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Ozone-friendly industrial development

**Impact and lessons learned—  
refrigeration and alternative  
technologies for  
domestic appliances**

UNIDO in the Montreal Protocol—  
technology transfer to developing countries



UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION  
economy environment employment

# **Ozone-friendly Industrial development**

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- technology transfer to developing countries**

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Technologies  
for Domestic Appliances**



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All tons are metric and all dollars are U.S. dollars.

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## About this series

This booklet is one of a series of six, designed for specialists interested in the effectiveness and efficiency of UNIDO's sectoral programmes for phasing out the use of ozone depleting substances (ODSs) by industry and agriculture. Covering refrigeration and alternative technologies for domestic appliances, refrigerant management plans, plastics foams, solvents (including process agents and aerosols) and fumigants, they focus on the complex interventions required to replace technologies, equipment and operating procedures in the main ODS-consuming sectors. Each sector calls for a different set of technical, economic and (in some cases) social solutions. Case study presentations show that the common benefit of adopting of ozone-friendly technologies is the opportunity to improve productivity, product design and quality and to move into new markets. The series documents not only the implementation of cost-effective projects, but also the many indirect benefits of UNIDO's work—such as technology transfer, employment generation, support for SMEs and institutional capacity building.

The series places UNIDO's efforts as an implementing agency for the Multilateral Fund (MLF) of the Montreal Protocol in the context of UNIDO's mission to support developing countries and countries in transition in their pursuit of sustainable industrial development. UNIDO interprets such development as the accomplishment of three things: (i) protecting the environment—with industry complying with environmental norms, efficiently utilizing non-renewable resources and conserving renewable resources; (ii) encouraging a competitive economy—with industry producing for export as well as domestic markets; and (iii) creating productive employment—with industry promoting long-term employment and increased prosperity.

## Abbreviations

CFC	chlorofluorocarbon
COP	coefficient of performance
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
MLF	Multilateral Fund of the Montreal Protocol
MP	Montreal Protocol
NGO	non-governmental organization
ODS	ozone-depleting substance
ODP	ozone-depleting potential
PU	polyurethane
R & D	research and development
TÜV	Technischer Überwachungsverein

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## FOREWORD

The year 2002 has seen a milestone in UNIDO's contribution to preserving the stratospheric umbrella that protects life on earth from the sun's radiation - the ozone layer. Eleven years ago in October, the Organization became an implementing agency to the Montreal Protocol. It accepted, thereby, the challenge of helping cut back the use of ozone depleting substances (ODSs) that threaten the future of all life forms on our planet.



In that short interval since UNIDO became an implementing agency for the Montreal Protocol's Multilateral Fund, the Organization successfully eliminated an annual consumption of more than 24,500 tons of industrial chemicals that would otherwise have torn an even larger hole in the protective ozone shield. The allocation of 25 per cent of the Multilateral Fund's resources to UNIDO, increasing, as of 2003, thanks to the strong portfolio of projects, is unequivocal recognition of the Organization's track record in tackling the industrial challenges of today's world.

Working closely with the Fund's Secretariat and the United Nations Environment Programme, UNIDO applies its expertise in industry to transferring technology and know-how so that ODS consumption and its ozone depleting potential are reduced. Their impact has far exceeded the limited staff resources available within the Organization. A major success factor has been the establishment of an organizational branch dedicated to Montreal Protocol activities, which I created when transforming UNIDO in 1998.

Since then, UNIDO's role in combating ozone depletion has gone from strength to strength. But it has also taken on a new dimension, namely to help developing countries to benefit from globalization through increased trade. By enabling their industries to comply with environmental export requirements, UNIDO has opened up new markets for their industrial goods thus encouraging the growth of selected manufacturing sectors. The cooperation between UNIDO, the Multilateral Fund, other international agencies, donors and ODS technology recipients in pursuing the goals of the Montreal Protocol, demonstrates that collective multilateral efforts can indeed have a substantial impact on threats - environmental, economic and others - that face mankind.

Meanwhile the task of eliminating ODSs from industry is far from finished. To meet the challenges ahead, UNIDO is expanding its support for Montreal Protocol activities. In addition to individual projects to transfer ozone-friendly technologies, UNIDO will help developing countries plan their own phase-out programmes for ODSs. This summary booklet and its accompanying technical reports are an insight into one of the key value-added services that UNIDO offers its clients. They are also an industrial blueprint for protecting the ozone layer in the twenty-first century.

Carlos Magariños  
Director-General



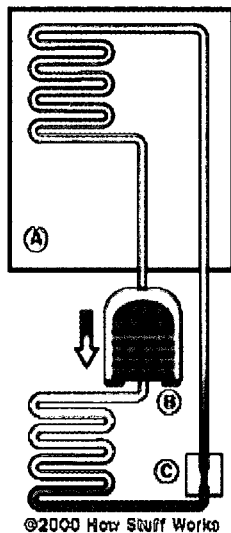
# Refrigeration

## *Refrigeration sector*

Refrigeration, making or keeping things cold, is a process with a very wide range of applications in the modern world. It allows us to preserve perishable food and distribute it over large distances. It is essential in many manufacturing processes including the production of food and pharmaceuticals, and it provides air conditioning for buildings, automobiles and other transport systems.

There are many types of refrigerating equipment, from common domestic refrigerators and freezers to air conditioners, heat pumps and chillers. They all operate on the same principle: when a solid is liquefied, or when compressed air expands, it absorbs heat. In most refrigeration systems a working fluid or refrigerant is used cyclically. In one part of the cycle, the process absorbs energy from the object being cooled, in another part the energy is dissipated to some form of heat sink. The typical refrigeration cycle of the domestic refrigerator is one of the most common examples.

A - Inside the refrigerator, B – Compressor, C - Expansion Valve or Capillary tube



1. The **compressor** compresses the refrigerant gas, which heats up as it is pressurized (orange).
2. **Coils** (the condenser) on the back of the refrigerator allow the hot refrigerant gas to dissipate its heat. Still at high pressure, it then condenses into refrigerant liquid (dark blue).
3. The high-pressure refrigerant liquid flows through the **expansion valve** or (in domestic or other smaller appliances) a **capillary tube**. On one side there is the high-pressure refrigerant liquid. On the other the pressure is lower because the compressor sucks the gas out.
4. As it passes through the expansion device (light blue)—the evaporator—the liquid refrigerant immediately boils and vaporises. This causes its temperature to drop considerably making the inside of the refrigerator cold.
5. The cold refrigerant gas is sucked up by the **compressor**, and the cycle repeats.

## *Refrigerant CFC*

When mechanical refrigeration systems were first developed, the most commonly used refrigerants were ammonia, carbon dioxide, sulphur dioxide and methyl chloride—all of which are toxic or hazardous. However, in 1931 a safer alternative became available with the introduction of CFC-12, the first chlorofluorocarbon refrigerant. CFC-12 has about the same boiling point as ammonia but in contrast to earlier refrigerants was non-flammable, non-toxic and showed low corrosiveness as well as excellent chemical stability. CFCs were also easy and inexpensive to produce and within a short time were widely adopted.

