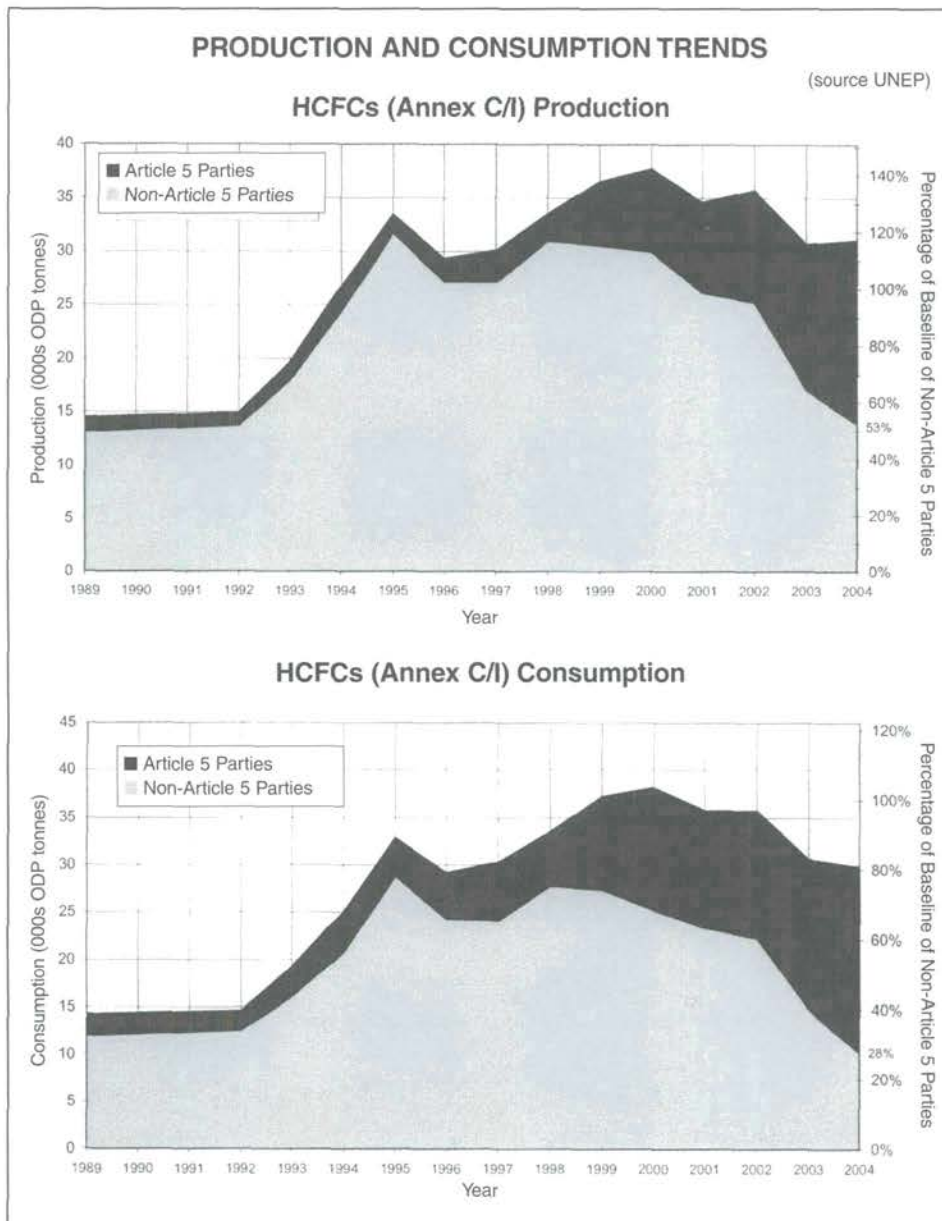
The IIR is pleased with the position of the European Union concerning the F-gas Regulation which should enter into force in 2007: this position places the emphasis on controls for leakage and training and certification of those who handle refrigerants. It also gives limits to the global warming impact of refrigerants which can be used (in the case of mobile air conditioning) without arbi-

trarily choosing one of them, giving place for better solutions thanks to new technological developments.

With regards to reducing energy consumption, which has 4 times the impact of emissions, the challenge is still ahead of us. Hence, it is necessary to set ambitious goals. The IIR - as early as 2000 in The Hague (COP-6) - set the objective: reducing the unitary energy consumption of refrigerating plants by 30-50% - according to applications - by 2020.

It is necessary:

- to further promote research and development in the field of natural refrigerants, in order to ensure that in the near future these refrigerants will become the refrigerants of choice in various refrigeration applications;
- to promote, on a per-application



basis, the most environmentally friendly option (HFC or natural refrigerant) on the basis of an objective reference taking into account the total climate impact i.e. not only emissions but also energy consumption; this reference, encompassing the energy efficiency of plants, should be codified and standardized;

- to continue to phase out CFCs and HCFCs: these refrigerants exert both ozone-depleting and global-warming effects. In developing countries or countries in transition, it would be better to replace CFCs directly with HFCs or natural refrigerants and not with HCFC's.

The IIR, faced with this challenge, is undertaking a number of actions:

- the IIR takes part in international meetings on the Montreal and Kyoto Protocols, thanks to its intergovern-

mental status. The IIR established a list of research priorities, with a focus on environment and energy efficiency;

- the IIR holds targeted scientific and technical conferences on possible technological solutions: Gustav Lorentzen conferences on natural working fluids (the next one in the series will be held in Denmark in September 2008 (Scandinavian countries are particularly involved in natural refrigerants, as Gustav Lorentzen himself did), conferences on ammonia (the next one in the series will be held in Macedonia in April 2007 (ammonia is still a widely used refrigerant in Eastern Europe)...

The next IIR International Congress of Refrigeration will be held in Beijing, China, (one of the most producers and users of refrigerating equipments now) in August 2007 (Web site:

[www.icr2007.org](http://www.icr2007.org)) and will include environmental sessions jointly organized with UNEP (United Nations Environment Programme) and IEA (International Energy Agency);

- the IIR publishes books, courses, manuals and Informatory Notes on the environment. It is currently preparing a new edition of its Guide on Energy Savings in Refrigeration and Air conditioning in order to address all recent and current developments in this field, in the context of climate change and rising energy costs. It published in 2004 an Informatory Note entitled "How to improve energy efficiency in refrigeration equipment" and will soon publish an Informatory Note on Liquefied Natural Gases.
- the IIR publishes articles in its journals, particularly in the International Journal of Refrigeration, which is the best scientific journal in engineering and transfer processes for refrigeration. FRIDOC, the IIR's worldwide database, is the largest one in the refrigeration-technology field. It contains over 76.000 references.

## CONCLUSION

Refrigeration is vital to human health, particularly because of its role in the food field. Its use will continue to expand but will have to comply with increasingly stringent health and environmental constraints. These constraints will take the form of more numerous stringent regulations and objectives in terms of efficiency and reliability, and are made all the more necessary by scientific and technical progress, quality improvement and sharing of reliable, homogeneous information worldwide.

The International Institute of Refrigeration is in an excellent position, thanks to its intergovernmental status, its expertise and its international network composed of persons in the public and private sectors, to address these challenges.

Please feel free to find out more about the IIR, and if you are not already a member I hope you will join us - check out the IIR's Web site: [www.iifir.org](http://www.iifir.org)



## Using Refrigeration Equipment when facing Climate Change. French Experience

LOUIS LUCAS

President of Association Française du Froid - AFF

*During the last two decades of the 20th century, both the consequences of human activity on the future of our planet and the need for international measures to limit these changes were highlighted.*

*The depletion of stratospheric ozone was the first example of such measures: the handling of the Montreal Protocol (1987) has showed the possibility to plan and to adopt global measures and has showed some efficiency. The Global Warming is the following case.*

*At the Johannesburg meeting in 2000, the International Institute of Refrigeration submitted, in its capacity as an Intergovernmental Organisation, a report on the role of the Refrigeration Industry in fighting the climate change.*

*This article aims to show a few aspects of the French experience in the field of the various uses of refrigeration, a sector that had already had some experience with the Montreal Protocol when the Kyoto Protocol was prepared.*

### 1) WHAT IS AT STAKE ?

The IPCC (International Panel on Climate Change) has established a scientific base for global decisions; concerning the role of human activity and, first of all, the consequences of burning fossil fuel and coal on the climate:

In 1992: their influence is possible

In 1995: their influence is likely

In 2001: their influence is most likely

The preparation of the next report (to be published in 2007) confirms this tendency:

although, it is not possible yet to know whether the frequency of storms or hurricanes is influenced or not by climate change, it is indubitable that the average global temperature has been rising steadily during the last century as has the average sea level (figures differ from one place to another; in France, the average temperature rose by between 1 °C and 1,2 °C between 1901 and 2000).

These rates are significantly higher than any such rates reported in the past.

The last decade for example is the warmest on record for the whole millennium.

For the future, depending on the hypotheses and models, the figures differ, but, in any case, acting "as usual" would lead to huge changes in the climate that would deeply disturb a lot of inhabited areas:

- a global average temperature rise of 1,5 to 6 °C by the end of the XXIst century (when the difference between ice periods and inter-iceperiods was

about 6 °C);

- sea level rise of 0,30 to 0,40 cm by the end of the century .

Measures such as those that have been taken until now are not even able to prevent the dramatic consequences that are foreseen for the next decades. In particular, the measures proposed by the Kyoto Protocol are necessary but are far from sufficient.

### 2) IN FRANCE

#### a) Fossil energy consumption is relatively low

In France, 78% of electric power (i.e. 33% of total energy consumption) comes from nuclear plants. This situation places France as one of the developed countries with the lowest consumption of fossil energy and the lowest contribution to global warming, with Sweden, Norway and Switzerland.

#### b) But a strong political commitment

In spite of that, our country has strongly committed itself to decrease our contribution to the climate change. Public opinion was made aware of the situation by the very hot summer of 2003. The heat wave caused the death of several thousands of elderly people: such high temperatures for several weeks are unusual. They were not likely to last so long.

This event confirmed the country in its decision to act.

- France has been in favor of international decisions on this matter. In particular, it backed the European decision

to comply with the targets of the Kyoto Protocol whichever countries ratify the Protocol, i.e. whether it be enforceable or not, decision that led to the regulation of Sept. 27 2001 and several legal texts of April 8, 2002.

It was also among those countries that encouraged Russia to ratify the Kyoto Protocol, a decision which made it enforceable.

- On the domestic front, France decided to anticipate the targets of the EU in several areas, with the programme-law of July 13 2005. For instance, the deadline for bio fuel to represent 5,75% of the fuel in France is set for 2008, two years earlier than in the EU).

In 2004 a "Climate Plan" was launched with special decisions concerning housing and transport, two sectors where energy demand has been rising. The plans aim for a strong decrease in CO<sub>2</sub> emissions by 2050: the plan is named after its target: "factor 4", i.e. 4 times less CO<sub>2</sub> emissions in 2040 than in 1990.

### **3) CONSEQUENCES ON PROFESSIONAL PRACTICES**

After the signature of the Montreal Protocol related to stratospheric ozone, France was among the first countries which adopted measures to encourage the confinement and recovery of refrigerants, with a decree of 1992, modified in 1998.

Most of its articles were included in the European regulation 2037/2000 adopted in 2000.

These dispositions have proved to be very useful in limiting global warming too. Consequently they have been included in the regulation on global warming and fluorinated gases that was published in May 2006 (f-gases).

Nevertheless, this regulation deals only with "direct global warming", i.e. that which results from gas release into the atmosphere, an event that regulations prevent. It does not take into consideration CO<sub>2</sub> emissions that result necessarily from the running of the equipment although these may represent most of the global warming emissions related to the system. (In the case of a domestic refrigerator running with R134a, in the total global warming effect, the "indirect effect" (resulting

from energy consumption) is as high as 95% of the total, reaching almost 100% when the refrigerator runs on hydrocarbons, which has become the most common case!)

It would be counterproductive to save (possible) direct emissions in a way that would lead to much higher "indirect CO<sub>2</sub> emissions".

Whereas limiting direct emissions requires changes in professional practices, limiting indirect emissions may require significant changes in social and economic habits.

### **4) CHANGES IN SOCIAL AND ECONOMIC HABITS**

#### **a) How to be cautious about saving energy**

Methods such as TEWI or life cycle analysis are based on statistical data for how consumers use equipment. The energy consumption of a piece of equipment depends on how it is used: everyone can observe this fact with their domestic refrigerator. It is obvious also with air conditioners. Few final users are aware of their responsibility in this.

#### **b) How to set standards and setting points**

If individuals can use equipment in different ways, thus saving or wasting energy, the same difference applies to large systems: air conditioning systems will consume more energy in summer with a setting point at 19 °C than at 20 or 21 °C. Why do so many people set the temperature control for heating at 22 °C in winter so that you can live in shirt sleeves and at 19 °C or even 18 °C in summer so that you may have to wear a sweater? Humidity control is often the cause of low control temperatures in summer but there are less expensive ways of tackling the problem.

#### **c) Measures able to decrease the need for refrigeration**

Architecture is responsible for a large part of heating and cooling costs in any building: glazed facades are very fashionable in spite of the high energy consumption. The Museum of the Arabic World in Paris was built with automatic systems inspired by musharabieh that

shade more or less of the surface of each square metre of the façade depending on incidental light. Such systems are quite anecdotic and very expensive. But shading systems and a right orientation of the facades and openings can save a lot of energy as well as making the inhabitants more comfortable in the premises.

The same kind of remark applies to car design.

In France, a recent decree made it compulsory to get an energy diagnosis of any building when is sold.

#### **d) How to use refrigeration technologies to decrease energy consumption in heating?**

Heats pumps have been known for a long time as a way to use less energy for heating. Countries like Austria, Switzerland and Sweden, have been pioneers in this. France has not been so active in promoting that technology. But since 2006, heating systems with heat-pumps are taken into account to decrease income taxes.

In fact, using such systems has proved rather difficult: their design, handling and maintenance is complicated for technicians who know little about thermodynamics. In addition, their efficiency decreases when temperature differences grow; consequently, the energy savings that they allow are much lower when they are strongly needed, in cold winters or hot summers! Nevertheless, with good technicians, they represent a valuable way to decrease CO<sub>2</sub> emissions.

\* \* \*

Human activity inevitably leads to increasing global warming. This article has raised some points in relation with refrigeration; many similar examples exist in other areas, let's only think about transportation and city design! Standards and regulations can limit this move. But individual behavior is a major component of the result. In France, a governmental agency (ADEME) has launched a widespread campaign "Faisons vite, ça chauffe" (Let's go quickly; it's warming!). In order to face this problem efficiently, technology is not sufficient. Political decisions are necessary; they suppose a real concern among public opinion.





## SolarChill Vaccine Cooler and Refrigerator: A Breakthrough Technology

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*The SolarChill Vaccine Cooler and Refrigerator exemplifies the proverb, “necessity is the mother of invention.” Like many inventions, the origin of SolarChill was happenstance. Serendipity is the word! During the Meeting of the Parties to the Montreal Protocol in 2000 in Ouagadougou, some delegates participated in a field visit that took them through the Burkina Faso countryside. While watching rural villages pass by their bus window, the Head of the United Nations Environment Programme (UNEP) OzonAction Programme and the Greenpeace representative noticed that the communities appeared to be financially poor but rich in two key elements: children, the wealth of the country, and sunlight, a limitless energy source if it could be tapped. Matching these two elements, and linking them to the future of refrigeration relative to the controls of the Montreal and Kyoto Protocols, UNEP and Greenpeace grasped the need for a vaccine cooler that could meet public health requirements in developing countries - notably vaccine preservation for use in childhood immunization campaigns - but which was designed to be both environmentally-friendly and able to use “off-grid” alternative energy sources such as solar. Independently, the Danish Technological Institute (DTI) had also started to think along similar lines.*

What started as an idea became an investigation of possibilities and finally transformed into action through partnership. Thus was born SolarChill. Africa is the origin of humanity. So also that of SolarChill!

SolarChill aims to deliver environmentally-sustainable vaccine and food refrigeration to regions of the world that lack electricity or have inadequate electrical supply. SolarChill thus bridges health, development and environment. The Project has evolved into a unique partnership between seven international organizations, which today comprises DTI, German Government Development Agency GTZ ProKlima, Greenpeace International, Programs for Appropriate Technologies in Health (PATH), UNEP, United Nations Children’s Fund (UNICEF) and the World Health Organization (WHO).

During the six-year R&D phase, the SolarChill Project also involved the participation of industry, primarily the Danfoss and Vestfrost companies. However, the SolarChill Partners do not endorse the products of any one company and the design and the basic technical principles of SolarChill will be made freely available to manufacturers worldwide.

At the present, most parts of the world that are without reliable electrical supply use kerosene or gas-powered absorption refrigerated coolers for both vaccine storage and household applications. Such coolers need a regular supply of fuel. Furthermore, they are often difficult to adjust and are thus problematic with regards to maintaining

the required temperatures.

The SolarChill Project has developed two models of a breakthrough refrigeration technology that is environmentally sound, can be powered by solar as well as DC or AC current, uses no lead batteries, has been tested to be technologically reliable, and most importantly, is possible to be manufactured at substantially lower cost than other solar refrigerators on the market. The first model of SolarChill (“Model A”) is for medicine and vaccine cooling. The second (“Model B”) is for food preservation as well as for some medical applications.

**Keeping Vaccines Safe:** SolarChill A is a 50 litre, chest cabinet, vaccine cooler. Designed for regions with inadequate electrical supply it is also applicable for emergency situations arising from natural or man-made disasters.