Except in some large industrial refrigeration equipment where ammonia is still used, they became the most commonly used refrigerants.

During the next 50 years or so, CFC applications expanded into a wide variety of areas and grew into a \$2 billion a year industry. World-wide consumption by 1988 reached over one million tons. It started to decline only after the environmental hazards associated with the release of CFCs into the atmosphere were internationally recognized, and regulations were put into force in accordance with the Vienna Convention of 1985 and the Montreal Protocol of 1987. By 1991 only 260,000 tons were used in refrigeration equipment world-wide.

In many countries, the majority of CFCs consumed are used as refrigerants and in less industrialized countries the refrigeration sector typically accounts for between 60 to 100 per cent of the total national consumption of ozone-depleting substances.

Chlorofluorocarbons have traditionally also played another significant role in refrigerator manufacturing, as the blowing agent in the polyurethane foam that is commonly used to insulate refrigerators and other refrigeration equipment.

CFCs are released from refrigeration equipment primarily when they are being serviced or disposed of. This means that even if CFCs were substituted in all newly produced refrigerators and air conditioners, there would still be emissions from the stock of older units. In highly industrialized countries, in fact, an important source of CFCs emissions is the high leakage rate from air conditioners in cars.

World-wide annual production of refrigerators and freezers is estimated as 72 million units (see table 1).

Annual growth rates, in rapidly developing countries like China, India and Indonesia are 15 per cent, over twice that in industrialized countries (7 per cent). Meanwhile, there are hundreds of millions of domestic refrigerator units already in use world-wide.

In the United States alone there are 150 million refrigerators and 100 million auto air conditioners in service. Good maintenance, conversion to non-ODS refrigerants and waste management of the older refrigeration appliances and equipment are therefore very important. Table 2 illustrates the actual situation in 1991, the baseline year.

<b>Region</b>	<b>Annual refrigerator production (million units)</b>
North America	11
Western Europe	17
Japan & Pacific OECD	6
Countries in transition	6
Latin America	6
Sub-Saharan Africa	1
West Asia/North Africa	4
India	2
China	14
S.E. Asia	5
<b>Total</b>	<b>72</b>

<b>Sector</b>	<b>New equipment and service (tons)</b>	<b>Banked in existing systems (tons)</b>
Domestic refrigerators and freezers	9,000	120,000
Commercial refrigeration including display cases and vending machines	55,200	no data
Cold storage and food processing	28,500	no data
Industrial refrigeration including chemicals, pharmaceuticals and ice manufacture	5,000	no data
Chillers	7,900	23,000
Transport refrigeration (truck, ship, rail)	7,000	60,000
Mobile air conditioning	147,000	600,000
Heat pumps (cooling/heating and heating only)	1,000	
<b>Total (for sectors where data are available)</b>	<b>260,600</b>	<b>803,000</b>

Source: Technology and Economic Assessment Panel of the Ozone Secretariat (1991 Assessment Report)

### ***Insulation foam blowing CFCs***

The other major application for CFCs in refrigeration is their use (mainly CFC-11) as blowing agent for rigid polyurethane foam insulation used in freezers, cold rooms, refrigerated cabinet walls and doors. Rigid foam not only acts as a thermal insulator but also serves as an essential structural component of the unit. Manufacturing a traditional domestic refrigerator or freezer requires approximately 120 to 200g of CFC-12 refrigerant and about 800g of CFC-11 blowing agent, i.e. almost 1 kg of CFCs per refrigerator/freezer. Based on current production levels of around 72 million units, the global consumption of CFCs for refrigerator production would have been about 70,000 tons of CFCs per year, if no measures had been taken to convert manufacturing from CFC to non-CFC technologies,.

### ***Refrigeration sector projects***

Realising the extent of the problems in this area, UNIDO initiated an ambitious programme in the refrigeration manufacturing and service sectors as soon as it became an implementing agency of the Multilateral Fund.

Table 3 presents the share of MLF approved refrigeration, compressor and recovery/recycling investment projects managed by UNIDO through to December 2002. It shows that refrigeration projects have the largest share in the UNIDO portfolio (57% in value and 49.9% in phase-out impact i.e. higher than the average of the Fund's portfolio). The leading role of UNIDO in this sector is evident in the 30.1% of the total amount approved for this sector by the Multilateral Fund for UNIDO projects, i.e. significantly greater than UNIDO's share of the total investment project fund of the MLF (only 24.5per

cent). UNIDO's refrigeration projects are 17.3 % more cost-effective than the sectoral average of all implementing agencies and UNIDO has been spending only \$10.65 per kg of ODS phase-out while the average of the total portfolio of the Fund was \$12.17 /kg.

**Table 3 UNIDO's share in refrigeration conversion (end 2002)**

Item	UNIDO		Multilateral Fund	
	Total	Share of total (per cent)	Total	% of Total
ODP phased out in refrigeration, (ODP tons)	13,489	37.7	39,192	22.7
MLF funds approved for refrigeration), \$ millions	143.7	50.6	477.4	36.8
Cost effectiveness \$/kg	10.65		12.17	
Funds for UNIDO refrigeration projects as compared to the total funds approved for refrigeration sector for all implementing agencies				30.1
Number of UNIDO refrigeration projects as compared to the total number of projects approved for refrigeration sector for all Implementing Agencies				31.5
Share of UNIDO in the total investment project fund approved for all Implementing Agencies				23.8

Source: MLF 38<sup>th</sup> Inventory

### *Conversion Technologies*

In the second half of the 1980s, all leading refrigerant and polyurethane foam manufacturers, in close co-operation with the refrigeration industry, started to search for CFC alternatives. Huge funds and human resources were invested in R & D and several replacements—basically new chemicals—were identified. The best alternatives were found to be hydrochlorofluorocarbons and hydrofluorocarbons (HCFCs and HFCs). Both were man-made chemicals; they were also:

- Physically and chemically inferior to traditional CFCs;
- Not readily available and more expensive than the respective CFCs;
- Still ozone-depleting (in the case of HCFCs), although less so than the equivalent amount of CFCs;
- High (in the case of HFCs) in global warming potential;
- Regarded (in the case of HCFCs) as transitional substances, and already regulated or being banned in many European, North American and Asian-Pacific countries. Regulations restricting them in also Article 5 countries are expected;
- Greenhouse gases (in the case of some HFCs) regulated under the Kyoto Protocol.