Providing a secure “cold chain” for vaccines and medicines remains problematic in many countries. The term “cold chain” refers to the cooling network that is required to safely deliver vaccines from the manufacturer to the recipient. The “cold chain” is only as reliable as its weakest link, and all too often that weak link is either the lack of reliable electrical supply or reliable vaccine coolers. Many millions of dollars worth of vaccines freeze or spoil each year because of an inadequate cold chain. The SolarChill Vaccine Cooler has been field tested and optimised over 18 months in Senegal, Indonesia and Cuba. The Project is now confident that the cooler is superior in performance and reliability to other existing solar or

## SolarChill's Contribution to the Millennium Development Goals

At the United Nations Millennium Summit, world leaders agreed to a set of time-bound and measurable goals for combating poverty, hunger, disease, illiteracy, environmental degradation and discrimination against women. Placed at the heart of the global agenda, they are now called the Millennium Development Goals (MDGs). The Partners have approached the SolarChill in the spirit of translating the MDG promises into action. The Project simultaneously addresses multiple MDGs:

- Goal 4: *Reduce child mortality*. By contributing to vaccine preservation in developing countries, SolarChill will help realise the goal of reducing by two thirds the mortality of children under five.
- Goal 7: *Ensure environmental sustainability*. By avoiding ozone depleting substances and significantly reducing greenhouse gas emissions, SolarChill units contribute to the long-term improvement of our global environment.
- Goal 8: *Develop a global partnership for development*. SolarChill has been developed by a unique public-private partnership that is making the benefits of new technologies available in the public domain.

kerosene vaccine coolers.

SolarChill A holds vaccine temperatures between the required 2 °C and 8 °C during typical day-night solar cycles. In low-sun situations SolarChill maintains acceptable temperatures below 15 °C for 5 days.

Compared to other vaccine coolers, SolarChill significantly supercedes the time the cooler maintains the required temperatures for keeping vaccines safe, even while not plugged into a grid, or in the absence of sunlight. This feat is achieved with super thick insulation. The SolarChill Vaccine Cooler is presently awaiting approval and certification from WHO which is a prerequisite for governmental procurement of all vaccine coolers. It is expected that upon receiving WHO certification the SolarChill vaccine cooler will be commercialised.

**Food Preservation:** The second SolarChill is a 100 liter upright freezer cabinet modified to be a food refrigerator. This prototype is currently undergoing field tests in India and Cuba. SolarChill B will be useful for hot climates where food preservation is especially challenging. It can also be utilized in emergency circumstances, refugee camps, rural blood banks, small scale commercial applications (e.g. grocery stores) in developing countries, and for off-the-grid recreational cottages in industrialized countries.

**SolarChill Design:** Both SolarChill models operate on the same principles and design. Energy, from three 60 W

solar panels, runs a direct current compressor, which enables the cooler to produce an ice bank that maintains the required temperature in the cabinet. Instead of storing energy in difficult-to-maintain and dispose-of lead batteries, the power of the sun is thus stored in an "ice battery".

Adding versatility in power sources, a converter can be installed so that the unit can run on both 12 V DC and 110/220 V AC current. Thick insulation ensures that the required temperatures are maintained overnight and during periods of low sunlight.

### Environmental benefits of SolarChill

**Ozone depletion:** SolarChill uses isobutane for the refrigerant and cyclopentane as the foaming agent. Both of these chemicals are harmless to the Earth's ozone layer. SolarChill technology helps developing countries avoid prolonged dependence on CFCs for servicing requirements and contributes to compliance with the Montreal Protocol.

"SolarChill technology eliminates the use of kerosene and with it, the associated CO<sub>2</sub> emissions. SolarChill vaccine coolers are well poised to replace the global fleet of approximately 100,000 kerosene vaccine coolers currently in use. SolarChill also avoids the use of HFCs, potent global warming substances commonly used in insulation foam and the refrigerant cycle.

The isobutane and cyclopentane in SolarChill have negligible global warm-

ing potentials. HFCs are controlled in a "basket of gases" under the Kyoto Protocol."

**Toxic metals:** SolarChill bypasses the use of expensive and toxic lead batteries that are currently a standard in other solar refrigerators and vaccine coolers. Lead batteries tend to deteriorate, especially in hot climates, and they are often misused for other purposes. They often require replacement with proper end-of-life management and have been a major obstacle in the uptake of solar power in developing countries.

**Costs:** SolarChill is expected to cost significantly less than existing solar refrigerators, once commercialised. The projected price, including solar panels, is US\$1,500-\$2,000. The reduced cost is achieved through the use of mass-produced freezer cabinets. In contrast, other solar vaccine coolers are custom made and therefore significantly more expensive.

SolarChill also compares favorably in cost to kerosene refrigerators. Though the purchase price is higher, because of the cost of the solar panels, the operating costs are much less as the need to regularly refuel kerosene is eliminated.

**Paradigm Shift:** SolarChill demonstrates in a very practical and vivid manner the possibility of meeting human needs with environmentally sustainable technologies. It can perhaps lead to a paradigm shift in refrigeration and inspire the world to adopt refrigeration and cooling methods that rely on renewable energy sources along with non-polluting technologies and materials.

### The basic technology of the SolarChill Vaccine Cooler

The core challenge for the SolarChill Project was to develop a vaccine cooler that meets the current WHO requirements for solar vaccine coolers with battery back-up. Currently there are no standards in place for solar coolers without batteries. According to current guidelines the design temperature interval for vaccines is + 2 °C to + 8 °C. The vaccine must also be kept cool for four days without power. The required hold over time determines the sizing criteria for the ice storage in the cooler.

### Specific energy of ice storage

Calculations made by DTI indicate that the cooling capacity, based on both volume and weight, in the ice storage is at similar levels to those in a lead battery. In reality, the ice storage outperforms the lead-acid battery, because the allowed daily cycling is less than the nominal energy storage, which corresponds to 100% depth of discharge.

### Compressor and controls

A new compressor was developed during the Project's R&D phase. The new compressor uses R600a (isobutane) and is equipped with an integrated electronic control, which ensures that

from the solar panels is sufficient, the compressor will start at low speed and slowly speed up again. The controller accepts a voltage between 10 and 45 V. The voltage from solar panels can vary, so this new feature is good for solar powered refrigerators and freezers. On a 12 V module, the compressor needs a current of about 4.5 A to start, and it can run continuously at 2 A.

### Cabinets

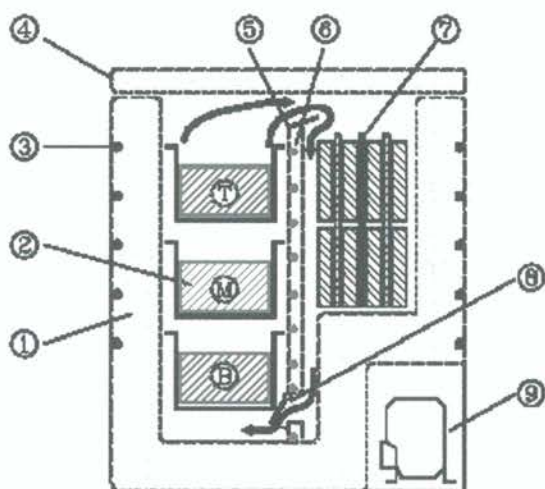
The vaccine cooler cabinet used for the prototypes was built by Vestfrost. It is a highly insulated, standard chest freezer cabinet. The SolarChill Project ran computer simulations that determined

ment gets too cold during the daytime, a small electrical heating element keeps the vaccine above freezing temperature. A thermostat controls the heater. At night the vaccine is kept cool by natural convection from the ice department.

### Conclusion

The SolarChill Partners expect that the technology will be available for release in the public domain in 2007. The Partners welcome inquiries from refrigerator manufacturers worldwide who are interested in using this innovative technology. The Partners also invite organizations that would consider pro-

Diagram of basic concept for the vaccine cooler



1. Cabinet wall with 100 mm of insulation (made by Vestfrost)
2. Vaccine packages (in three baskets)
3. Integrated condenser
4. Lid (also 100 mm insulation)
5. Internal wall, insulated
6. Electric heating element, thermostat controlled by temperature in the bottom of the box
7. Evaporator (wire on tube) and ice packs
8. Self-acting damper
9. Compressor (made by Danfoss Compressors)



Photo1: Prototype of vaccine cooler. The vaccine will be placed in three baskets, placed vertical in the left side of the cabinet. The ice storage is placed under the blue lid in the right side of the photo. The compressor is placed in a room under the ice storage.

photovoltaic solar panels can be connected directly to the compressor without an external control.

The compressor is able to smooth start at low speed and is equipped with an adaptive energy optimizer (AEO-control). By using this control, the compressor will slowly speed up from minimum to maximum speed (from 2000 to 3500 RPM). If the panels can not provide sufficient power, the compressor will stop and after a short while it will try to start again. If the start fails, the compressor will try to start again after another one minute. Once the power

that the most efficient mass-produced cabinets on the market for the purpose of vaccine cooling were the chest freezer types with 100 mm polyurethane insulation.

The net volume of the vaccine compartment is about 50 litres. The compartment is separated from the ice storage. Approximately 18 kg of ice is stored in a number of standard plastic containers.

The evaporator is integrated into the ice storage. During daytime, forced convection cools the vaccine. When the temperature in the vaccine compart-

ment of SolarChill vaccine coolers - e.g. health care companies, government health agencies, private foundations, NGOs - to learn more about the effectiveness and benefits of this environmentally-friendly health care solution. For further information, please visit [www.solarchill.org](http://www.solarchill.org)

The President of India has agreed to install the SolarChill vaccine cooler in the Presidential Estate of New Delhi called "Rashtrapati Bhavan". It will be placed in the clinic for live trials from November 2006 onwards.



## The environmental impact of refrigerants

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*The world of refrigeration and air conditioning has undertaken a huge process of transformation in the last 15 years due to the necessity to substitute the traditional chlorinated refrigerants with alternative environmentally benign substances. This process began with the ban of CFCs, as stated by the Montreal Protocol and its amendments, to overcome the problem of stratospheric ozone depletion. But it is still underway due to the arising awareness of the dangerous effects of global warming caused, amongst other fluids, by the HFCs, the most important alternative refrigerants, which are among the substances controlled by the Kyoto Protocol. Moreover, ozone depletion and global warming are connected each other: for example, not only ozone is a greenhouse gas, but changes in climate could impact ozone in a number of different ways. Though the scientific issues are complex, it is then necessary to understand these processes and their connections to properly address the technical and political choices to insure a sustainable future to the Earth. In this paper, an analysis of the scientific basis and the still unsolved issues will be presented. In particular, the mechanisms of ozone depletion and global warming will be described, and the necessity to contain the refrigerants emissions and improve the energetic efficiency will be pointed out.*

### THE DEPLETION OF THE OZONE LAYER

Ozone is a gas formed by three atoms of oxygen ( $O_3$ ) that is naturally present in the Earth's atmosphere. Roughly the 90% of atmospheric ozone is in the stratosphere, the layer of atmosphere situated between around 10 to 50 km altitude, where it forms the so called "ozone layer". The remaining 10% is in the troposphere, the lowest region of the atmosphere. The distribution of natural ozone is shown in figure 1.

The stratospheric ozone layer has the essential function of absorbing the ultraviolet radiation (UV-B) coming from the Sun, reducing the risks of skin cancer, cataracts and depression of the immune system for human beings due to exposure to UV-B.

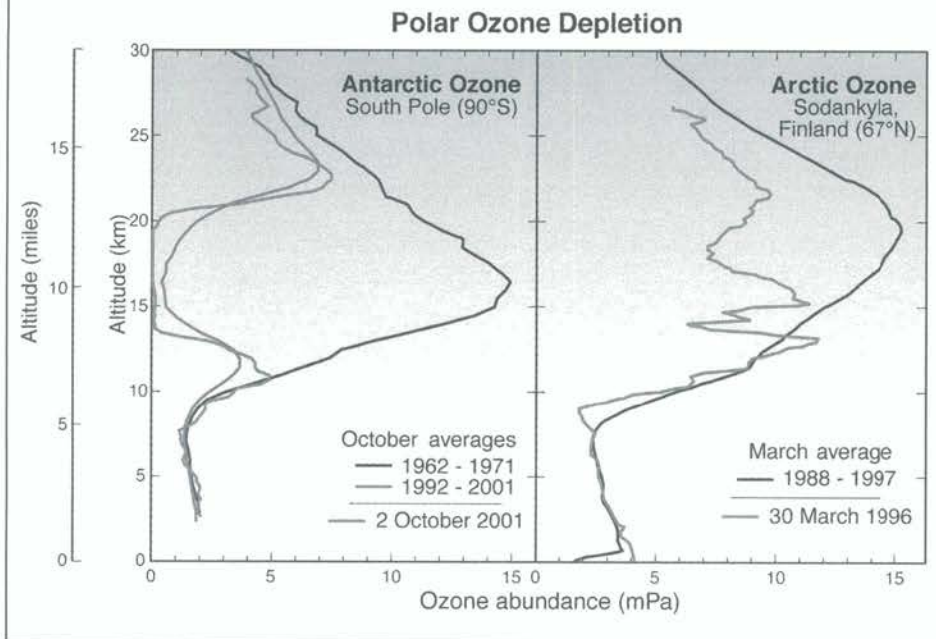
In the 1970s, the studies on the stratospheric ozone layer of dr. Molina and dr. Rowland established that the synthetic chlorofluorocarbons (CFCs) constitute a considerable risk to the ozone layer. At the beginning of the 1980s, these studies were confirmed by the observation that the ozone layer began to lessen, reducing till its disappearance in a stratospheric zone over the Antarctica, forming the so called "ozone hole" (figure.1).

In fact, the emissions of ozone depleting substances (ODSs) containing chlorine and bromine by human activities or by natural processes, like volcanic eruptions, are the main responsible of the ozone hole. These gases are very stable and then can be trans-

ported up into the atmosphere during their long life cycle. Here they can accumulate and can be carried by the air winds to the stratosphere. The ultraviolet radiation of the Sun converts the halogenated gases in highly reactive gases, i.e. hydrogen chloride (HCl), chlorine monoxide (ClO) and bromine monoxide (BrO). These gases react with the stratospheric ozone causing its depletion, mainly following three cycles of reactions, shown in figure 2, where chlorine and bromine act as catalysts. Cycle 1 is typical in stratospheric regions at tropical or middle latitudes, since ultraviolet radiations from the Sun are more intense and can form atomic oxygen (O) reacting with  $O_3$  and  $O_2$ . Cycles 2 and 3 occur in polar regions of the stratosphere, where ClO or BrO concentrations are higher. In winter and at very low temperatures, the polar stratospheric clouds greatly enhance the formation of ClO that can enter in the cycles of the ozone destruction in spring, when the Sun ultraviolet radiations activate the reactions. Moreover, the air winds at the poles isolate air in the polar stratospheric regions, trapping the chemical substances and enhancing the reactions. The "ozone hole" is particularly present in the Antarctica, where the weather conditions facilitate these reactions, as shown in figure 1.

The depletion of the ozone layer caused by a chemical compound is a function of its chemico-physical characteristics, interaction with the atmosphere and lifetime. The most used index to evaluate the effect of a com-

Figure 1.  
Ozone distribution in the Antarctica and the Artic. Source [1]



pound on the ozone layer is the ODP (Ozone Depletion Potential). It represents the amount of ozone destroyed by a gas emission over its entire atmospheric lifetime, relatively to that due to the emission of the same mass of trichlorofluoromethane (R11) [2]. Table 1 summarizes the ODP for the most common refrigerants [3-4].

The first step in the prevention of the negative environmental effects of the ozone-depleting gases was the "Montreal Protocol on substances that Deplete the Ozone Layer", signed in 1987, followed by its subsequent Amendments, i.e. the London Amendment (1990), the Copenhagen Amendment (1992), the Montreal Amendment (1997) and the Beijing Amendment (1999) [3], where the reduction or the phase-out of the production and consumption of the chlorinated and brominated gases were scheduled. In particular, these protocol and amendments issued the phase out of CFCs in the developed countries by 1996 and, with respect to the 1989 HCFCs consumption plus the 2.8% of the CFCs 1989 consumption, a reduction of HCFCs by 35% by 2004, 65% by 2010, 90% by 2015, and 99.5% by 2020, with their phase out in 2030. For the developing countries (art. 5), CFCs must be reduced, with respect to the average consump-

tion of 1995-1997 average, by 50% by 2005, 85% by 2007, 100% by 2010; HCFCs consumption must be frozen from 2016 and phased-out on 2040. More restrictive limits were adopted by some countries and in particular the European Community (regulation EC 2037/2000).

The most recent scientific assessment of ozone depletion stated the Montreal Protocol is working and the ozone-layer depletion from the Protocol's controlled substances is expected to begin to reduce within the next decade to bring back within 2050 to the levels of 1980. However, failure in the compliance of the Montreal Protocol would delay or could even avoid the ozone layer recovery.

## THE GREENHOUSE WARMING EFFECT OF REFRIGERANTS

Scientific measurements has shown that in the last century, the Earth's average near-surface atmospheric temperature rose  $0.6 \pm 0.2$  °C, mostly attributable to human activities increasing the concentration of CO<sub>2</sub> and other greenhouse gases (GHGs) in the atmosphere. Moreover, a global temperatures increase by between 1.4 and 5.8 °C between 1990 and 2100 has been predicted by the models proposed by the Intergovernmental Panel on Climate Change (IPCC) [4].

The greenhouse warming effect causes an increase in global temperatures and other potentially catastrophic effects, such as rising sea level, changes in the amount and pattern of precipitation, increasing the frequency and intensity of extreme weather events, higher or lower agricultural yields, glacier retreat etc.. These are the reasons why the international community has decided to control the emissions of GHGs through the Kyoto Protocol [5] signed in 1997 and entered into force in 2005.

But what is the way GHGs act on the thermal equilibrium of atmosphere?

### Greenhouse warming effect

The Earth receives energy from the Sun in the form of electromagnetic radiation. Part of this energy get the surface of the Earth and is absorbed by soils and oceans. The incoming energy is returned to the atmosphere as sensible heat, latent heat and as thermal infrared radiation.

Some of the gases forming the atmosphere absorb the outgoing infrared radiation and then partially trap the

Figure 2.  
Reactions responsible of the ozone depletion.

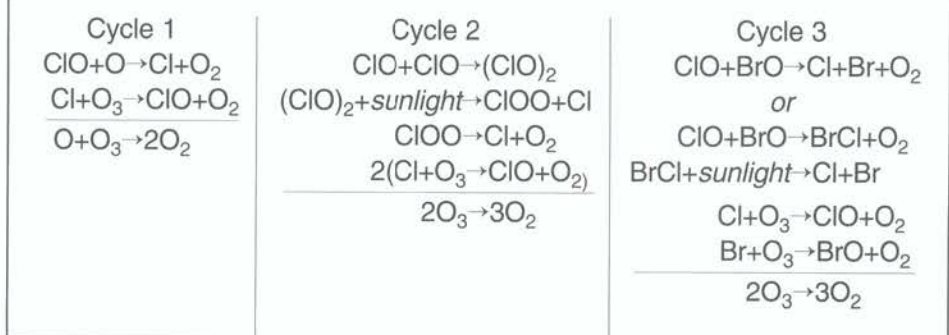


Table 1.  
ODP and GWP of some refrigerants.

	Fluids	Chemicals	Lifetime / year	ODP [4]	GWP 100 year [5]
CFC	R11	CCl <sub>3</sub> F	45	1	4600
	R12	CCl <sub>2</sub> F <sub>2</sub>	100	1.0	10600
HCFC	R22	CHClF <sub>2</sub>	12.0	0.055	1700
	R141b	CCl <sub>2</sub> F-CH <sub>3</sub>	9.3	0.11	700
HFC	R32	CH <sub>2</sub> F <sub>2</sub>	5	0	550
	R125	CHF <sub>2</sub> -CF <sub>3</sub>	29	0	3400
	R134a	CF <sub>3</sub> -CH <sub>2</sub> F	13.8	0	1300
	R143a	CH <sub>3</sub> -CF <sub>3</sub>	52	0	4300
	R152a	CHF <sub>2</sub> -CH <sub>3</sub>	1.4	0	120
Natural refrigerants	Ammonia	NH <sub>3</sub>	1	0	0
	Carbon Dioxide	CO <sub>2</sub>	120	0	0
	Isobutane	CH(CH <sub>3</sub> ) <sub>3</sub>	1	0	3

energy that would pass back to the space. This allows an average temperature of 14 °C at the Earth's surface, that would be otherwise 30 °C colder. The gases absorbing the infrared radiation are either naturally present in the atmosphere or produced by human activities.

These last emissions affect the natural energy balance of the atmosphere and then induce an effect on the temperature and the climate.

### Direct global warming of refrigerants

The halocarbons, and among them the main refrigerants, absorb the infrared radiation in a spectral range where energy is not removed by CO<sub>2</sub> or water vapor (figure 3), thus warming the atmosphere (figure 4). Actually, they are strong GHGs since their molecules can be thousand times more efficient at absorbing infrared radiation than a molecule of CO<sub>2</sub>. CFCs and HCFCs have also a significant indirect cooling effect, since they contribute to the depletion of stratospheric ozone that is a strong UV radiation absorber, but this effect is less certain and should vanish with the reduction of the ozone hole.

The direct warming potential of a molecule is proportional to its radiative effect and increases with its atmospheric lifetime. A proper index to evaluate this effect is the Greenhouse Warming Potential (GWP). It is calculated as the ratio between the global

warming of a kilogram of a gas relative to that of a kilogram of CO<sub>2</sub> in a defined horizon of time, most often set at 100-year. The GWPs of the main refrigerants are reported in table 1.

The direct global warming effect of a given mass of substance is the product of the GWP and the amount of the emissions: this explains why CO<sub>2</sub> has

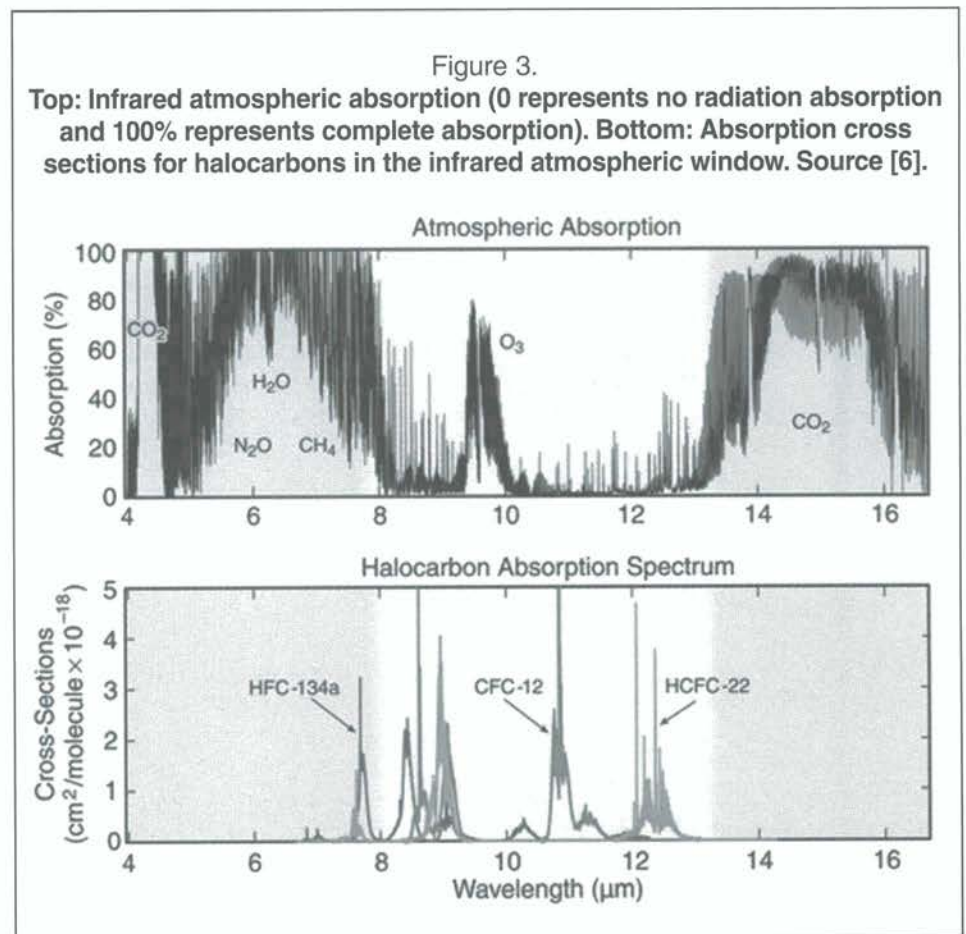
a much larger direct global warming effect than halocarbons. Direct emissions of GHGs may occur during the manufacture of the GHG, during their use in products and processes and at the end of their life. Thus, the evaluation of their emissions over all their life cycle is necessary.

It is worth to note that at present a large amount of halogenated refrigerants is in banks, i.e. is contained in existing equipment, chemical stockpiles, etc., and then is not yet released to the atmosphere.

The banks emission could give a significant contribution to global warming in the future, though banks of CFCs and HCFCs are not covered by neither the Montreal Protocol nor Climate Convention and Kyoto Protocol.

### Indirect GHG emissions by refrigerant use

The total warming effect of a refrigerant must include, aside the direct effect, an indirect effect due to the emissions of GHGs (mainly CO<sub>2</sub>) related to the energy consumption (fuels and electricity) during the entire life cycle of the application. Then, to



determine which technology option has the highest GHG emission reduction potential, both direct and indirect emissions have to be assessed.

The most suitable tools for such evaluation are the TEWI (Total Equivalent Warming Impact), that is a measure for GHG emissions during the use phase and disposal, and the LCCP (Life Cycle Climate Performance), which add to the TEWI the direct GHG emissions during manufacture, and the indirect GHG emissions associated to energy consumed during the production of the substances.

### ACTIONS TO REDUCE THE ODSs AND GHGs EMISSIONS

In view of the necessity to contribute to the reduction of the ozone depletion and the greenhouse warming effect, HVAC&R sectors must adopt measures to reduce the negative environmental effects connected to the use of halogenated refrigerants as working fluids.

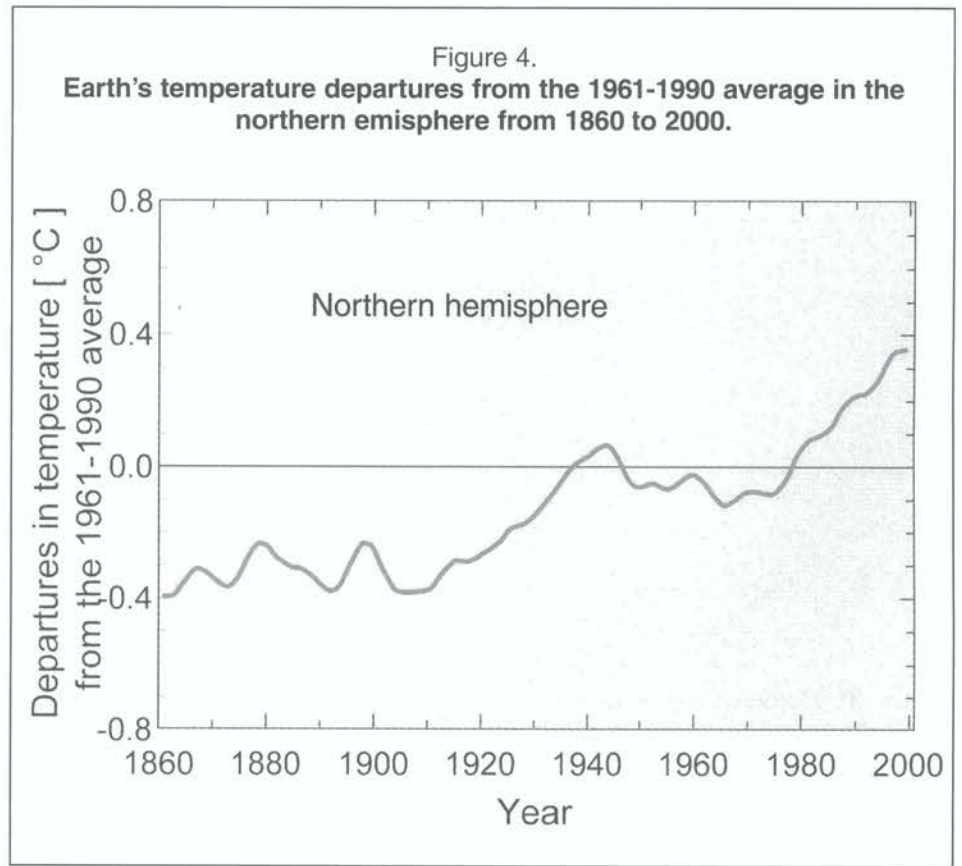
The main options identified by [6], to reduce the direct emissions are:

- improved containment: leak-tight systems,
- recovery, recycling, and destruction of refrigerants during servicing and at the end of life of the equipment,
- application of reduced charge systems:
  - lower refrigerant charge per unit of cooling capacity,
  - reduced refrigeration capacity demand,
- use of alternative refrigerants with a lower or zero global warming potential (e.g. hydrocarbons, carbon dioxide, ammonia, etc.), and
- not-in-kind technologies.

The indirect GHG emissions caused by the production of energy used to action the machines where refrigerants operates may be up to an order of magnitude larger than direct GHG emissions.

These emissions can significantly be reduced by improving the energy efficiency, particularly where the use-phase is long.

The reduction potential of indirect emissions is highly dependent on the application and the working conditions. However, energy efficiency



improvements can be profitable and reduce the net costs of the emission reduction options.

### CONCLUSIONS

Stratospheric ozone depletion, global warming and climate change are the main environmental issues related to the use of halogenated refrigerants. Ozone depletion has been faced by the Montreal Protocol and its Amendments, leading to the progressive ban of CFCs and HCFCs.

Scientific assessments suggest that the effects of the Protocol are positive, though few decades are still necessary to "close" the ozone hole. Moreover, a strict control in use and emissions of CFCs and HCFCs is still required, especially in the developing countries.

The problem of global warming is vice versa still open and, as stated by the Kyoto Protocol, requires the control in the emissions of HFCs, that is the fluids identified as substitutes for the traditional chlorinated refrigerants.

Further, the indirect energy-related emissions of GHGs impose the increase in energy efficiency of the appliances.

Training of operators, technological innovation, refrigerant emissions control are the main actions the world of refrigeration has to promote to successfully contribute to the solution of these huge problems.

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# Predictions of CFC, HCFC and HFC emissions from refrigerating and AC systems for the period 2002 - 2015<sup>1</sup>

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## 1. REFRIGERANT MARKETS

One of the essential steps in the calculation procedure applied here is the determination of the markets (i.e., demand) of all different refrigerants by adding up the annual amount of refrigerant charged in all types of new equipment and the complementary refrigerant charges needed for all servicing operations globally (see Table 1). When calculating these data, they are cross-checked with refrigerant market data as declared by refrigerant manufacturers and distributors. In many countries the refrigerant quantities sold are monitored, and the refrigerant distributors publish their annual sales of CFC, HCFC, and several HFC refrigerants.

### 1.2 Refrigerant markets

In 2002, HCFC-22 was the most widely used refrigerant representing nearly

half of the global demand for refrigerants. A large demand can be found in developing countries such as China. In 2002, the global HFC demand was close to 200,000 tonnes and the CFC market was still at a level of more than 100,000 ODP tonnes.

## 2. REFRIGERANT BANKS

The top-down calculation method developed is unique in so far that it builds up all equipment (with their charges) from manufacturer, statistical, and economic data. It considers the manufacture, the charging, imports and exports of charged equipment etc., and is in so far a unique calculation method, or rather, a unique program that has been developed over the years. It is also considers the gradual phase-in of different non-ODS types of refrigerants, including hydrocarbons, carbon dioxide and ammonia.

In 2002, the global bank of refrigerants is calculated as 2,600,000 metric tonnes. Where it concerns the different refrigerants, the global bank is composed as follows (see Table 2):

- 1.5 million tonnes of HCFCs;
- 490,000 tonnes of HFCs;
- 530,000 tonnes of CFCs, and
- 110,000 tonnes of non-fluorinated refrigerants.

## 3. REFRIGERANT EMISSIONS

From the bottom up method which is used to determine the banks, emissions can be calculated by applying certain leakage percentages per year (dependent on the year of manufacture of the equipment), service practices, and treatment at end of life. The treatment at end of life is assumed to be different in the different regions of the world.

The refrigerant emissions calculated for

Table 1. Refrigerant markets in 2002.

Refrigerant market in 2002	tonnes		ODP tonnes	
CFC	R-11	5.884	149.260	118.528
	R-12	131.652		
	R-115	11.724		
HCFC	R-22	345.815	356.790	14.039
	R-123	7.695		
	R-124	3.280		
HFC	R-125	23.473	189.614	-
	R-134a	133.322		
	R-143a	28.499		
	R-152a	1.254		
Other	R-32	3.065		
	R-717	22.371	23.075	-
	R-44	-		
	R-600a	703		

Table 2. Refrigerant banks in 2002.

Refrigerant bank in 2002	tonnes		ODP tonnes	
CFC	R-11	45.444	592.976	458.065
	R-12	486.533		
	R-502	60.999		
HCFC	R-22	1.397.057	1.500.161	57.942
	R-408A	32.727		
	R-401A	26.630		
	R-123	43.746		
HFC	R-134a	380.249	488.515	-
	R-404A	78.712		
	R-407C	12.003		
	R-410A	7.151		
	R-507	10.402		
Other	R-717	106.560	109.317	-
	R-744	-		
	R-600a	2.757		



**Table 3.  
Refrigerant emissions in 2002.**

Refrigerant emissions in 2002		tonnes	
CFC	R-11	7.106	144.225
	R-12	126.644	
	R-115	10.475	
HCFC	R-22	229.303	236.318
	R-123	4.151	
	R-124	2.864	
HFC	R-125	9.872	100.644
	R-134a	74.343	
	R-143a	14.765	
	R-152a	1.095	
	R-32	568	
Other	R-717	17.913	17.948
	R-744	-	
	R-600a	35	

2002 are close to 500,000 metric tonnes, if one includes all refrigerant species, i.e. CFCs, HCFCs, HFCs and others. The emissions of HCFC refrigerants (of which HCFC-22 forms the main part, other HCFC emissions are small) are almost the same as the total of the 2002 CFC and HFC emissions.

#### 4. FORECASTING FOR THE PERIOD 2002-2015

##### 4.1 TWO SCENARIOS FOR THE PROJECTIONS FOR 2015

Projections are made for banks and emissions up to the year 2015, using two scenarios, a business-as-usual (BAU) and a mitigation (MITIG) one, which take into account regulatory schedules, technological choices, and professional practices.

Each of the following refrigeration sectors is studied independently (1) domestic refrigeration, (2) commercial refrigeration, (3) refrigerated transport, (4) industrial refrigeration, (5) stationary air conditioning, and (6) mobile air conditioning. Calculations have been made for ten countries and/or country groups: (1) Africa, (2) America (South and Central), (3) Asia (North and West), (4) Asia (South and East), (5) China, (6) Europe (Eastern and Russia), (7) European Union, (8) Japan, (9) Oceania, and (10) The United States of America. All regulatory frameworks is taken into account in the projections towards 2015. The market growth is estimated following the growth in the last ten-years before 2002, taking into account the economical situation in each country group.

##### 4.1.1 Business As Usual Scenario

In this scenario, the usual practices and emission rates are kept unchanged for the period until 2015. Recovery efficiency is assumed to not increase. Nevertheless, regulatory decisions related to refrigerant phase-out are considered in the case of refrigerant replacements.

##### 4.1.2 Mitigation Scenario (maximisation of the use of low GWP alternatives)

In this scenario, substantial improvements are made in the different sectors, thereby reducing the refrigerant emissions in CO<sub>2</sub> equivalents:

- The system leak tightness is improved by choosing more reliable components.
- The recovery efficiency is much improved at servicing and at the end-of-life of equipment. Recovery is applied in all sectors where it was not done before.
- Technologies for the reduction of the refrigerant charge are introduced and applied (compactness, indirect systems).
- Low or lower GWP refrigerants are the preferred ones whenever possible. Fugitive emissions are reduced via bet-

(BAU) scenario. The HFC bank would increase by a factor of about 4-5 in 13 years (2002 versus 2015). All the policies aimed at the reduction of refrigerant emissions do not have a significant effect on the size of the refrigerant banks during the period 2002-2015 (due to the long lead times, i.e., lifetime of the equipment, before a change becomes visible in the bank). In the mitigation scenario (MITIG), the refrigerant banks would more or less stabilise at a level of 4 million tonnes in 2015 (if the refrigerant NH<sub>3</sub> is included).