As the Montreal Protocol obligations approached at the end of the 1980s, when HCFCs and HFCs were the only alternatives available, refrigeration equipment manufacturers initially began to modify the foaming process—using a mixture of 50% CFC-11 and 50% water to reduce the amount of CFC-11 used for foam blowing, for example. Then, as soon as the new chemicals became widely available in industrialized countries, producers started to convert their foam technologies and their products, mainly to HCFC-141b, or in some cases to HFC-134a foam blowing agent. The refrigerant of choice in domestic

refrigeration was HFC-134a. In the commercial and industrial refrigeration sector, other HCFCs and blends were also introduced in addition to HFC-134a.

Conversion to these new alternatives required both changes in appliance manufacturing technologies and introduction of sophisticated production equipment. It was also necessary to modify the design of the refrigeration products to compensate for the adverse effect of the inferior technical properties of the new alternatives. In 1991 all the implementing agencies of the Multilateral Fund also started to follow this route.

In the spring of 1992, the NGO Greenpeace initiated production of the world's first domestic refrigerator that was totally free of any fluorocarbons, the 'Greenfreeze'. It used hydrocarbons for both the insulation foam blowing agent and the refrigerant. The initial refrigerant was a mixture of propane (R290) and isobutane (R600a); cyclopentane was employed for foam blowing. Later, as soon as the appropriate components became available, pure isobutane gas took over as the refrigerant. The chemicals' main benefits compared to their synthetic counterparts were:

- Natural (not man-made) products;
- Harmless to the ozone layer;
- Insignificant with respect to global warming potential;
- Compatible with materials normally used in refrigeration equipment;
- Similar in terms of physical properties to CFCs;\*
- Higher in cooling capacity—less refrigerant is needed (40 per cent compared to CFC-12);
- Lower in price compared to HFC refrigerants and HCFC blowing agents—so that today they are even cheaper than CFCs.

\* The insulation properties of cyclopentane are slightly inferior to CFC-11, but the efficiency (coefficient of performance) of isobutane is better than CFC-12;

Technical parameters and process changes using environmentally benign alternatives to CFCs are presented later in the section on alternative technologies for domestic appliances. Their major disadvantage, namely that they are flammable, has to be mitigated through adequate safety measures in production and product design.

In Europe, hydrocarbon-based refrigerators first went into mass production at Foron, a former East German company struggling for survival. Well-received by German consumers thanks to their environment friendly image, their concept was quickly adopted by large European refrigerator manufacturers that soon recognized the market appeal of the new line of fully CFC-free appliances.

The energy efficiency of hydrocarbon refrigerators has proved to be as good as, or better, than those using CFCs or HFC-134a refrigerant, and insulated with foam blown with CFCs or HCFC-141b. Moreover, the efficiency of hydrocarbon refrigerators will further improve as the technology continues to develop. A European company has developed a new hydrocarbon compressor, for example, that is approximately 40 % more efficient than previous designs. As a result, hydrocarbon technology is now the most common approach for domestic refrigeration manufacturing in Europe. Models are now marketed in virtually all European countries and all the major European companies offer hydrocarbon technology-based refrigerators. More than 90 per cent of new refrigerators sold in Austria and Germany now use isobutane as the refrigerant.

Hydrocarbon refrigeration technology has also spread to other continents, such as Asia, notably to developing countries that can ill-afford a two step CFC phase-out (first to transitional substances and then to hydrocarbons).

The use of HCFC-141b as foam blowing agent was meanwhile banned in Europe, Japan and the United States as of 2002/2003. The foresight of UNIDO engineers (see below) thus saved time and resources for many enterprises, which, by following UNIDO's advice to adopt the latest technology offered by the MP funding framework, could gain prompt access to international markets.

### *Technology transfer leadership*

UNIDO, which became an Implementing Agency two years after the United Nations Development Programme (UNDP) and the World Bank, formulated its first investment projects in the refrigeration sector in 1993. Their target was domestic refrigeration companies in Egypt, Jordan and Iran. UNIDO never considered the 50 per cent CFC-reduced foam option, realizing from the very beginning that it would only be a first and very short transitional step. UNIDO's first concept was prepared using HCFC-141b foam and HFC-134a refrigeration technology.

The team of UNIDO engineers working on Montreal Protocol projects was also quick to recognize the emerging trend towards cutting edge hydrocarbon technologies. In close cooperation with the management of UNIDO Montreal Protocol operations, it started to actively advocate them. As a result, projects for Iran, Jordan and Egypt were rapidly redesigned for cyclopentane foaming technology, gaining approval from the Executive Committee of the Multilateral Fund in mid-1994.

Acceptance of isobutane refrigerant technology by both the Executive Committee and the major European manufacturers took more time—until sufficient evidence could be collected regarding the feasibility, safety and appropriateness of the technology and commercial availability of isobutane in Article 5 countries. Thanks to the pioneering role of UNIDO, the first two fully hydrocarbon (isobutane and cyclopentane) domestic refrigeration projects were approved by the Executive Committee as early as 1995. They were for UNIDO's conversion of two large Chinese refrigerator producers and were followed in the same year by two further UNIDO-designed projects—for converting the operations of two Chinese compressor manufacturers to isobutane. Transfer of the latest technologies to developing countries by UNIDO therefore took place within two years of their introduction in Western Europe—a feat unprecedented in any other field of industrial technology.

Statistics (see table 4) show that the amount of CFC replaced by the latest technologies through UNIDO projects (60.2 per cent and 55.3 per cent respectively) is well above the average of UNIDO's share in the total refrigeration sector portfolio of the Multilateral Fund (42 per cent). UNIDO thus leads the way in promoting transfer of the latest technologies to developing countries in the refrigeration sector.

**Table 4 Conversion technologies in UNIDO's refrigeration portfolio\***

Conversion type	Conversion to	CFC phased out, (ODP tons)	
		(ODP tons)	(%)
1	Foam: Cyclopentane	3,329.8	
	Refrigerant: Isobutane	624.5	
2	Foam: Cyclopentane	4,360	
	Refrigerant: HFC-134a	1,295.5	
3	Foam: Cyclopentane	17.0	
	Refrigerant: HCFC-22	30.0	
4	Foam: HCFC-141b	1,841.9	
	Refrigerant: HFC-134a	919.2	
5	Foam: HCFC-141b	58.5	
	Refrigerant: HCFC-22	2.5	
6	Refrigerant: HFC-134a	88.35	
<b>Replacement alternatives</b>		<b>UNIDO's share of total MLF approval by substance</b>	
		<b>(ODP tons)</b>	<b>(%)</b>
Total cyclopentane (foam blowing agent)		7,706.8	55.3
Total isobutane (refrigerant)		624.5	60.2
Total HFC-134a (refrigerant)		2,303.05	35.3
Total HCFC-141b (foam blowing agent)		1,900.4	22.8
<b>Grand total</b>		<b>12,534.75</b>	<b>42</b>

\* All refrigeration projects approved up to the 39th MLF Executive Committee meeting, excluding compressor, recovery and recycling sub-sectors (April 2003)

Source: MLF 39<sup>th</sup> Inventory

#### *Scope and approach of conversion projects*

Conversion for developing countries has not come easily. One of the main reasons is the relatively long process that must be followed for an enterprise to gain conversion funding from the Multilateral Fund. It begins when the government requests UNIDO to provide assistance in the phasing ODS out of the refrigeration sector. One of the refrigeration experts from the Montreal Protocol Branch of UNIDO then visits the country to identify eligible enterprises (usually in co-operation with the National Ozone Office) and to collect baseline production, consumption, technological and product data. One of the main tasks of UNIDO's staff during the discussions with the company management is to inform the enterprise concerning the full range of currently available conversion technologies. In co-operation with the plant, they help select the most appropriate one, taking into consideration the specific conditions of the enterprise and its market. UNIDO then prepares the project, clears it with the Government and the enterprise, and submits it for approval to the Executive Committee of the Multilateral Fund.