#### 4.3 PROJECTIONS OF REFRIGERANT EMISSIONS TO 2015

##### 4.3.1 Refrigerant emissions by type

In 2002, the refrigerant annual emissions were calculated at almost 470,000 tonnes if one would include 100,000 tonnes of HFCs. In the same year, HCFCs represent half of the total global refrigerant emissions. According to the BAU scenario, refrigerant emissions in 2015 would reach the 850,000 tonnes level where HFCs would have a high share (42% of the global emissions of all refrigerants). In the MITIG scenario, maximum efforts are done

**Table 4. Refrigerant banks in 2015 (tonnes) for two scenarios**

Bank (tonnes)	CFCs	HCFCs	HFCs	HCs	Total
BAU	103.769	1.791.370	2.297.873	13.025	4.206.037
MITIG	101.276	1.491.239	2.082.504	60.467	3.735.486
Bank (ODP tonnes)	CFCs	HCFCs	HFCs	HCs	Total
BAU	82.124	71.132	-	-	153.256
MITIG	80.105	59.139	-	-	139.245

ter servicing and the use of control devices on refrigeration equipment. Refrigerant recovery is generally applied in all sectors; operators are assumed to be well-qualified and equipped with the right tools. Technological choices are based on selecting the lowest possible refrigerant charges and low GWP refrigerants whenever possible. All assumptions are detailed on a country by country and sector by sector basis in (GGECC, 2003).

#### 4.2 PROJECTIONS OF REFRIGERANT BANKS TO 2015

##### 4.2.1 Refrigerant banks

The refrigerant bank will increase from 2.3 million tonnes in 2000 to 4.2 million tonnes in 2015 in the business as usual

within the normal technical framework. Fugitive emissions are reduced thanks to better servicing and the installation of control devices on refrigerating equipment. Refrigerant recovery is generally applied in all sectors; operators are assumed to be well-qualified and equipped with the right tools. For this MITIG scenario, global emissions would reach their maximum at 520,000 tonnes in the period 2008-2010. Thereafter, with a decreasing trend, they are predicted to be just below the 2002 level in the year 2015 (total emissions being 435,000 tonnes, see Figure 2). The increase in HFC emissions would be rather moderate. They would be about 40% of the total emissions (in tonnes) in the MITIG scenario (total HFC emissions being 160,000 tonnes).

Figure 1.  
Evolution of refrigerant banks (tonnes)

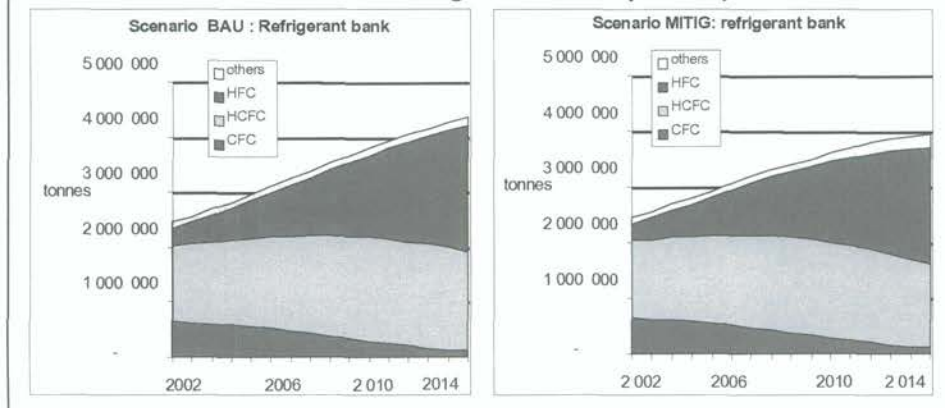
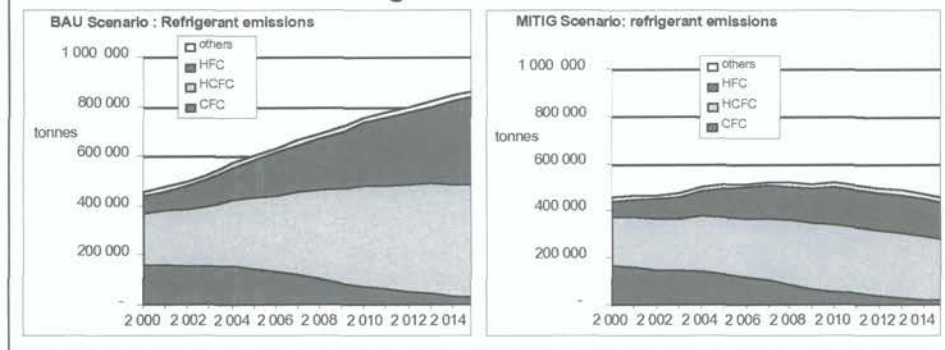


Figure 2.  
Trends in refrigerant emissions 2002-2015.



## 5. CONCLUSIONS

A bottom-up method to determine global refrigerant banks and emissions from refrigeration equipment provides qualitative insight in what the sizes of refrigerant banks and emissions could mean for the environment. In 2002, the largest bank is found in R-22 applications, followed by CFCs (R-12) and HFCs (mainly R-134a). In stationary AC and mobile AC, 60% of the banks expressed in tonnes is stored.

Emissions in 2002 are mainly from commercial, stationary and mobile AC (87%). However, where it concerns the global warming impact, the CFC emissions are predominant, followed by HCFC-22 and HFCs (the latter being 5% of the total).

For deriving emission scenarios for the period 2002-2015, one can apply a BAU and a mitigation (MITIG) scenario. In the BAU scenario total emissions in CO<sub>2</sub> equivalent amount to almost 1.5 Gtonnes, of which HFCs emissions are about 35%, i.e. 0.5 Gtonnes. By assuming the MITIG scenario, the total CO<sub>2</sub> equivalent emissions in the year

2015 can be reduced to about 0.8 Gtonnes, where HFCs will represent about 0.3 Gtonnes. In case of the MITIG scenario, the emphasis will be clear if one has to address minimising global warming impact from refrigerant emissions during the period 2002-2015. The largest amount of "global warming" originates from the CFCs (55%), followed by the HCFCs (30%) and the HFCs (15%). This emphasises addressing the avoidance of emissions during operation of the equipment and at end of life. Although percentages change, this conclusion does not change for the BAU scenario.

In summary, following needs attention if one wants to reduce global warming impact from refrigeration and AC applications over the next decade:

- Minimisation of emissions during servicing and end-of-life via appropriate servicing and disposal (destruction), which should be considered first priority;
- Replacement of HCFCs in commercial refrigeration and stationary air conditioning, the two main contributing sectors, where it concerns global warming

emissions. Global warming impact may decrease if the appropriate measures for emission reductions are taken;

- Minimisation of leakage during charging, repair and end-of-life of HFC based mobile air conditioning, followed by the application of low GWP options (such as HFC-152a or carbon dioxide). It will be clear from the above that due to the sizes of the banks of CFCs, HCFCs and HFCs, first reductions in global warming can be found in good practices, how to manage the banks, and to a lesser degree in applying low GWP options in the short term, where the long lead time (lifetime of the equipment) cannot yield substantial reduction results over the next decade.

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## Harmonisation of EU refrigeration training and certification becomes a reality

ROBERT H. BERCKMANS

Secretary General AREA

JEAN JACQUIN

President AREA

**AREA is the European Federation of National Refrigeration and Air Conditioning Associations. Established in 1988, AREA represents the industry of refrigeration, air conditioning and heat pump installation, in particular at the level of the European Institutions.**

**The associations which are members of AREA, represent, in their own country, the enterprises responsible for the design, installation, maintenance and repair of refrigeration and air conditioning equipment in the various applications.**

**Today AREA comprises the associations of the following countries : Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany (2), Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, Norway, Poland, Slovakia, Spain, Sweden, Turkey and United Kingdom (2).**

Fluorinated gases are still the best refrigerants in many applications (e.g. commercial refrigeration and air conditioning) because HFC-based technologies still provide superior energy efficiencies than available alternatives, besides their merits in safety and the zero effect on ozone depletion. Indeed only life cycle metrics such as the Life Cycle Climate Performance LCCP or the Total Equivalent Warming Impact TEWI are found to properly quantify the overall climate change impact (energy related emissions from the use of refrigerants in refrigeration and air conditioning equipment, including heat pump and reversible air-conditioning systems, account for an average of 84 % of the total).

However HFC should only be applied where their use is justified and where emissions can be controlled by competent personnel. Toxic refrigerants (e.g. ammonia), high pressure CO<sub>2</sub> and flammable fluids are options to be used or further developed for applications offering energy efficient, safety and commercially viable ways, reinforcing the need for highly qualified personnel and responsible installation and service companies.

Well designed installations remain at their optimum energy efficiency level only if they are adequately controlled and maintained. Likewise there is no effective containment without proper qualification of the personnel handling the refrigerants.

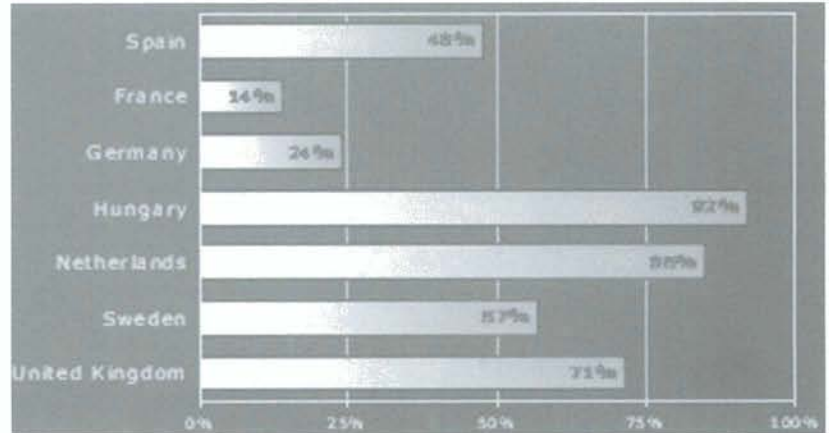
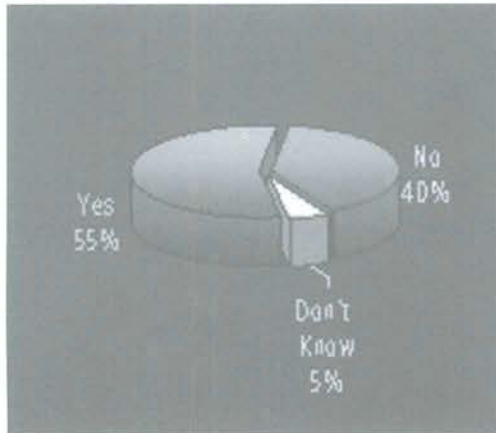
There is a need for harmonized quality education, training and certification in the refrigeration industry. Important dif-

ferences in the educational schemes do exist between European countries. Advanced countries do not want to accept craftsmen from other Member States with insufficient competence. Some countries, sometimes among those called the more developed ones, have no valid certification system. This cannot be a long lasting situation while building up an operational European Union where the concept of mutual recognition will now be applied by law. The educational programmes have to follow fast technological changes and to monitor an increasing number of changing rules, environmental legislations and European norms. The vast majority of the refrigeration and air conditioning installation companies are SME. As the issues to be dealt with, are global issues, the questions of minimum levels of professional qualification and of essential certification criteria have to be addressed with the European Authorities.

The European Commission has hired the consultants ICF to assist in the evaluation of measures taken by the Member States regarding the minimum qualifications requirements and programmes for RAC personnel pursuant to ODS Regulation EC N° 2037/2000 which already addressed the above mentioned issues. Their report stated in January 2005 that very few Member States complied with the recommendations regarding minimum personnel qualifications / programmes. The reason for the limited response of the Member States seems to be that the ODS Regulation was not precise nor

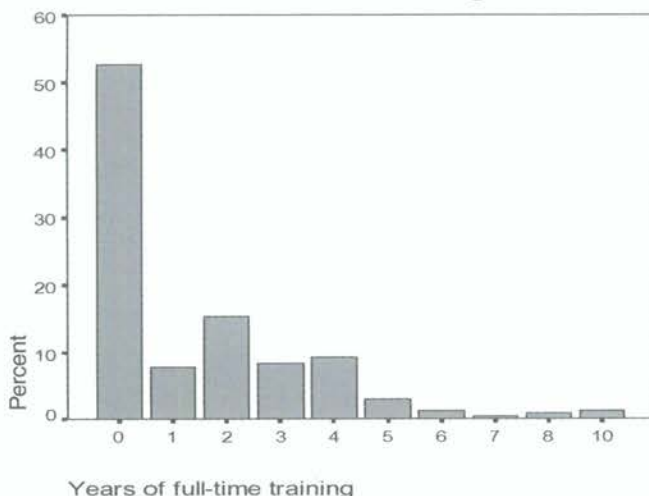
**Results of a 2004 survey (347 refrigeration craftsmen interviewed in 7 representative European countries):  
 "Do you have an environmental certificate as an air conditioning / refrigeration engineer?"**

**% Yes answers per country:**

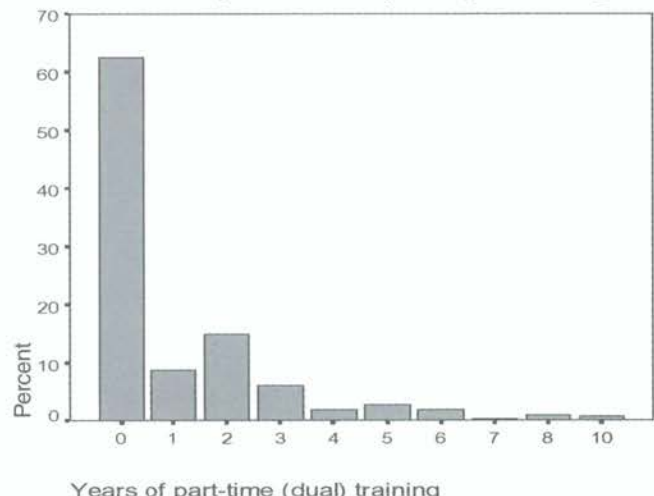


**and on questions about training programmes:**

**Years of full-time training**



**Years of part-time (dual) training**



demanding enough.

AREA has been an active participant in the European Climate Change Programme ECCP and has obtained a more complete wording of the article 5 - Training and Certification - of the F-gas Regulation that has been published on June 14, 2006.

This time, compulsory "minimum requirements and conditions for mutual recognition shall be established by the Commission in the scope of the Regulation on fluorinated greenhouse gases, in respect of training programmes and certification for both the companies and the relevant personnel involved in installation, maintenance or servicing of stationary refrigeration, air conditioning and heat pump equipment and circuits, as well as for the personnel involved in inspection and recovery

activities".

AREA has obtained that not only refrigeration technicians but also their employers must be certified. The certification of the companies is absolutely needed to guarantee the technical expertise of the management, its concern for environmental protection, the necessary related work procedures and the availability of adequate tooling.

**Recommendations for the requirements and conditions for mutual recognition to be established in the EC Regulation on certain fluorinated greenhouse gases (applicable to ODS substances also)**

The National Authority is the governmental institution, for instance a

Ministry or a National Agency, responsible for controlling the implementation of the overall scheme.

The scheme includes a Certifying Body or Certifying Bodies carrying out the functions of assessment and certification / registration **of companies' working procedures and structure:** the National Authority has to recognize the competence of such a Body in accordance with standard EN 45012.

The scheme also includes a Certifying Body or Certifying Bodies operating systems of certification **of personnel:** the National Authority has to recognize the competence of such a Body in accordance with standard EN 45013 / ISO 17024.

The Certification Bodies must have experience within the refrigeration sector and employ specialists in refrigera-

tion and air conditioning.

The Advisory Committee of Experts assists the National Authority in its controlling mission and serves as a counselor to define and update - when necessary - the criteria for certification (e.g. demands and terms of examinations, structures and terms of inspections,...). The members of the Advisory Committee are experienced representatives of the government, refrigeration vocational education bodies / schools and relevant trade associations (industry and end users).

### Requirements for the Certification of Companies

A company seeking certification has to fulfill the following requirements :

- it has to comply with the National legislation and administrative procedures;
- it has to have at least one person with a valid certificate assessing the competence corresponding to the activities carried out;
- it has the necessary equipment and tools to ensure in particular the safe

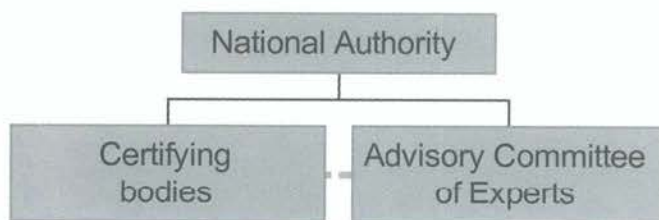
istration and documentation system;  
- it has the necessary work procedures (leakage control, recovery, log books of equipment serviced,...).  
The certification provides formal recognition to the competence of the companies; a company is certified as long as it can demonstrate that its competence is maintained.

After a certificate has been issued, the Certifying Body must control the company regularly, so that the certificate can be renewed year after year, after a successful visit and report of the Certifying Body's inspector. The surveillance will concentrate on competence of personnel, inspection of equipment, equipment calibrating, review of management system and relevant documentation, compliance with the work procedures.

When the Certifying Body refuses to renew the certification after the surveillance, the company concerned has to file a new application.

In summary: no effective containment nor optimum energy efficient installations without properly qualified personnel and adequate certification schemes.

### GENERAL STRUCTURE IN THE MEMBER STATES



### Requirements for the Certification of Personnel

Persons, who are responsible for installation, inspection, testing, operation, maintenance, repair, disposal and assessment of refrigerating systems and their parts shall have the necessary training and knowledge for their task to achieve competence.

Competence in each task shall be required for health, safety, environmental protection and energy conservation purposes.

The normative references are the standards EN 378-1/2/3/4 and EN 13313.

These persons responsible for guaranteeing the maximum containment of the systems, must be capable of:

- making leak tight joints using brazing, silver soldering and flare joint methods;
- identifying potential leakage points in a system;
- using direct acting leak detection methods;
- recovering refrigerant;
- evacuating systems or part of them;
- pressure testing;
- commissioning new systems / re-commissioning repaired systems.

Proof of proficiency in the above must be tested by examination or assessment before certification.

handling of refrigerants (refrigerant recovery equipment, gauges, reference gauges, vacuum equipment, leak detection equipment);  
- it has the necessary refrigerant admin-

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## Using Refrigerants Responsibly

DAVID LEWIS

MARK MENZER

Air-Conditioning and Refrigeration Institute - ARI

*United States manufacturers of heating, ventilation, air conditioning, and refrigeration (HVACR) equipment have played a leadership role in making sure refrigerants are used and handled responsibly. In 1994, the Air-Conditioning and Refrigeration Institute (ARI), the trade association of North American HVACR manufacturers, published the Industry Recycling Guide, a guide to recovering, recycling, and reclaiming refrigerants. This guide established the authoritative rules for those activities and was referenced in the regulations of the U.S. Environmental Protection Agency. Recently, ARI and the industry have embarked on an ambitious program to increase their efforts to keep refrigerants contained and to properly dispose of refrigerants at the end of their useful life. ARI's Refrigerant Responsible Use Initiative (RUI for short) involves all sectors of the refrigeration and air-conditioning industry. This article outlines the main initiatives of the program.*

The use of refrigerants in the U.S. extends from CFCs, still used in thousands of older chillers; to HCFCs, now used mainly in packaged equipment and chillers; to HFCs, which are being used at a growing rate in all types of refrigeration and air-conditioning equipment as a replacement for CFCs and HCFCs. HFCs are the recognized permanent replacements for CFCs and HCFCs and have an environmental advantage - they do not contribute to stratospheric ozone depletion. But they, like the CFCs and HCFCs they replace, are global warming gasses and need to be handled carefully. In spite of the hard work and diligence of the HVACR industry, atmospheric analysis shows that a significant amount of refrigerants are escaping to the atmosphere. For HFCs to remain a viable long term refrigerant, the HVACR industry will have to demonstrate that they can be contained and handled properly. The U.S. is a signatory of the Montreal Protocol and the U.S. government regulates the use of ozone depleting CFCs and HCFCs through the U.S. Clean Air Act. That Act states that intentional

emissions of these refrigerants are illegal. Regulations specify in great detail how refrigerants are to be monitored, handled, how leaks are to be fixed and how refrigerants are to be disposed. These regulations specify the level of expertise a technician must achieve before handling refrigerants, how much vacuum must be maintained when evacuating a system, and when a leak must be repaired. For CFCs and HCFCs the rules are detailed and are numerous.

The rules are a bit different for HFCs. Because the U.S. is not a signatory to the Kyoto Accord on Climate Change and the U.S. Clean Air Act does primarily focus on ozone depleting chemicals like CFCs and HCFCs, the authorizing language in the statute is not as clear about HFCs. The Clean Air Act states that HFCs cannot be vented/released to the atmosphere but needs to be responsibly cared for. The U.S. Environmental Protection Agency, the regulating authority, has not taken a strong position on enforcement of HFCs even though the rules covering CFCs and HCFCs mention that similar enforcement folds over onto the alter-



### NEW TRENDS OF TRAINING

ATF in the name of the 19 European Associations which are associated in AREA (Air conditioning and Refrigeration European Association) has signed a final agreement with NATE (the most important association which certifies the HVACR US technicians). This has been done to satisfy the increasing requirement to have qualified technicians and certify their qualification, to distinguish them from other operators not properly trained and qualified. This arises from the fact that Centro Studi Galileo's certificate in 30 years of activity has achieved a very high reputation, as now CSG certificate is recognised and required by some of the most important companies of HVACR sector and the most important international associations and institutes. In relation to this, as a further service, Centro Studi Galileo, following the international request of qualification of the operators, will follow the USA example of NATE, and so will mentor the technicians who will seek the ultimate recognition of their professionalism with a "Merit Certificate".

native refrigerants. The first goal of the Responsible Use Initiative is to encourage the EPA to aggressively enforce the no venting rules! The next step will be to strengthen and enhance the Clean Air Act to proactively promote the responsible use of HFCs. ARI is working with Congress and the U.S. EPA to treat the handling and use of HFCs in the same manner that they treat other refrigerants.

Another project of the Responsible Use Initiative is to demonstrate that manufacturers are proactive within their manufacturing facilities to contain refrigerants. ARI surveyed manufacturers to learn about their practices to contain refrigerants as they use them to charge the millions of units manufactured every year. The results of this survey were reviewed by industry experts and compiled into a list and published as the **Responsible Use Guide for Minimizing Fluorocarbon Emissions in Manufacturing Facilities**. This guide has been distributed to all ARI manufacturers. It has been printed in a format that makes it easy for facility managers to carry it with them as they inspect their plants to assure measures are being taken to contain refrigerant in a facility. This guide is available to other industry associations and to HVACR equipment manufacturers around the world from the ARI website at [http://www.ari.org/\\_documents/RUI-guide.pdf](http://www.ari.org/_documents/RUI-guide.pdf). An important development in the responsible use of refrigerants is **ASHRAE Standard 147, Reducing the Release of Halogenated Refrigerants from Refrigerating and Air Conditioning equipment and Systems**. This standard has the potential of demonstrating the industry's leadership in promoting responsible use. ASHRAE has provided a valuable service in promulgating this standard and with some revisions; it can be embraced by manufacturers. These revisions might include a repeatable method of measuring small leaks as well as a leak rate standard, acceptable for varying types of equipment. ASHRAE has established a standards committee to consider improvements to the standard.

It is clear that technicians who are properly trained tend to be more responsible in refrigerant handling. In the U.S., technicians must pass a gov-

### **"Indian Leadership for Improved Mobile Air Conditioning (MAC)"**

*By Karen Thundiyil, Stephen O. Andersen (US Environmental Protection Agency); Sridhar Chidambaram, Yash P. Abbi (The Energy and Resources Institute, India)*

Recent changes in regulatory policy and corporate leadership have stimulated the development and adoption of environmentally superior mobile air conditioning (MAC) systems. Cognizant of the growing demand for car A/C in India, key Indian stakeholders are working with an international team of experts to transform A/C technology in new cars manufactured and sold in India in order to save customers money while protecting the climate. The idea is to have car buyers pay a little bit more for a more efficient and reliable A/C that will save enough fuel to more than pay back that investment in less than one year.

"Cooperation on this project has been extraordinary..." said United Nations Environment Programme, Division of Technology, Industry and Economics's (UNEP DTIE) Rajendra Shende, "The Indian MoEF joined with UNEP-DTIE, the United States Environmental Protection Agency (US EPA), The Energy and Resources Institute (TERI), and the Society of Indian Automobile Manufacturers (SIAM) to assess the potential fuel savings. Such assessment will help the Government of India set policies for sustainable use of fuel."

"Now is the time to introduce fuel efficient A/C..." said Dilip Chenoy, Director General of the Society of Indian Automobile Manufacturers (SIAM), "...because A/C is already standard on 75% of cars sold today and by 2010 all cars sold in India will have factory-installed car A/C." In 2004, India successfully phased out CFCs in car A/C systems. At that time, approximately 65% of vehicles had factory-installed A/C.

The analysis, which will be featured during the 18th Meeting of the Parties to the Montreal Protocol in New Delhi this year, confirms that energy-efficient MACs offer extraordinary benefits in India's hot and humid climatic conditions where A/C fuel consumption is 3 to 5 times higher than in the US or Europe.

MAC technology developed by the MAC Climate Protection Partnership Program offers fuel savings of 30% or more and refrigerant emissions reductions of at least 50%, leading to significant financial and environmental benefits to the increasingly affluent and environmentally conscious Indian consumer. The emissions savings of improved car A/C systems are indicative of future car emissions reduction possibilities: significant savings are predicted from improved car alternators and power train systems.

As part of its mandate to facilitate the transfer of knowledge and technology for sustainable development, UNEP plays a catalytic role in this MAC initiative by providing strategic advice and bringing together the international partners with their Indian counterparts.

It is hoped that the India experience with next-generation MAC will provide inspiration to other developing countries so that they too can leapfrog to cutting-edge technologies (<http://www.epa.gov/cppd/mac>).

ernment test in order to be able to purchase and use refrigerants. While that is good, U. S. industry is encouraging a higher level of competence. It has instituted a technician certification program, called the North American Technician Excellence Program (NATE). NATE administers a series of tests that measure a technician's competence.

Industry feels that NATE certification should be required for technicians that work on refrigerant containing equipment. As a first step, industry would like the U.S. federal government to require NATE certification in order to work on federal projects.

The most ambitious project in ARI's responsible use portfolio is called Refrigerant Management USA (RM USA). Some would claim that every bit of refrigerant that is manufactured will eventually wind up in the atmosphere.

RM USA will provide incentives for technicians to return used refrigerants, for wholesalers to process them and for reclaimers to either clean or destroy used refrigerants. Planning is in the formative stages and more information should be available later this year.

The Responsible Use Initiative is a wide ranging and ambitious effort to improve the containment of refrigerants, improve refrigerant handling practices, and make refrigerants benign at their end of life. It will take the cooperation of the entire HVACR industry: manufacturers, installers, and service and maintenance personnel to make this effort a success. It is imperative that we succeed, if we are to have a variety of safe, efficient and reliable refrigerants available in the years to come.





## Mobile Air Conditioning

CARLOANDREA MALVICINO

Centro Ricerche Fiat - Interiors & Thermal Systems Dept. - Vehicle Systems

***Today Mobile Air Conditioning (MAC) systems are commonplace, being considered to be an essential feature of all vehicles in many countries, particularly in the western countries, while diffusion is also rapidly increasing in almost all markets across the globe. Such systems are considered important, not only as regards overall comfort and well-being, but also in terms of contributing in a significant way to vehicle safety by enhancing visibility and reducing the driver fatigue threshold.***

***Nowadays up to 70% of passenger cars and light commercial vehicles worldwide are equipped with a MAC and penetration is expected to raise up to the 80% before the 2010 due to the forecasted increase in demand for vehicles particularly in Eastern Europe, Asia and South America [1] and the required improvement in safety and comfort. This means that more than 640 millions of cars and light commercial vehicles should be equipped with an air conditioning by 2010.***

MAC systems are based on a sub-critical vapour compression cycle: a refrigerant fluid - normally a HFC gas - is compressed up to 15 bar, then cooled and condensed with the ambient air and undergoes to a pressure drop through an expansion device. Then the fluid evaporates cooling the air to be newly compressed. The refrigerant commonly used is the HFC 134a, it has a GWP (Global Warming Potential) of 1300 times the Carbon Dioxide (CO<sub>2</sub>), that has a GWP of 1, and no effect on the ozone layer; the R134a replaced CFC fluids that have a high depletion effect on the ozone layer.

The reduction of greenhouse gas emissions by 8 % compared to 1990 within the EU countries agreed in the Kyoto Protocol corresponds to a reduction of more than 300 million tons CO<sub>2</sub>-equivalent, and this will require an intense effort: MAC system could play a significant role being responsible for Global Warming contribution both indirectly due to additional fuel consumption and directly through refrigerant emissions via leakage.

On the basis of the studies carried out both by the Ecole de Mines de Paris and by the CRF in a joint project [2, 3] and by other organisations [4], 0.8 l/100 km represents a rough estimation of the annual average fuel consumption due to the presence of the air conditioning system, a figure which varies depending on average climate conditions, as might be expected.

Considering an average travelled distance of about 20,000 kilometres per

year, the impact of the MAC systems on the world fuel consumption can be estimated to be approximately 75 millions of tons of fuel equivalent to 175 millions of tons of CO<sub>2</sub> and representing around 3.5% of the world CO<sub>2</sub> emission from road transport, estimated to be 5 billions of tons of CO<sub>2</sub> [5]. Instead studies carried out by Sintef [6], Armines [7], Jama [8] and Dupont [9] indicated that the average annual emission of HFC is approximately 100g per vehicle. This leads to a global annual emission of about 85 millions of tons of CO<sub>2</sub> equivalent (68,000 tons of HFC).

Correspondingly the present MAC technology, projected to 2010, could be responsible of Green House Emissions of about 270 millions of ton of CO<sub>2</sub> or equivalent gases.

As a consequence of the public opinion, high sensitivity regarding environmental issues and the Kyoto protocol, the E.U. has adopted a policy which promotes the reduction of the environmental impact of MAC systems resulting in a decision to ban the HFC refrigerants for mobile applications starting from the 2011 and to limit the HFC annual emission to 40 g per vehicle from 2007.

Europe's position has been strongly influenced by the research movement started by Gustav Lorentzen [10] in late 80s' and focused to demonstrate that natural refrigerants could replace the synthetic ones while guaranteeing acceptable performance and eliminating all negative effects on the environment. The research, which was mainly



conducted in Europe [11], identified Carbon Dioxide (CO<sub>2</sub>), labelled R-744 when used as refrigerant, as the most favourite candidate to replace the HFC. CO<sub>2</sub> has long been used as a refrigerant, is a well-know fluid, and is the greenhouse gas with unity global warming potential.

Now, components and parts for R-744 systems are available and the major suppliers are ready to go in production; however, despite the significant R&D efforts addressing the on-board system efficiency, the cost (particularly for small cars) and operational safety are still open issues. This scenario could change, in case other world regions will join Europe in its way to apply R-744 MAC systems.

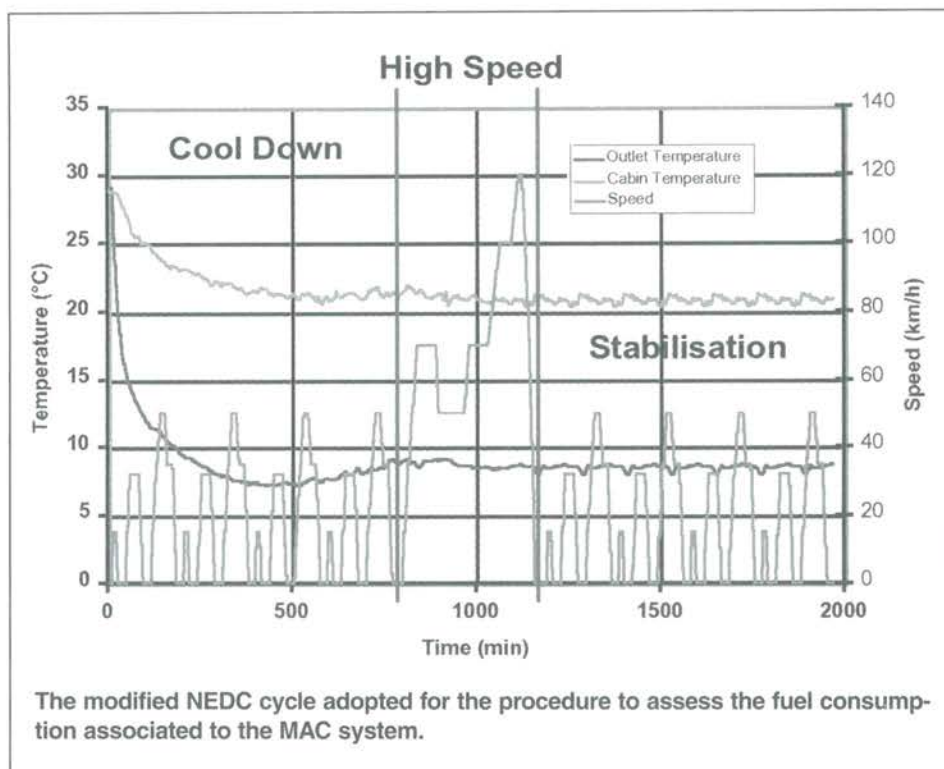
Several activities are on-going which focus on these issues including the B-COOL project [12], partly funded in part by the E.U., which aims to develop a R-744 low cost system with high



**Thermal Manikin used to measure the Operative Temperature and the thermal comfort level. The manikin is produced under CRF licence by SixTau.**

efficiency for segment A and B (compact and sub compact) cars: within the project a Fiat Panda and a Ford Ka will be equipped with the system.

A second viable alternative is represented by the use of HFC 152 that has a GWP of 130 but is slightly flammable and a major decomposition product is HF. This solution has been deeply examined by U.S. companies demonstrating that a safe use of this refrigerant can be achieved with the adoption of specific safety devices or of indirect expansion architecture. This last guarantees other advantages in terms of fuel efficiency and being particularly



suitable for vehicle having hybrid or stop & start power train [13]. This feature is not dependent on the refrigerant choice, however, this aspect could be very important in case of a broad diffusion of this type of power train that requires special system able to guarantee the thermal comfort when the thermal engine is off.

Recently, large chemical companies proposed other HFC fluids with very low GWP [14]. These fluids are not a no real "drop in" solution and their major drawback is that, at present, are considered toxic and with a certain level of chemical instability. R&D activity is progressing rapidly but these fluids could not be considered a viable solution: even if the toxicity will be re evaluated will remain the risk of a negative campaign that could affect end user purchasing decision having an impact on car sales that will favorise the car manufacturers adopting the R-744 MAC systems.