Through the conversion projects approved by the Fund, UNIDO provides assistance in:

- Specifying required equipment and services;
- International and local bidding
- Selecting and procuring new machinery and equipment;
- Modifying existing machinery and equipment, wherever technically and economically feasible and/or necessary;
- Redesigning, reconstruction, prototyping manufacture and testing of new refrigerators and freezers;
- Installation commissioning, trial operation, start-up and on-the-job operational training;
- Training in maintenance and safety techniques and procedures;
- Safety inspection and certification of the manufacturing technologies and products.

All of these activities require frequent and close cooperation with the counterpart to achieve project goals on time, within the specified quality targets and within funding limitations.

The process is usually further complicated because the conversion projects are usually not “green field” projects. They have to be carried out in factories where production can only be suspended during specified low production periods and for a very limited duration.

### *Safety*

Perhaps the most difficult part of conversion to hydrocarbons is mitigating hazards related to their explosive and flammable nature, an area pioneered by UNIDO. When the first projects were underway (in 1994-1995) the processes were so new that only a few companies and experts were conversant with them. From information collected by UNIDO engineers from suppliers of chemicals, machine manufacturers, manufacturers of refrigerators, compressor manufacturers, universities and research institutions, it soon became clear that it was not sufficient only to supply components and machines certified by the manufacturers according to the applicable safety standards. The whole production cycle (storage, handling and transportation of hydrocarbons within the plant, processing and charging hydrocarbon and the mixtures into the appliances etc.) had to be inspected and certified as a safe working system at the site after commissioning the new technology. Hazardous situations had to be prevented up front, i.e. safety had to be built in and not added on. Furthermore, proper operation of the system had to be monitored and, in case of any malfunction, countermeasures had to be automatic. In order to avoid unnecessary delays and extra cost, the inspection and certification process had to start right from the beginning of the equipment and process design, and to follow the whole conversion process to its completion. This concept was new—even for the manufacturers of the foaming and refrigerant charging equipment.

After contacting a number of institutions providing safety inspection and certification services, UNIDO selected the German technical safety association, TÜV. TÜV had experience in certifying hydrocarbon refrigeration and foaming technologies from the beginning of their commercialisation. On the insistence of UNIDO, foaming and refrigeration equipment suppliers signed co-operation agreements with TÜV immediately after contracting to supply equipment. They were thus bound to co-operate closely, and to follow TÜV’s advice and instructions throughout the design, manufacturing, commissioning and start-up phases of the project. The suppliers had to prepare safety



concepts and follow them through with the involvement of the recipient company and local safety authorities. One of the major components of this process was the training of plant technicians and operators in safe handling of hydrocarbons, processing and maintenance. Thanks to strict adherence to this method, there have been no safety problems at any of the UNIDO hydrocarbon conversion projects.

### *Product quality*

All Montreal Protocol projects aim to reduce the ozone depletion caused by regulated substances. However, unless appropriate countermeasures are taken, conversion to the new technologies and alternative chemicals will affect (usually adversely) the quality of the products being manufactured. Thus, in order to maintain the quality of the products, there is a need to evaluate the influence of the new technologies, and to plan and implement appropriate interventions. For example, in the case of refrigeration appliances, the operation and design of the cooling circuits has to be optimized. UNIDO often finds that appliances were designed many years earlier and that even the original design was not done in accordance with the best product design practices. In most cases, UNIDO projects deal with appliances that are outdated in terms of efficiency and energy consumption. The conversion process therefore provides an opportunity to implement important product modifications taking advantage of new design principles and components that fully utilise the increased efficiency and other benefits offered. In case of hydrocarbon refrigerant, additional design changes are required to ensure safety of the products.

To address the crucial issue of quality and technical level of the product, UNIDO assists the recipient companies to implement redesign with the help of international consultants and research and design institutions. For this purpose, UNIDO identifies a pool of reputable consultancy institutions that are experienced in refrigeration technologies and also able to work in developing country conditions and to transfer the required technology and information adapted to local needs.

In order to make the transfer of technology sustainable the process is implemented as follows. After being selected (in agreement with the counterpart) from UNIDO's roster, a consultancy company visits the project site to collect information on the baseline quality of the products. It conducts a short training programme on best practices in the design and manufacture of refrigeration equipment and demonstrates practical implementation of various parts of the product optimisation process. Appliances from various models are then selected at the plant and sent to the laboratory of the consultancy company for redesign of the cooling circuits. A similar batch is redesigned by the engineers of the recipient company at its own premises, guided by regular advisory services and information flow through e-mail.

At the end of the process the results are compared. Where there are discrepancies, the reasons are clarified during the next site visit of the consultant. If the two parties arrive at the same conclusions, it means that the engineers of the counterpart have acquired proficiency in redesign. UNIDO closely monitors the redesign process throughout, giving comments and advice on the interim reports and communications received from both parties. It resolves technical and communication problems, and makes sure that the work is done as planned and reaches its goals. Having completed the redesign of the first batch of models with the assistance of the consultant, local engineers continue the redesign of the remaining models on their own. The company is thus able to produce the converted products right after completion of the conversion of the production lines. For a full year

after the last site visit the training and consultancy programme continues from the home base of the consultant.

To facilitate application of appropriate design techniques, the laboratory facilities of the enterprises are complemented with the necessary testing instruments, and with data collecting, logging and processing equipment and software. The success criteria are the rate and stability of cooling efficiency, energy consumption and safety of the appliances. It is also necessary to ensure incorporation (to the extent possible) of domestic components and raw materials in order not to increase the share of imported items used.

The above approach has proved very effective and leads to the following results:

- Improved efficiency of appliances, even in comparison to the baseline situation;
- Appliances that meet international safety standards;
- Adherence to environmental regulations;
- Reduced energy consumption of appliances;
- Enhanced theoretical and practical skills of technical staff;
- Introduction of best practices into the manufacturing process resulting in good and consistent product quality.