Beside the European policy and research activity mainly oriented to the replacement of GHG gases so to eliminate the direct greenhouse effect of the MAC, other initiatives have been launched to promote the development of more efficient and tight MAC systems. An American Chemical Company and the US EPA launched the I-MAC [9] cooperative action aim-

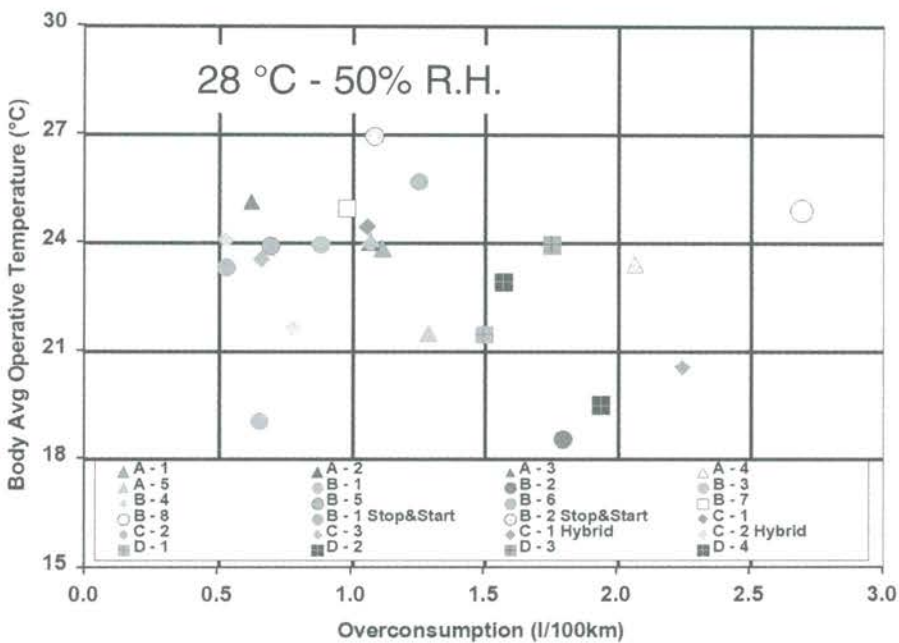
ing to develop to and diffuse technical solutions able improve the MAC efficiency of about the 30% and to reduce of up the 50% the HFC refrigerant emissions. The initiative had a very broad international support and gathers the major part of U.S., European and Japanese organisations.

Finally, UNEP under the sponsorship of U.S. EPA, launched in the 2006 the initiative named EcoMAC devoted to the development of an high efficiency MAC system based on HFC fluid for small cars.

The project has the role to increase the sensitivity towards the MAC fuel efficiency, contributing to promote regulations and other measures aimed to incentivate the adoption of energy and fuel saving systems so to avoid the risk of an even sharper increase of fossil fuel consumption. The EcoMAC relevance is even more important in perspective of the rapid diffusion of cars and MAC in the developing countries, where regulations are under discussion and evaluation.

EcoMAC, coordinated by the Fiat Research Center, is focused to the development of an high efficiency mobile air conditioning system for a small car. A Fiat Panda prototype will be realised and tested.

The technical activity will be carried out in parallel with the definition of a



Measured fuel additional consumption of a panel of commercialised and prototype vehicles applying the testing procedure elaborated within the B-COOL project and under discussion in the framework of the EcoMAC initiative.

procedure to evaluate the fuel consumption associated to the system. This procedure will be used to compare the EcoMAC prototype with the baseline vehicle and with other similar vehicles having different MAC system (e.g. the B-COOL Fiat Panda).

The testing method has been proposed initially the framework of a project funded by the ADEME French agency, further developed within the B-COOL project and it is under discussion and refinement in the framework of the EcoMAC project.

The proposed procedure [15] is based on a modified NEDC cycle performed at 35 °C and 60% R.H., 28 °C and 50% R.H. and 15 °C and 70% R.H.

In addition, provisions have been identified on the MAC system regulation in case of automatic as well as manual control. The thermal performance of the system is based on the Operative temperature measurement in the cabin using Thermal Manikins [16].

The general scenario puts in evidence the efforts of National and Supranational organisations, Research Entities and finally by Companies to develop a new generation of Mobile Air Conditioning systems having a lower impact on the environment. So, the original Gustav Lorentzen idea generated a positive

reaction of the world community that resulted in a progressive increase of the efficiency of the HFC based systems, in the production of MAC systems based on natural refrigerants and recently in the development of very low GWP HFC refrigerants.

The process is not completed, but just started and very important achievements are expected in the next years on the technical and scientific side as well as on the policy and regulation side. The on-going actions, as the EcoMAC and the B-COOL projects, are examples of actions that in the coming years will contribute to solve the remaining open points and that will increase the general awareness on the important efforts of the Public and Private entities to reduce the negative impact of human activities on the environment.

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# Refrigerants Replacement and Environmental Protection in China

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Chinese Association of Refrigeration - CAR

*It is very important for refrigeration industry to research and use environment-protecting refrigerants, because CFCs and HCFCs, which are widely used in refrigeration system and in heat insulation materials processing in present, do great harm to ozone layer and result in or at least aggravates greenhouse effect. This article reviews the history and present status of refrigerants utility, and also discusses the development trend and the replacement of refrigerants in China.*

## Introduction

It can be traced back to ancient time, that refrigeration was used by Human being, using stored ice and a number of evaporative processes.[1] However, actual refrigerants did not appear until the 1830's, when Jacob Perkin invented a vapor compression refrigerating system using ethyl ether in a closed circuit and took out a patent on that.[2] The period from 1830's to early 20th century was the first stage of refrigerants use. During this stage, natural materials and some easy-gained chemicals like water, air, ammonia, sulphur dioxide, carbon dioxide, methyl chloride, propane, isobutene, etc. came into use.

Attention was mainly paid to safety and performance in that time. An ideal refrigerant was believed to be stable, non-toxic, non-flammable, capable of

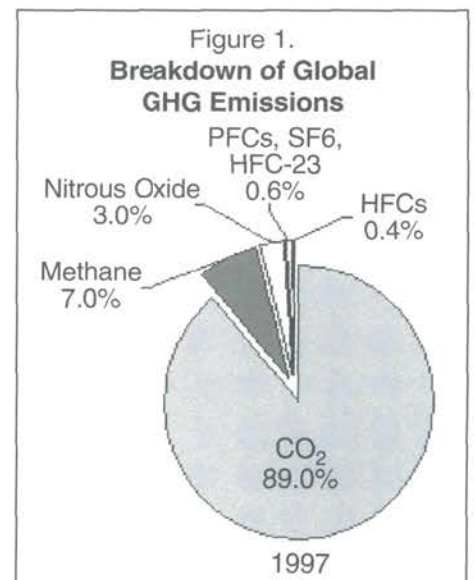
operating in a domestic refrigerator without leaking below atmospheric pressure, and to be a substance with a low index of compression, etc. None of those refrigerants mentioned above meet such requirements completely. Therefore, Thomas Midgeley started his excellent job to find such refrigerants in 1928, which was a task from General Motors. The first nearly-perfect refrigerant Thomas found was R12.[3] The emergence of R12 as a refrigerant began the second stage of refrigerants use. Various CFCs and HCFCs like R13, R123 and R22 were gradually found and came into use. All of these chemicals were stable, non-toxic, non-flammable and highly efficient. They became the dominant refrigerants rapidly and were used in the complete range of domestic, commercial, industrial and air-conditioning applications. Most of the early refrigerants retired and it appeared that there would soon be nothing left but CFCs and HCFCs. However, researchers Molina and Rowland's research connected CFCs with Ozone Layer Depletion in 1974.[4] Since then, attention began to turn to environmental protection. It seemed that a new era of refrigerants, marked by limitation on CFCs and HCFCs use and turning to HCFs or coming back to natural refrigerants, was coming in 1990's.

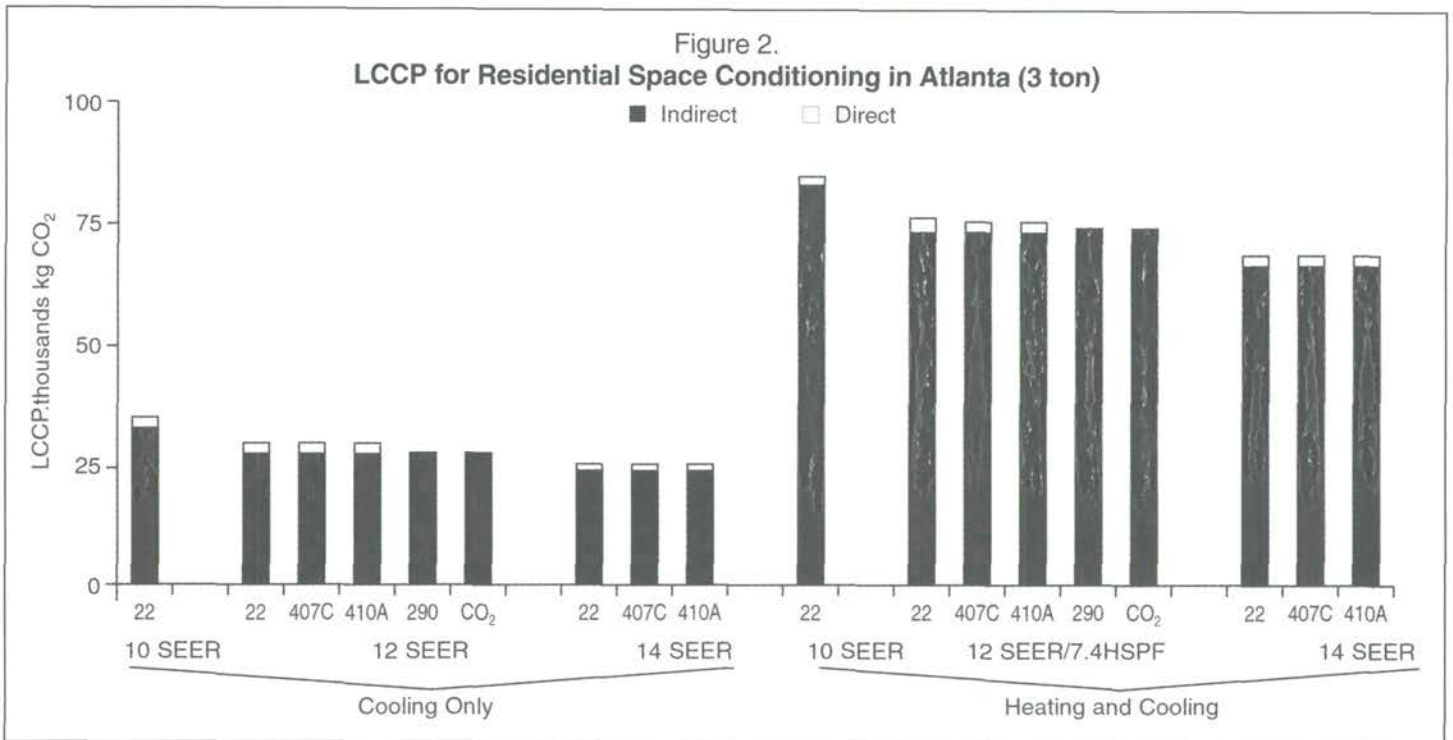
## Environmental Issues

The main challenges for air conditioning and refrigeration industry in present are the global environmental

issues: Ozone Layer Depletion and Global Climatic Change.

Molina and Rowland first released their hypothesis on CFCs' damage to Ozone Layer in 1974. In 1985, it was observed that the ozone layer over Antarctica was being progressively destroyed as they had predicted.[5] People began to take Ozone Layer Depletion as a serious problem and took rapid actions. In 1987, Montreal Protocol, a landmark international treaty to protect ozone layer, was reached. Montreal Protocol and some further reports propose strict restriction on CFCs and HCFCs use. Generally speaking, CFCs use should be banned in 1996 in developed countries and 2010 in developing countries; HCFCs consumption should be banned in 2020 in developed countries and in 2040 in developing countries.





The IPCC (2001) reevaluation report indicated the 90s of 20th century were the warmest ten years and 1998 was the warmest one in the 90s from the record results. HFCs were classified as greenhouse gases (GHG) along with carbon dioxide, methane, nitrous oxide, PFCs and SF<sub>6</sub> in the Kyoto Protocol. The protocol requires developed countries to first eliminate any growth in their GHG emissions that took place over the two decades (since 1990) and then collectively to further reduce their emissions 5.2% below 1990 levels on average over the 2008 to 2012 time period.

#### Trade-off in Refrigerants Selection, environmental impact in particular consideration

Selection of any refrigeration is a compromise. Basic requirements for a successful refrigerant in present are that it should be zero ODP and low GWP, and that it should be efficient to use in conventional refrigeration machinery and be safe, etc. It is almost impossible to meet all these requirements at the same time.

HFCs have nearly zero ODPs and they have been promising and essential substitutes for these Ozone-Depleting refrigerants. However, they are included in the basket of GHG for control by the Kyoto Protocol, which

leads to uncertainty of some countries and organizations about future HFC applicability. Europe countries tend to come back to natural refrigerants for their low GWP.

As is broken down in the Figure 1, however, HFCs are very small part of GHG emissions [6]

Also, another important question which is concerning is how to evaluate the impacting of HFCs (HCFCs) on climate change as well as natural refrigerants scientifically.

The LCCP analysis methodology is introduced as a more scientific and complete procedure. It accounts for warming impacts due to direct GHG emission for the product and to indirect GHG emissions associated with the energy consumption of the product over the entire life cycle of refrigerant and equipment including inadvertent emissions from chemical manufacture, energy embodied in components, and emissions at the time of disposal or recycle. The lower the LCCP value, the lower the environmental impact.

The LCCP value was compared in Fig.2, for residential unitary air conditioning include HFC blends (primarily R407c and R410a), propane (HC-290) and HCFC-22. LCCPs have been calculated for a typical application in Atlanta, GA, USA, at three efficiency levels-seasonal energy efficiency ratio (SEER) level of 10, 12 and

14Btu/Watt-hr.

According to LCCP values, HFCs, HCFCs and natural refrigerants are very similar in the environmental impact. A report of the TEAP HFC and PFC Task Force (TEAP, 1999) stated, "the categories of ODS replacement based on chemical nomenclature such as HFC, HCFC, HFE or natural refrigerants are unreliable indicators of environmental acceptability".[7] This has been recognized and should become the basis for industry and governmental actions instead of GWP.

#### Refrigerants in the future

There are no ideal refrigerants in present or in the future. The selection of refrigerants should be a trade-off between several basic properties, and depend on the specific application.

##### HCFCs

HCFCs are up to 98% less ozone depleting and have 80% shorter atmospheric lifetimes than the corresponding CFCs they replaced, and they are also energy efficient and low-toxic. They will be popular used in developing countries in the coming several decades in different area.

##### HFCs

HFCs are convenient, safe, cost-effective, high-efficiency, and the impacting to environment is not much more than nature refrigerants, as discussed

Table 1.  
**10 kinds of ODSs to phase out in China according to London Amendment**

		ODS	ODP	ODS	ODP
Annex A	Group 1	CFC-11	1.0	CFC-12	1.0
		CFC-113	0.8	CFC-114	1.0
		CFC-115	0.6		
	Group 2	Halon 1211	3.0	Halon 1301	10.0
Annex B	Group 1	CFC-13	1.0		
	Group 2	CTC	1.1		
	Group 3	TCA	0.1		

Table 2.  
**The reduction expected in different kinds of CFCs consumption of China, ODP ton**

	1999	2006	2007	2008	2009	2010
CFC-11	2048	2880	2875	1040	3410	140
CFC-12	3110	2040	1780	690	520	2560
CFC-113	0	550	0	0	0	0
CFC-114	0	0	10	0	0	0
CFC-115	0	0	100	0	0	0
CFC-13	0	0	50	0	0	0

Table 3.  
**The expected reduction of ODSs consumption in different areas, ODP ton**

	1999	2006	2007	2008	2009	2010
Foaming industry	2789	2460	2825	1000	3370	0
C&I refrigeration	360	1360	550	440	340	1340
Domestic refrigeration	2046	200	0	0	0	200
Cleaning industry	0	654	104	104	104	104
Cigarette industry	0	150	0	0	0	0
MAC	220	250	280	290	220	160
Halon industry	5370	6470	0	0	0	1000

above. They should still be main alternatives, especially in the sealed system. For myself, the author doesn't agree with the rapid and unnecessary phase-out of HFCs, although the responsible use for them is essential.

#### Natural refrigerants

The main problems for natural refrigerants are their safety and special requirements. It will be limited in the recent years before the technical is developing.

#### Refrigeration Replacement In China

Great efforts have been made in China to protect environment and replace of refrigerants.

China subscribed Montreal Protocol in 1991, and approved a national project to phase out ODS in 1993. The national project was updated in 1999 and a

more scientific and detailed schedule was given. In 1998, China subscribed Kyoto Protocol.

As a developing country, China's most important task is to phase out CFCs. As is shown in Table 1, 6 of the 10 kinds of ODSs to phase out in China are CFCs, according to Montreal Protocol (London Amendment). Moreover, Table 2 shows the expected reduction of different kinds of CFCs consumption and Table 3 is about the expected reduction of CFCs consumption in different areas, according to the national project.

The CFCs replacement in China has come to a success in some areas. R134a and R600a have become the most popular refrigerants for refrigerator instead of R12. Also, R134 has replace R12 to be refrigerants for MACs in recent years and CO<sub>2</sub> MACs

technology is in research. For room conditioners and unitary air-conditioners, R22 has become the most popular refrigerant used, and environment friendly refrigerants like R410a and R407c are also used for export. R134a and R22 have replaced R11 to be the main refrigerants used in centrifugal chillers.

China has subscribed Kyoto Protocol in 1998. There are further tasks for China to phase out HCFCs, and maybe finally CFCs, as the protocol requires. However, time is needed for such transition and acceleration of the HCFCs phase-out schedule and reduction of the HCFCs production cap in the developing countries like China should not proceed before furthering technical development, commercial availability and recognizing the economic costs to society.

#### Conclusion

As is stated for many times, any refrigerant selection is a compromise. We have to evaluate a candidate completely and scientifically with consideration of both the several basic principles and the specific application and market.

In the near future, HCFCs (mainly for developing countries like China), HFCs and natural refrigerants could be expected to be in concurrence but in deferent uses.

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# Refrigerants, Naturally! Clever cooling vs. global warming

## REFRIGERANTS NATURALLY PARTNERS

**A change towards sustainability in the retail sector involving multinational corporations took place in recent years. The United Nations Environment Programme (UNEP) promotes such change which aims at finding solutions to more than one global environmental issue. Hydrofluorocarbons (HFCs) are widely used as replacements for replacement of ozone depleting chlorofluorocarbons (CFCs) in many commercial refrigeration applications, such as beverage coolers, vending machines, ice cream freezers, and open deck coolers and freezers used in supermarkets. HFCs have zero Ozone Depletion Potential (ODP), but still have a high Global Warming Potential (GWP) and belong to the gases whose emissions are controlled under the Kyoto Protocol. With HFC production increasing with the successful replacement CFCs under the Montreal Protocol, concerned companies and organizations are seeking long-term solutions to address both of these global environmental issues. Part of the answer lies in the development and widespread commercialization of alternative refrigeration and cooling technologies such as hydrocarbons, carbon dioxide, Stirling cycle, thermoacoustic, and solar cooling. In 2000, at the request of the The Coca Cola Company and Mc Donald's, UNEP along with the US Environmental Protection Agency (USEPA) convened an experts group to review the options and inform the process of technology choice at the enterprise level.**

*The Coca Cola Company*



### OBJECTIVES

After 4 years of work on different options by the enterprises, Refrigerants, Naturally! was launched in 2004 as a voluntary corporate initiative by The Coca Cola Company, Unilever and McDonald's, and supported by UNEP and Greenpeace. Its objective is to promote a shift in the point-of-sale cooling technology towards alternative refrigeration technology that protects the Earth's climate and ozone layer. The initiative encourages the development of HFC-free technologies for point of sale commercial refrigeration.

### SUMMARY

The initiative's members are companies that have point-of-sale cooling applications in the food and drink, food service and retail sectors. Members must show commitment to:

- eliminating HFCs in point-of-sale cooling applications
- developing a timetable for doing so
- making a make a substantial resource commitment to achieve fluorocarbon

elimination, including R&D, testing, financial investment, staff time or political energy

- sharing information between members via regular meetings, special events/workshops, and bilateral exchanges

- sharing data and results with other companies, government decision makers and the public

*Refrigerants, Naturally!* provides members with a working group and a supportive environment where information is shared to encourage and spread excellence for those committed to eliminating HFCs in point-of-sale refrigeration.

The partnership also provides a platform and a critical mass in communicating with the refrigeration technology supply chain, with other users, governmental, political and public institutions about the feasibility and environmental gain of non-HFC-cooling.

The partners are seeking other major companies in the concerned business sector worldwide to join the initiative and adopt similar technology. New partners will be expected to both contribute resources in terms of internal research and development/investment in alternative refrigeration technologies, and to participate fully in the process to manage the initiative itself.

### RESULTS

Within the framework of *Refrigerants, Naturally!*, The Coca Cola Company, Unilever and McDonald's together with their suppliers have developed, tested



and purchased innovative, commercially-viable HFC- and CFC-free refrigeration technologies. Some of the results achieved to date include:

- **The Coca-Cola Company** has launched a US\$ 10 million Research and Development program that has allowed it to identify, develop and test CO<sub>2</sub>-based cooling applications designed to efficiently chill products while reducing greenhouse gas emissions. Initial field tests, performed during 2004 in Greece, Spain and Australia, indicated that CO<sub>2</sub> equipment in real-life conditions was between 17% and 35% more energy efficient than the equivalent units using standard refrigerants. Today, the Coca-Cola System has deployed over 2,000 coolers and venders using CO<sub>2</sub> refrigeration technology. This number will grow to over 4,500 by mid-2006 as pre-commercial market tests continue. HFC-free insulation has been implemented for the majority of Coca-Cola new sales equipment purchases and work is in process to substantially reduce the energy consumption of equipment, targeting a 40-50% reduction over a 2000 baseline by the end of the decade. Coca-Cola estimates that, when its environmental refrigeration will be fully deployed, yearly greenhouse gas emissions savings will be equivalent to removing 150,000 cars from our roads.

- Tests in the first **McDonald's** HFC-free pilot restaurant in Vejle, Denmark showed encouraging results. The restaurant used approximately 12 percent less energy than a conventional McDonald's restaurant and its emissions according to the Total Equivalent Warming Impact (TEWI) calculation are 27% lower. Based on these results, McDonald's is focusing the development plans with their suppliers on the 3 (of 10) equipment items (HVAC, walk-in freezer and ice cream/shake machines) that account for 97% of the total impact.

- **Unilever** owns the world's largest ice cream business selling branded ice cream such as Magnum, Cornetto, Carte d'Or, Ben & Jerry's and Breyers. Out of home sales are made through branded ice cream freezers of which Unilever owns about 1.8 million. In 2000, Unilever made a commitment to buy HFC-free ice cream freezers by 2005 and to meet that commitment,

Unilever has worked closely with their suppliers and industry experts to introduce ice cream freezers using hydrocarbon refrigerants. The first public test of the hydrocarbon freezers was with 50 units at the Sydney Olympics in 2000 followed by long scale trials in Sydney and Brisbane. Independent studies published by the Danish Technological Institute showed that these hydrocarbon freezers were 10%



more energy efficient than the equivalent HFC freezers. Unilever moved to large scale trials in Denmark in 2003 and a Europe wide roll out in 2004. By 2006, Unilever will have 100,000 hydrocarbon refrigerated ice cream cabinets on the market in Europe. Hydrocarbon freezers will be in the market in Latin America in 2006 and in Asia in 2007. The key to the successful transition to environmentally friendly freezers has been a close relationship with our supply chain, ensuring that not only the technical but also the wider social elements underlying the switch to hydrocarbon refrigerants were fully understood. Unilever has held launch events in several countries to support the intro-

duction and to raise consumer awareness of the initiative and has developed a training package for servicing hydrocarbon freezers, which will be made available to third parties.

Other than hydrocarbon refrigerants, Unilever has been actively involved with developing and testing other environmentally friendly technologies like the solar panel assisted freezer and thermoacoustics. These tests have provided support to fledgling technologies and valuable data to underpin their future introduction. Unilever's wider Environmental and Social activities are in their annual report which can be found at: <http://www.unilever.com/our-values/environmentandsociety>

The companies were awarded the United States Environmental Protection Agency's **Climate Protection Award 2005** in recognition for their leadership in developing innovative ways to combat global warming by promoting the development of environmentally-friendly refrigeration technology.

The partners organized an international **conference** in Brussels in June 2004 that showcased the initiative and the companies' achievements. They will organize another event in 2006 to introduce new members to the initiative and to highlight new refrigeration technologies that suppliers have brought to market.

*Refrigerants, Naturally!* is recognised as a "**Partnership for Sustainable Development**" by the UN Commission on Sustainable Development as a voluntary, multi-stakeholder initiative that contributes to the implementation of Agenda 21, Rio+5 and the Johannesburg Plan of Implementation.

For more information, visit [www.refrigerantsnaturally.com](http://www.refrigerantsnaturally.com)



*High interest on natural refrigerants: picture from the latest European Seminar about carbon dioxide as a Refrigerant held in Milan, organized by Centro Studi Galileo and Associazione dei Tecnici del Freddo.*



# CO<sub>2</sub> as Refrigerant, an Option to Reduce GHG Emissions from Refrigeration, Air Conditioning and Heat Pump Systems

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*Emissions of halogenated refrigerants represent a major challenge for the environment both due to ozone depletion and green house warming. On a global basis today, the refrigerant emissions represent GHG emissions equivalent to about 10% of CO<sub>2</sub> emissions resulting from fossil fuel burning (IPCC/TEAP, 2005). In principle emissions can be reduced through improved containment.*

*However, even with strong focus and incentives introduced by governments, it has proved to be difficult to reduce emissions to acceptable levels, especially for some applications. A change to use of alternative refrigerants with a lower or zero global warming potential therefore represent a more sustainable long term strategy. CO<sub>2</sub> is a substance occurring naturally in the biosphere. Thus, it is a long term alternative, known not to have adverse effects on the environment if emitted to the atmosphere. CO<sub>2</sub> is also a non-toxic and non-flammable alternative, properties preferred in many applications. The CO<sub>2</sub> used as refrigerant is waste CO<sub>2</sub> from industrial processes, the same CO<sub>2</sub> as used for carbonizing beverages. It is also important that it has excellent availability world-wide already today.*

Ozone depleting substances are controlled through the Montreal protocol and will be phased out. However, they are still extensively used in many countries, especially developing countries that potentially may use these ozone depleting substances for many years to come, even if this is undesirable from an environmental point of view. Unique is that these countries may use this opportunity to convert their technology directly to long term solutions using natural refrigerants.

Since refrigeration, air conditioning and heat pumps generally generate indirect CO<sub>2</sub> emissions through their power consumption, either through electricity production based on fossil fuels or in engines for transport and mobile applications, it is important to focus also on these emissions, and thereby on energy efficiency. One way to address this is through life cycle climate performance evaluations, LCCP, which takes the total emissions during the lifetime into account.

CO<sub>2</sub> has become a viable alternative refrigerant for several different applications. It may serve as an alternative in replacing ozone depleting and global warming refrigerants. A review of some important aspects of CO<sub>2</sub> as refrigerant and the importance it may play as an alternative refrigerant are given here. LCCP calculations for different climates and applications are presented in order to substantiate CO<sub>2</sub> as an alternative. Focus will be given to systems using CO<sub>2</sub> as the only refrigerant. Thus, use of CO<sub>2</sub> in cascade systems or as brine is not covered.

## ENERGY EFFICIENCY AND AMBIENT CONDITIONS

Due to the difference of CO<sub>2</sub> thermo-physical properties and cycle characteristics compared to HFC refrigerants, typical efficiency curves (COP, Coefficient Of Performance: cooling capacity divided by power input) shows different trends with the ambient temperature. CO<sub>2</sub> tends to be more efficient at lower ambient temperatures, while HFC systems may be slightly more efficient at the highest ambient temperatures. This tendency has been verified for various applications, such as vehicle air conditioning and supermarket refrigeration. Figure 1, from Hafner et al. (2004) illustrates this.

The crossover temperature, given by the intersection of the two curves, will vary depending on various factors, such as component efficiency and system design. Results comparing CO<sub>2</sub> and HFC options reported in Hafner et al. (2004) for mobile air conditioning systems showed a crossover temperature above 30 °C.

When comparing energy efficiency for CO<sub>2</sub> systems and alternative technologies it is of utmost importance to make a seasonal comparison based on the operating conditions the systems will experience during the year. A comparison only at rating conditions, typically 32 or 40 °C, will not give comparability with respect to energy consumption. Usually the rating point is given for the most severe condition the equipment is likely to experience. It is very important to ensure the required cooling or heat-



ing capacity at these conditions, but operation at this condition will most often not be important for the annual energy consumption of the equipment. Results show that CO<sub>2</sub> systems satisfy capacity requirements at the highest ambient conditions very well.

For several applications it has now become a common procedure to work out energy consumption based on a seasonal variation of the climate in order to compare different systems and technologies. This holds for example for HVAC units in USA, hot-cold vending machines in Japan and mobile air conditioning systems. LCCP calculation comparisons for some applications are presented below.

### CO<sub>2</sub> AS AN ALTERNATIVE IN DIFFERENT APPLICATIONS

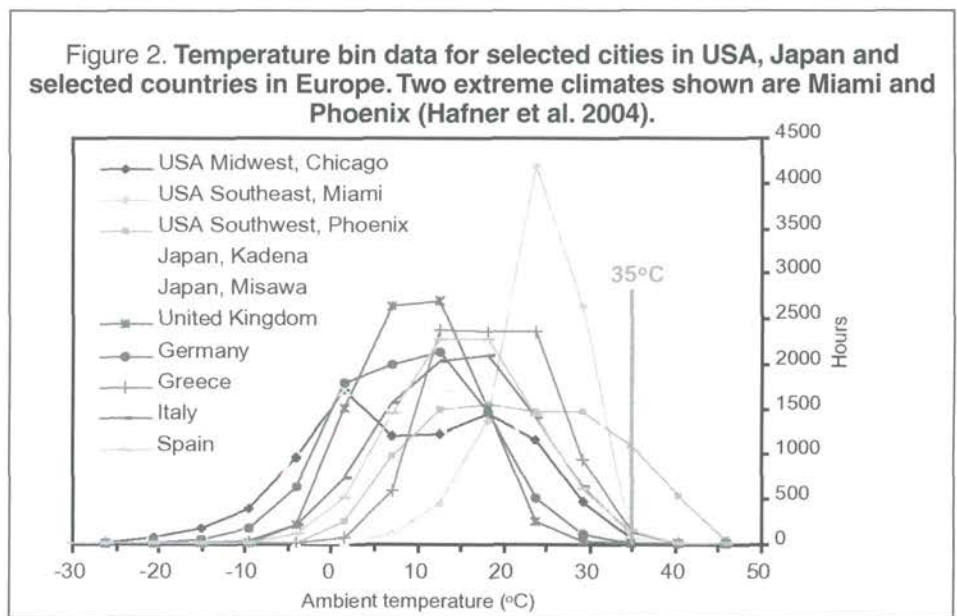
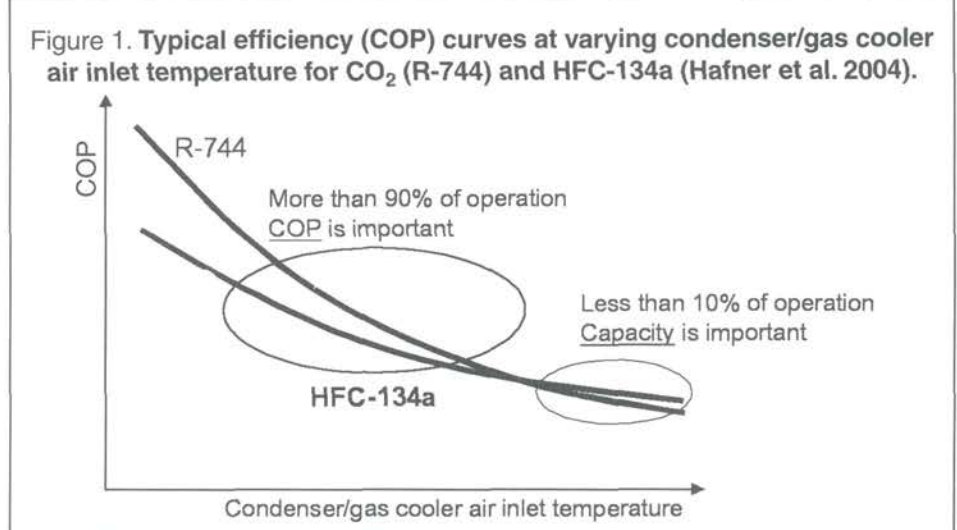
CO<sub>2</sub> systems have been commercialised in some applications, are readily developed from an R&D point of view for several different applications and systems for yet others applications are still under development.

#### Commercial Refrigeration

The commercial refrigeration sector represents the largest GHG emissions from refrigerant leakage within the refrigeration sector, more than 40% of the CO<sub>2</sub>-eq emissions.

Figure 3 shows total yearly CO<sub>2</sub>-eq emission for a supermarket in kg CO<sub>2</sub>-eq. Assumptions; charge 600 kg HFC-404A, yearly leakage 30% (world average), end of life recovery 50%, seasonal COP of refrigeration machinery 2,5 and a yearly operation time of 75 % with a nominal capacity of 250 kW. Power production are illustrated for an average European power system (0,51 kg CO<sub>2</sub>/kWh), Norway (0 kg CO<sub>2</sub>/kWh) and Denmark (0,84 kg CO<sub>2</sub>/kWh). World average is 0.57 kg CO<sub>2</sub>/kWh. The figure is taken from Neksa and Lundqvist (2005). A major part of the emissions is direct emissions from refrigerant leakage. Even though leakage may be reduced by better containment and red. charge, it illustrates the great need for non-HFC alternatives.

CO<sub>2</sub> is an important refrigerant alternative to HFCs in commercial refrigeration systems. Some of the major companies have introduced direct sys-



tems using only CO<sub>2</sub> as a refrigerant with a transcritical/subcritical cycle, depending on ambient temperature, for both low- and medium-temperature refrigeration. So far, between 10 and 20 supermarkets have been built in Europe with this kind of system design, from Italy in south to Norway in north. Energy consumption and cost is reported to be within the range of today's direct expansion R-404A systems and indirect system designs, Giroto et al. (2004). Reduced cost and increased energy efficiency is expected due to ongoing development. Further LCCP figures and mitigation cost data may be found in Harnish et al (2003) and IPCC/TEAP (2005).

Also in the light commercial sector, i.e. stand alone equipment such as bottle coolers and vending machines, some of the major companies have intro-

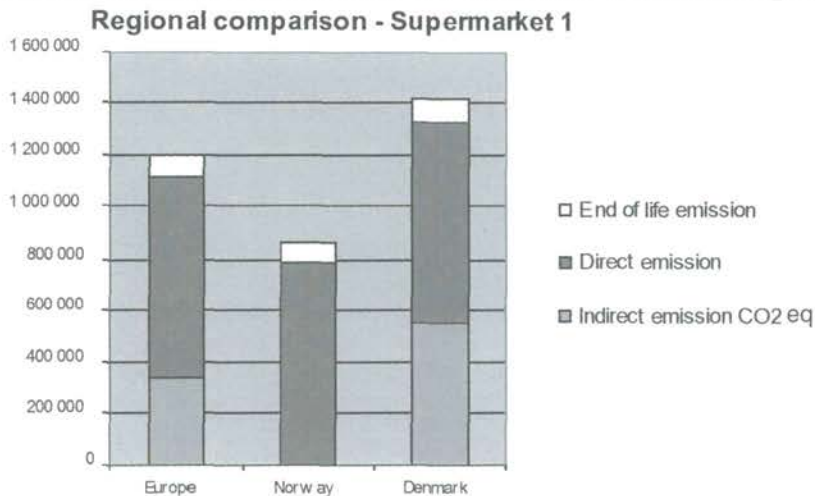
duced CO<sub>2</sub> technology (RefNat 2004). Jacob et al. (2006) reported 4000 units installed in a pre-commercial deployment test. Efficiency comparison with comparable HFC systems shows that CO<sub>2</sub> competes well for even most of the hot climates around the world. Zimmermann and Maciel (2006) showed very promising energy efficiency for both medium temperature and low temperature cabinets.