#### *Conversion of technological lines*

Introduction of new refrigerants and foam blowing agents also necessitates modification and replacement of major production equipment. It is not simply equipment procurement, but rather, a complex engineering undertaking. The first and most important task of the UNIDO refrigeration expert is to review the baseline situation and (after selecting the most appropriate alternative technology) to design the new process. This has to accommodate many constraints, including site conditions, existing technological processes, layout, current production level and capacity utilization, budgetary constraints dictated by the cost effectiveness threshold, requirements of the new technology; availability of skilled personnel, raw materials and utilities (power, water, steam etc.). The UNIDO expert has to arrive at a balanced solution that satisfies both the requirements of the plant and the funding criteria of the MLF.

Throughout the project life, counterparts rely heavily on the advice of UNIDO, whose responsibility is significant. At the project design stage, the new technologies are mostly unknown to the recipient enterprises. Technical advisory services of UNIDO experts are therefore a major factor in the success of the design and implementation of the project. A first crucial step is to prepare the final list and specifications of the equipment and services required—recognizing that proper selection of equipment within the budgetary limitations can be the factor that determines the success or failure of a project. The whole process and its implications also have to be made clear to the recipient enterprise. Only when there is agreement of both sides on basic document can UNIDO start the international bidding and procurement process. While the technical evaluation of the bids is done by a UNIDO expert, it is carried out in close co-operation with the counterpart. The methodology thus gives plant management an insight into the international bidding procedures, upgrading its procurement skills.

During the period in which the equipment is manufactured by the supplier, the counterpart implements its own inputs to the project. Technical assistance at this stage helps in the

preparation of drawings, documentation and compilation of data of utility and infrastructure requirements. UNIDO meanwhile regularly monitors supplier activities to make sure that all inputs are provided as planned. This prevents, for example, contractors from passing on their contractual obligations to a counterpart which may not be either conversant with all the details of a conversion project, or familiar with international contracting procedures. UNIDO is therefore the main guarantor for the fair implementation of all obligations of the contractor. It also assists the contractor to resist unjustified demands from the side of the counterpart. In addition to this, regular monitoring of the process and its interventions minimizes the delays originating from either side.

### ***Secondary transfer of technology***

Other important technology transfer inputs are the project's identification of local suppliers of equipment, materials and components, and its upgrading of their skills. This enables them to supply, for example, new types of products (e.g. storage tanks for hazardous chemicals, some production equipment, new types of components etc.) according to international standards. This is part of the "secondary technology transfer" impact of conversion projects. The same applies to the installation of equipment, which is carried out by local workers under the supervision of the international equipment supplier. Here again, additional skills are passed on to the local staff to enable them to perform construction and assembly of sensitive and up-to-date equipment involving hazardous technologies, advanced electronics and controls.

## Compressor sector

Compressors are core components of refrigeration and air conditioning equipment. For domestic refrigerators and freezers, small hermetic compressors (50 – 300 W) such as that in fig. 1 are used—a typical hermetic compressor for use in a domestic appliance.

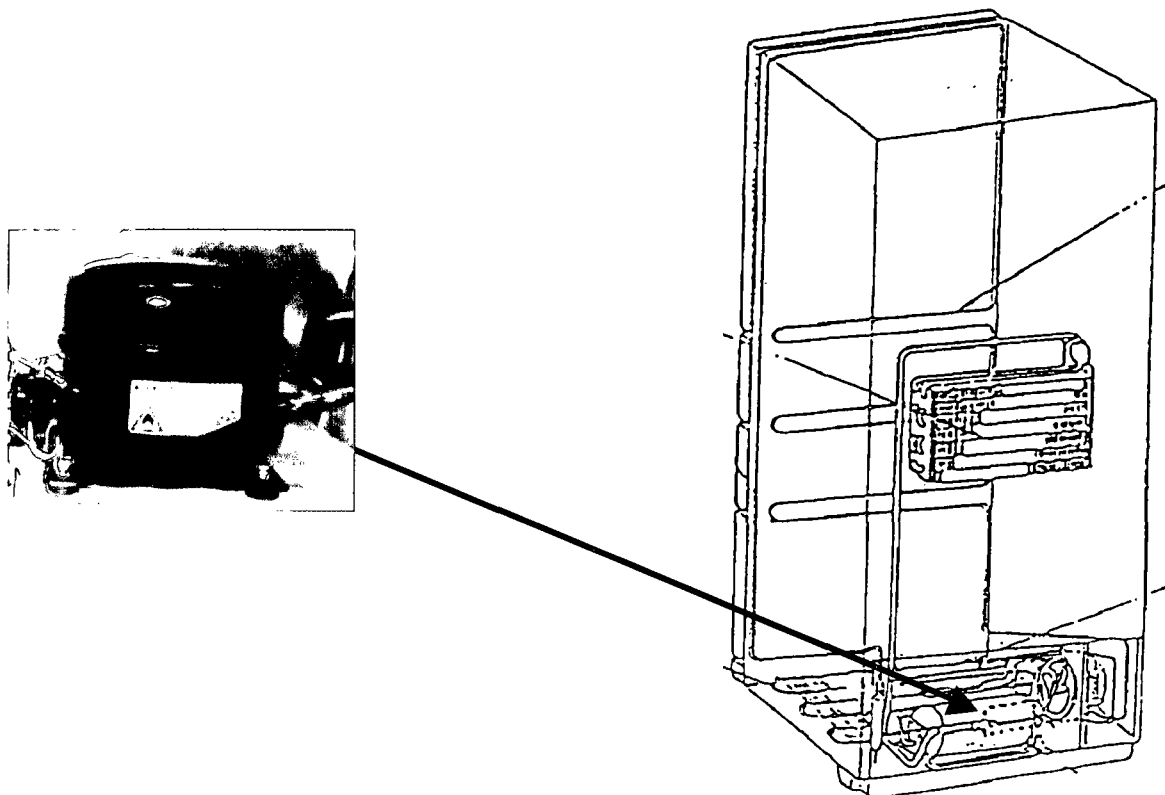


Fig. 1: Domestic refrigerators depend on small hermetic compressors

Recent figures indicate global production of hermetic compressors of between 80 to 90 million units per annum. Some 70 million are required by appliance manufacturers for manufacturing of new refrigerators and freezers; a further 20 million units per year are for servicing. Precision-engineered machines, compressors are built with around 100 or more components most of which are normally produced by the compressor manufacturers themselves. Detailed know-how is required for their design or modification, such as adapting them to new refrigerants or improving efficiency and quality. Every compressor is designed for a certain type of refrigerant and it cannot be used with another type. Replacing CFC-12 with another refrigerant may call for substantial redesign of the compressor itself and major changes to the equipment used to manufacture it.