#### Mobile Air Conditioning

Mobile air conditioning is the application with the largest HFC emissions and the second largest GHG emissions in CO<sub>2</sub>-eq resulting from refrigerant emissions. This is also one of the reasons why EU will ban use of HFC-134a in mobile air condition systems for all new car models from 2011.

Hafner et al (2004) gives an in-depth

Figure 3. Direct, indirect and end of life emissions from a supermarket with refrigerant emissions representative for the world average, kg CO<sub>2</sub>-eq.



with HFC as refrigerant. Stene et al. (2006) presents CO<sub>2</sub> systems for combined heating and cooling of non-residential buildings. The theoretical evaluation demonstrates that CO<sub>2</sub> systems can achieve equal or higher seasonal performance factor than heat pumps using HFC refrigerants. Air-to-air reversible residential heat pumps are also under development.

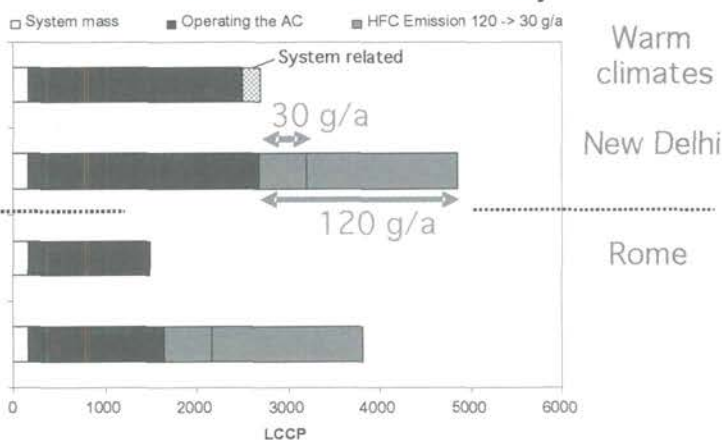
### Other Applications

R&D of CO<sub>2</sub> systems for several other applications are being performed. Transport refrigeration, containers and bus air conditioning are all applications with large emissions, where development of alternative systems will be important.

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Figure 4. Life Cycle Climate Performance (LCCP, kg CO<sub>2</sub>-eq) comparison between CO<sub>2</sub> (R-744) and HFC-134a for the relatively hot climates New Delhi in India and Rome in Italy.



LCCP comparison between CO<sub>2</sub> mobile air conditioning systems and HFC-134a and HFC-152a systems based on experimental data and climate data from different cities around the world. Compared to HFC-134a the investigations showed 18-48 % reduced LCCP, and thereby reduced emissions, for the CO<sub>2</sub> system. Least reductions for the very hot climate of Phoenix in USA and most for a more moderate German climate. Figure 4, from Hafner and Nekså (2006), shows calculated LCCP figures for CO<sub>2</sub> and HFC-134a for the hot climates of New Delhi in India and Rome in Italy. Leakage rates of 120 g/a for the HFC-134a system represents today's global average emission rate from these systems, while 30 g/a is expected to be best case future emission scenario.

As shown, significantly reduced emissions can be achieved by changing to CO<sub>2</sub> as refrigerant.

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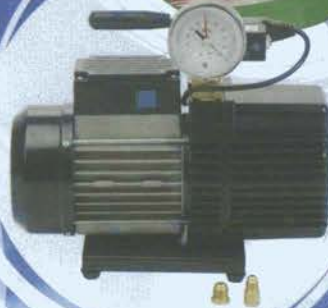
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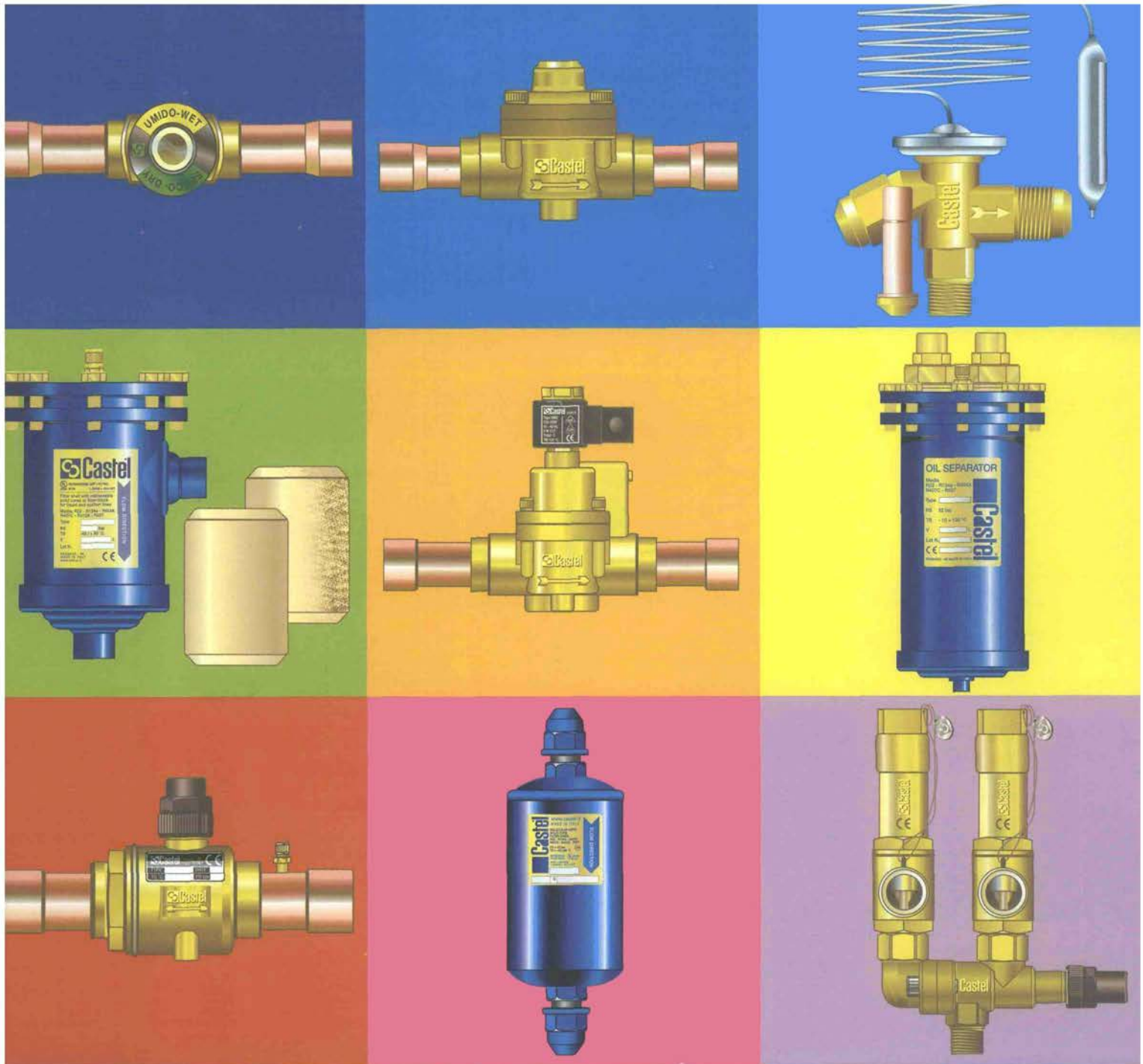
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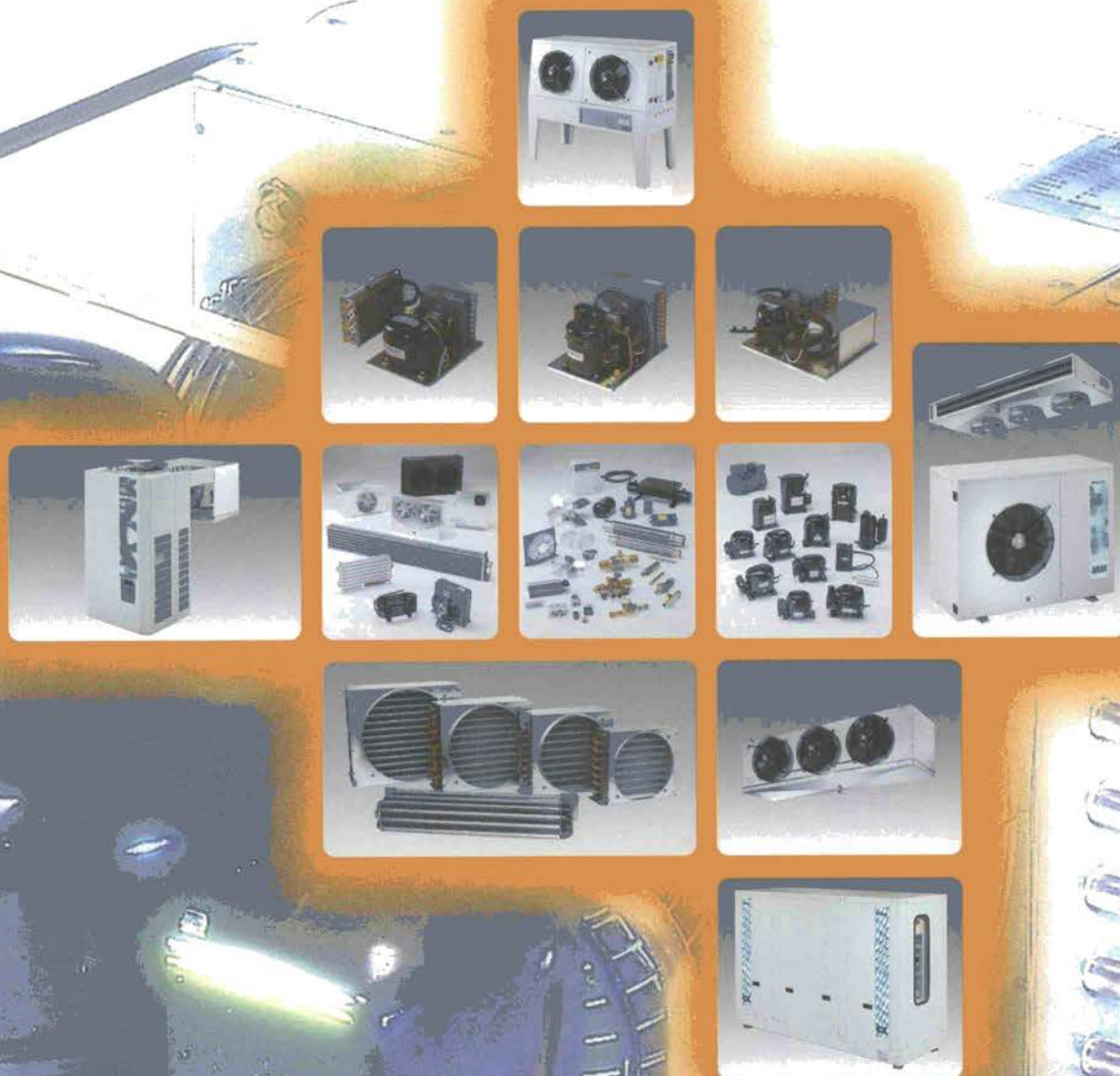
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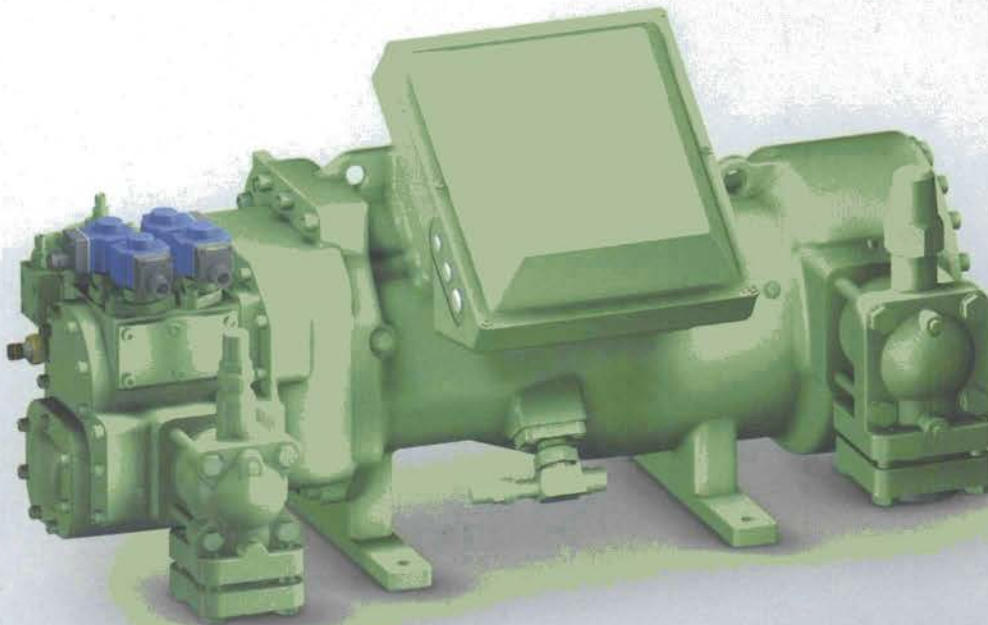
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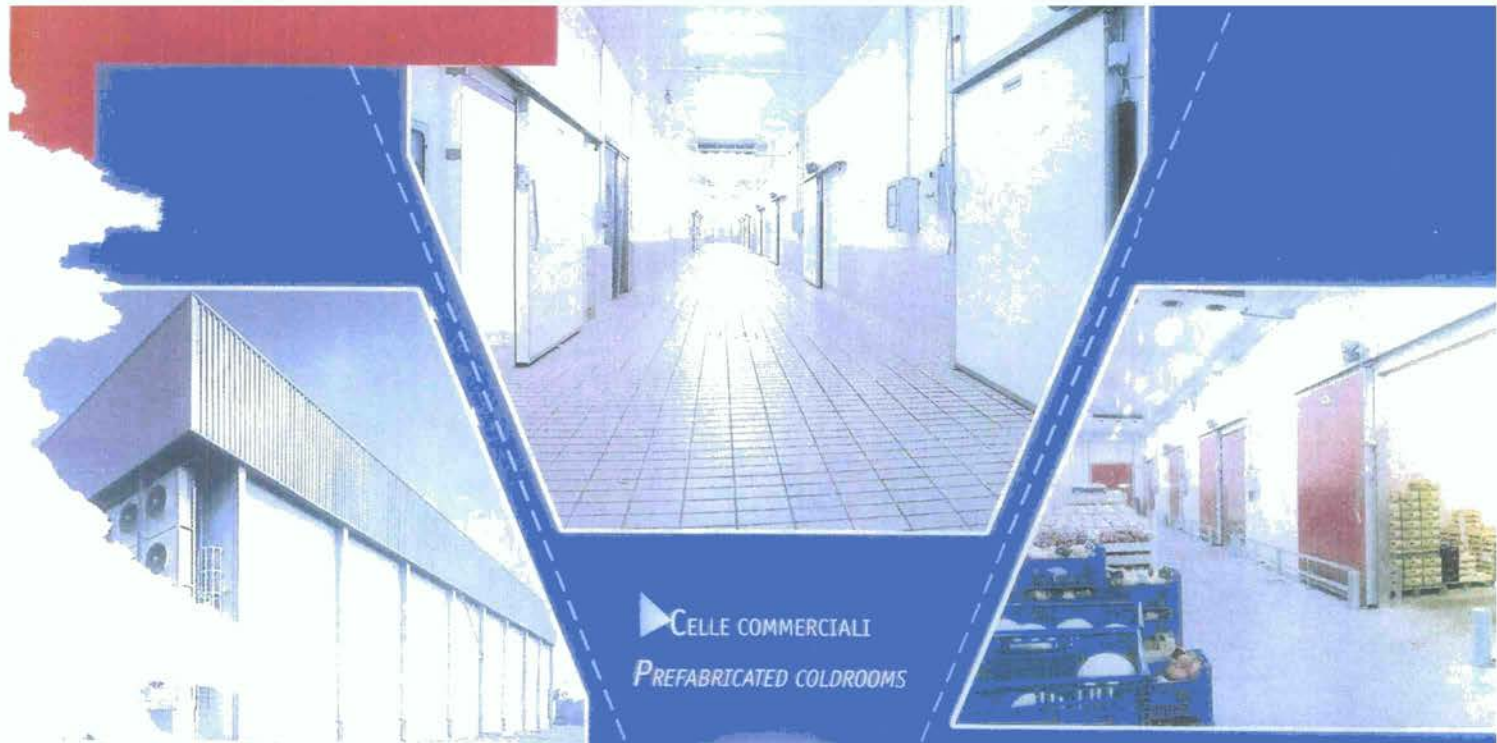
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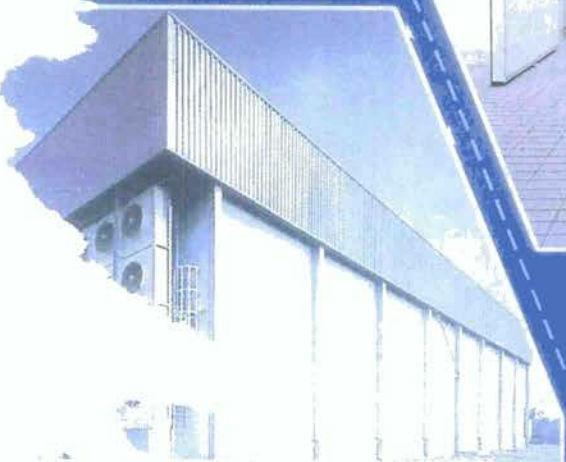
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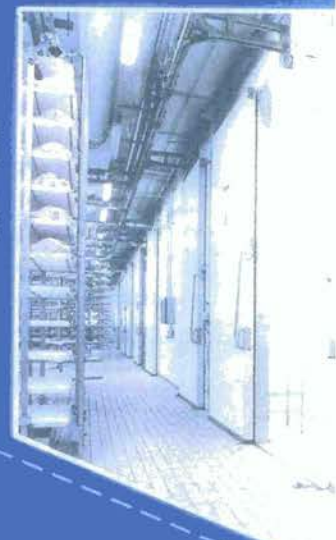
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