Compressors are produced in large volumes, a company under 1 million units annual production being considered a small manufacturer. Indeed, such firms in highly industrialized countries have failed to withstand the competition, unable, for example, to

finance the large research and design costs. As a result, the compressor business has consolidated in recent decades and today only a limited number of independent (multinational) manufacturers are operational in the industrialized countries. Likewise only a few Article 5 countries have compressor factories, e.g. Brazil, China, Colombia, Egypt, India, Iran, Mexico, Thailand and Venezuela. Some operate under license from multinationals, some are jointly owned, and most serve the domestic market or supply other Article 5 countries. The MLF assists conversion of those countries' refrigerator and freezer manufacturers by ensuring the availability of non-CFC compressors from local suppliers. This is particularly significant in countries with large markets for domestic appliances markets.

Due to the scale of production in compressor manufacturing, even minor improvements or savings in production technology and design can have a significant positive financial impact for their manufacturers. Correspondingly, their technical know-how is more closely guarded than in the refrigerator manufacturing sector, and there is fierce competition among producers to make incremental improvements in compressor efficiency, a key differentiator for compressor customers. Compressor reliability is also crucial because the compressor is the heart of any refrigeration system, and its reliability determines the reliability of the whole appliance or system. Again due to the scale of production, small errors in the manufacturing process can result in a large number of rejects. If those defects remain unnoticed, and the compressors get into the marketplace, the damage to the refrigerator manufacturers' reputation can be enormous, and easily leading to major loss of market share. For all these reasons, compressor manufacturers keep their technology and designs strictly confidential.

Technology transfer is therefore a major prerequisite of the success of any compressor conversion project. However, it is very difficult to find reliable technical resources required for the conversion of CFC-12 compressors in Article 5 countries. In this context, again, the role of UNIDO has proved essential.

### ***Technology selection***

The selection of technology to replace CFC based equipment must take into account the needs of end-users (i.e. the refrigerator or freezer manufacturers). The market in which the compressor enterprise operates must therefore be carefully assessed before any selection is made. The high cost of technology transfer also has to be taken into consideration.

The principal alternatives to conventional CFC-12 refrigerants, namely HFC-134a and isobutane (R-600a), are described later. Suitable compressors for them have been developed in industrialized countries and are accepted by the Technical Advisory Committee of the Multilateral Fund. UNIDO collects detailed information on these new technologies and informs the relevant countries through workshops and site discussions.

HCF-134a refrigerant has similar physical properties to CFC-12. It is neither flammable nor toxic. However its thermodynamic properties are inferior, and its material compatibility is different from CFC-12, requiring a new type of synthetic compressor lubricant. The pressure and temperatures at discharge are also higher than CFC-12 in the refrigeration cycle. This requires extensive redesign of compressors, including

modification of sliding parts, improved surface treatment of metallic material, additional cooling systems, and noise reduction devices. Due to the hygroscopic nature of the new lubricant, stricter control of the production process of compressors is also needed. Cleaning of metallic parts has to be done with non-chlorine systems to avoid contamination with chlorinates, which are also not compatible with the new lubricant.

Isobutane has a higher refrigeration efficiency and works with conventional mineral oil compressor lubricant. However, it has a lower volumetric cooling capacity than CFC-12 (i.e. a higher volume has to be circulated by the compressor), so bigger compressors are required. In turn, modification of machining centres as well as fixtures for machining of parts is required to make the bigger compressors. Flammability is another important aspect for compressor manufacturers. For the conversion to R-600a technology, better instruments and procedures are needed to ensure zero leak of refrigerant from compressors. Performance test equipment and test rooms have to be modified for safe operation with flammable substances.

## Compressor sector projects

UNIDO started implementing compressor projects at the request of respective governments as early as 1994, when the alternative technologies became available in industrialized countries. Table 5 lists those already completed, showing how much CFC was phased out either directly or indirectly. Direct phase-out is when CFC-113 or CFC-11 cleaning systems for metallic parts are replaced by aqueous based cleaning. Indirect phase-out refers to phase-out of CFC-12 by appliances manufacturers, which is enabled by the availability of suitable compressors.

**Table 5 UNIDO Compressor projects (end 2002)**

Country	Enterprise	Project cost	ODP phase-out, (tons OPD)		Alternative technology	Remarks
			Direct	Indirect		
		\$				
Brazil	Elgin Maquinas	460,339	0	89	HFC-134a	
China	Jiaxipera	1,490,000	96	200	R-600a	
China	Xian Yuan Dong	1,590,615	0	120	HFC-134a	
China	Dongbei	898,776	60	100	R-600a	
China	Wanbao	2,249,734	3	250	HFC-134a	
China	ZEL	962,175	30	400	HFC-134a	Partly owned by foreign company
China	Yuhuan	1,453,661	116	145	HFC-134a	
China	Hangli	861,000	0	223	R-600a	
China	Changshu	2,250,000	75	120	HFC-134a	Financed from Japanese bilateral MP contribution
Iran	ICMC	1,160,148	0	250	HFC-134A	
Serbia Montenegro	Prva Petoletka	223,412	2	9	HFC-134a	

Source: MLF 38<sup>th</sup> Inventory

Table 6, which summarizes all domestic compressor projects approved by the Fund, shows that UNIDO accounted for the majority of the phase-out in the domestic compressor sector and achieved a higher-than-average efficiency of all compressor projects of the MLF.

**Table 6 Summary of domestic compressor projects**

	<b>Direct impact, (tons ODP)</b>	<b>Indirect impact, (tons ODP)</b>	<b>Project cost, \$</b>	<b>Cost effectiveness, \$/kg ODP (for indirect impact)</b>
Total MP	382	2,626	22,050,876	8.4
UNIDO	382 (100 %)	1,906 (72.6 %)	13,599,859 (61.7 %)	7.14

Source: MLF 38<sup>th</sup> Inventory

### *Technology Transfer*

UNIDO held extensive discussions with each counterpart enterprise to determine the most appropriate selection of the alternative technology, taking into account market trends and existing capability of each factory. R-600a was selected by three Chinese enterprises; all other companies in Brazil, China and Iran selected HFC-134a.

In all the projects UNIDO followed a two-stage approach. In the first step, UNIDO identifies and contracts a technology partner for the supply of technical services related to:

- Redesign of existing compressor models;
- Modification of the existing production process;
- Preparation of the list of equipment to be replaced or modified;
- Compilation of technical data of materials, components and utilities to be used for the manufacturing of the new compressor models;
- Training of counterparts in compressor redesign, laboratory and process line testing as well as quality assurance techniques;
- Advice for start up and trial manufacturing and product certification.

The second stage includes:

- Equipment purchase
- Implementation of modification of the production
- Testing and quality assurance processes.

During this second stage, to achieve the most cost-effective solution, UNIDO organizes international bidding for each equipment item independently. This approach, even though it calls for considerable effort and human resources from UNIDO, is the most effective way to keep projects within budgetary limitations. Compared to the cost of turnkey contracts offered by multinational companies, the effective work of UNIDO's refrigeration and procurement experts saves an average of \$1 million per project.

According to the rules of the Multilateral Fund, no improvement of quality should be supported by conversion projects. On the other hand, new non-CFC compressors must have higher performance than CFC-12 in order to be sold in the competitive market. Therefore, in the compressor sector, the counterparts themselves did further development work based on the training received as part of the technology transfer contract.



### *HFC-134a Projects*

As noted, one of the main problems with using HFC-134a is to ensure the cleanliness and dryness of any components that come into contact with the new refrigerant and lubricant. Thus, major equipment items to be provided are the highly efficient cleaning and surface-treatment machines using water-based cleaning technology. Many factors are to be taken into consideration: the layout of the existing factory, the particular surface treatment required for each part, the cleaning specifications required for the use of HFC-134a and the need for waste water treatment. The issue is addressed by having the technology partner provide the basic specification, and reaching a final specification through intensive discussions between UNIDO and the counterpart enterprises.

Other equipment for compressor conversion projects includes a lubricant purification and charging unit, a set of performance test instruments, instruments to check materials, and a plastic injection moulding machine for manufacturing noise reduction components. In practice, however, each project is different and the scope of supply varies considerably from one to another, depending on the existing products and manufacturing conditions. Detailed discussions with counterpart enterprises are essential in every case for the success of compressor projects.

### *R-600a Projects*

Redesign of compressors with R-600a is more straightforward than with HFC-134a technology. For two such projects, UNIDO contracted international engineering companies for the job, and in one case, the counterpart enterprise took responsibility for the conversion, working with a local research and design institution.

The production equipment affected by conversion to R-600a is primarily the machining centres, machining fixtures to make parts of compressors and some measuring and testing instruments, which are needed to ensure that compressors are leak-free and meet quality requirements. Some new performance test equipment and test rooms for flammable substances are also provided.

The selection of correct instruments depends on detailed collaboration with counterparts. Thanks to its vast experience with conversion projects in the refrigeration sector as well as its procurement capabilities, UNIDO has a significant advantage in this kind of service. All three of its compressor projects—Zel, Wanbao (see fig. 6) and Jiaxipera—evaluated among the completed compressor projects were highly ranked by the evaluation team of the Multilateral Fund in 2001, ahead of similar projects of other implementing agencies.

The compressor manufacturing industry provides a country with critical technology infrastructure for the whole refrigeration industry. Countries with large appliance markets need reliable compressor suppliers offering non-ODS technologies. On the other hand, the compressor business is global, and national manufacturers must compete with multinationals in the domestic market as well as internationally. UNIDO compressor projects provide compressor manufacturers with state-of-the-art technology, ensuring improved efficiencies and reliable product quality. This helps local manufacturers to stay in business, and develop business in domestic and international markets in a sustainable way.

Compressor manufacturers have thousands of employees, and thousands more are employed by component suppliers. Hence, sustainable development of the compressor industry is important in terms of employment.

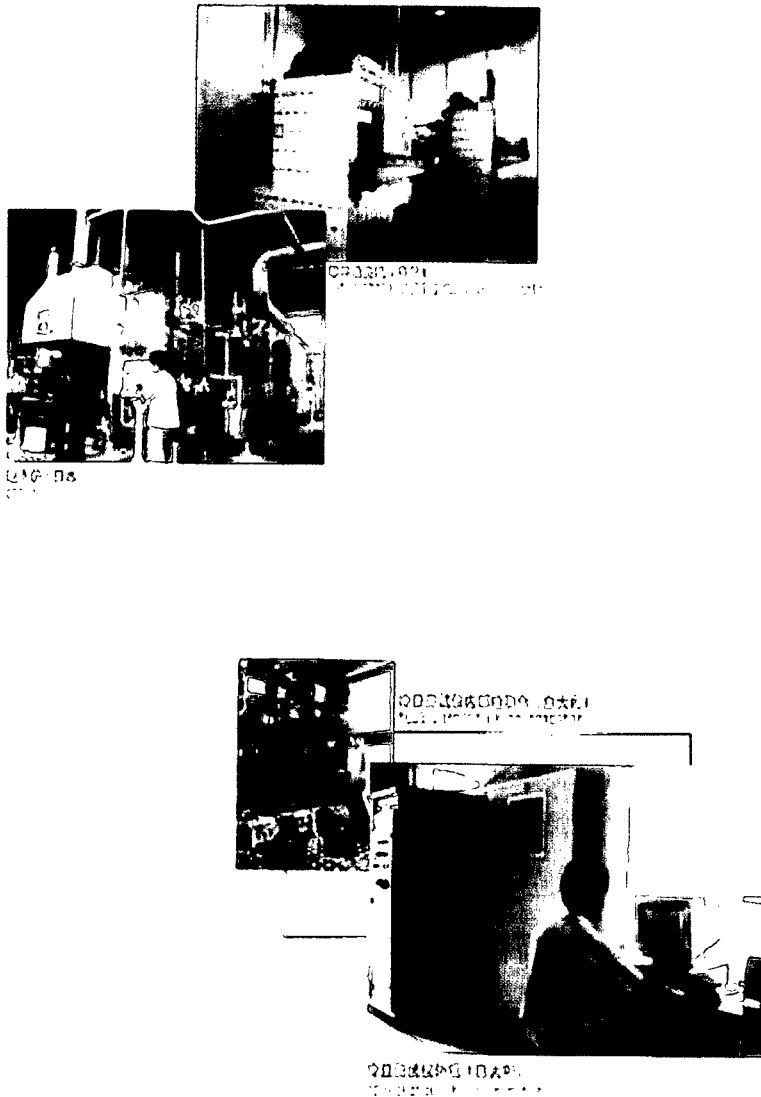


Fig. 2: Converted compressor factory and laboratory  
At Wanbao Refrigeration (China)

## **Case studies**

*Phasing CFCs out of freezer production: Qingdao Aucma Co. (China)*

Sector: Domestic Refrigeration

Company: Qingdao Aucma Co. Ltd

315 Qianwangang Road, Qingdao, P.R. China

Project no.: MP/CPR96/184

Project title: Phasing out CFC at the Freezer Plant of Qingdao Aucma Co. Ltd, China

### ***Background***

Aucma is a 100 per cent Chinese, collectively owned, enterprise. It was established in 1988 and is today the largest freezer manufacturer in the country. In the beginning it produced only chest freezers. But, as the freezer business started to flourish, the company extended its range to air conditioners, dishwashers, electric heaters and other electrical goods. In 1995, when project formulation started, its annual chest freezer production amounted to 650,000 units, representing 24 per cent China's domestic market. Exports were limited to a few thousand units yearly and were sold exclusively in developing countries. The number of employees in 1995 was 3,450.

Prior to the project, CFC-12 was used as a refrigerant and CFC-11 as foaming agent for freezer insulation. The 20 main models were destined for household and commercial uses (small shops, ice cream stalls etc.). They were produced on four assembly and 7 foaming lines.

### ***Alternative technology selection***

Aucma decided, in close consultation with UNIDO and the Government, to apply long term alternatives, i.e. cyclopentane insulation foam blowing and HFC-134a refrigerant. It rejected the hydrocarbon refrigerant option because of safety concerns and lack of sufficient information regarding application of isobutane in commercial freezers.

### ***Services provided***

Existing vacuum pumps and charging machines were retrofitted; six new production line leak detectors were purchased.

Thanks to reorganization and rationalization of the foaming department only five of the seven foaming machines were converted to cyclopentane; two old machines were disposed of. Two mixing units, cyclopentane storage facilities were installed.

Cyclopentane monitors and alarms, safety ventilation, nitrogen neutralization and automatic fire extinguishing systems were procured and installed to ensure the safety of the flammable cyclopentane technology. All equipment in the hazardous parts of foaming lines was designed, manufactured and installed as explosion proof, existing equipment was properly modified and earthed. All the new equipment and the complete manufacturing line were inspected and certified for conformity with the latest industrial safety standards by TÜV Germany.

The first batch of freezers was redesigned with the assistance of a British refrigeration institute. Aucma engineers were trained in redesign and subsequently finalized conversion of the remaining models on their own. This was facilitated by provision of up-to-date laboratory equipment to enable fast and reliable redesign of products.

Training of operators and maintenance staff in best operating and maintenance practices as well as up-to-date safety philosophy and methods was carried out in Europe and on site.

Aucma provided overall support to the project by rationalizing and relocating the production technologies to a new building at a safe site in an industrial development zone and paying for various local work and supplies.

### ***Impact***

Phasing out 708 tons of CFCs reduced the environmental impact and improved working conditions, occupational health and safety in all areas of the company. Annual production increased from 650,000 (1995) to 1,003,000 units (2001). Exports to developed countries increased from a few thousand to 170,000 units in 2001. Under an agreement with General Electric Co. (U.S.A.), 500,000 freezers were exported in 2002.

The quality assurance procedures and quality of the products were strengthened and Aucma received ISO 9001, ISO 14000 and ISO 18000 certification.

Long-term employment of staff and additional direct and indirect employment were secured through better business opportunities and human resource development.



Fig. 3: Chinese chest freezers for U.S. markets: Aucma Qingdao (China)

## *Phasing CFCs out of refrigerator production: Huari Group (China)*

Sector: Domestic Refrigeration

Company: Zhejiang Huari Group Co. Ltd

Jio Bao, Hangzhou, 310019, P.R. China

Project No.: MP/CPR/96/042

Project title: Phasing out CFC at the Refrigerator Plant of Huari Group Co. Ltd.

### *Background*

Huari is a 100 per cent Chinese, collectively owned enterprise established in 1984. Its main products are high-end refrigerators with fuzzy electronic control. In addition to some forty models of refrigerators and freezers, the company is active in other consumer goods sectors including its recently started production of electrical bicycles. Refrigerator/freezer production employs 720 people. In 1995 when the project was formulated annual refrigerator and freezer production amounted to 312,000 units, which represented a 4 per cent market share in China. There were almost no exports.

Prior to the start of the project, CFC-12 was used as a refrigerant and CFC-11 as foaming agent for the insulation of the refrigerators and freezers. The appliances were produced on four production lines installed in various buildings in different residential areas of the town.

### *Alternative technology selection*

Reflecting the company's technical capacity, market conditions and technical advice received from UNIDO, Huari pioneered the application of long term hydrocarbon alternatives in China, using cyclopentane insulation foam blowing and isobutane refrigerant. The hydrocarbon foaming agent and refrigerant were selected for their technical advantages and the innovative nature of the latest technology. As a producer of very attractive high-tech refrigeration appliances, Huari understood the strong marketing potential of fully environmentally benign and energy-efficient products. Calculations showed that the appliances could be produced with hydrocarbon technology at lower cost than with the environmentally less friendly HFC alternative.

### *Services provided*

After approval of the project, Huari decided to utilize the opportunity of conversion to CFC-free technologies to upgrade its premises and rationalize the manufacturing process. It made significant investments in a new building in an industrial zone that took into consideration the requirements of the new technologies.

On each of two assembly lines new production line leak detectors, charging stations, recovery pumps and ultrasonic welding machines were installed through the UNIDO project. All were designed for use with the flammable isobutane refrigerant. Isobutane storage and pumping systems were provided. The three foaming machines were converted to cyclopentane and a mixing unit and cyclopentane storage facilities erected. The project procured and installed cyclopentane monitoring and alarm systems, safety ventilation, nitrogen neutralization and automatic fire extinguishing systems that ensured the safety of

the flammable cyclopentane and isobutane technology. All equipment in the hazardous parts of foaming lines was designed, manufactured and installed as explosion proof, existing equipment was properly modified and earthed. All new equipment and the complete manufacturing line were inspected and their conformity with the latest industrial safety standards certified by TÜV Germany.

The first batch of appliances was redesigned with the assistance of German experts who trained Huari engineers to redesign and finalize conversion of the remaining models on their own. The products were then safety certified. Training of operators and maintenance staff in best operating and maintenance practices as well as up-to-date safety philosophy and methods was carried out in Europe and on site.

Huari provided overall support to the project by rationalizing and relocating the production technologies to a new building at a safe site in an industrial development zone, and by paying for various local work and supplies.

### *Impact*

Huari is one of the first companies outside of Europe to introduce the most modern and environmentally-sound fully hydrocarbon technology. Some 338 tons of CFCs were phased out, reducing environmental impact and improving working conditions, occupational health and safety in all areas of the company. Annual production slightly increased, worker productivity rose 30 per cent (from 352 to 455 units/worker/year). Exports increased forty times—from \$50,000 to \$2,000,000. Quality assurance procedures and quality of the products were strengthened and Huari was certified to ISO 9001.

Long-term employment of Huari's staff was secured through better business opportunities and human resource development in a very competitive business climate, i.e. despite extensive industrial consolidation in this sector in China.



Fig. 4: Charging of Isobutane refrigerant



Fig. 5: Ultrasonic welding of cooling circuit



Fig. 6: Domestic appliance manufacturer:  
Zhejiang Huari Group, Hangzhou (China)

### *Sectoral cooperation*

UNIDO worked hand in hand with the Government and the industry to reach a compromise between the compressor (supplier) and refrigerator (end-user) manufacturers regarding the various refrigerant alternatives selected. Thus, the converted compressor factories could establish long-term, mutually beneficial strategic partnerships with their major customers offering a stable market on one hand and reliable core component supply on the other. As a result, by the time the project had been completed, Huari could easily obtain isobutane compressors on the local market to be used in its refrigerators. The manufacturers of these compressors (Jiaxipera) were converted to the new refrigerant with assistance of UNIDO through another MP project.

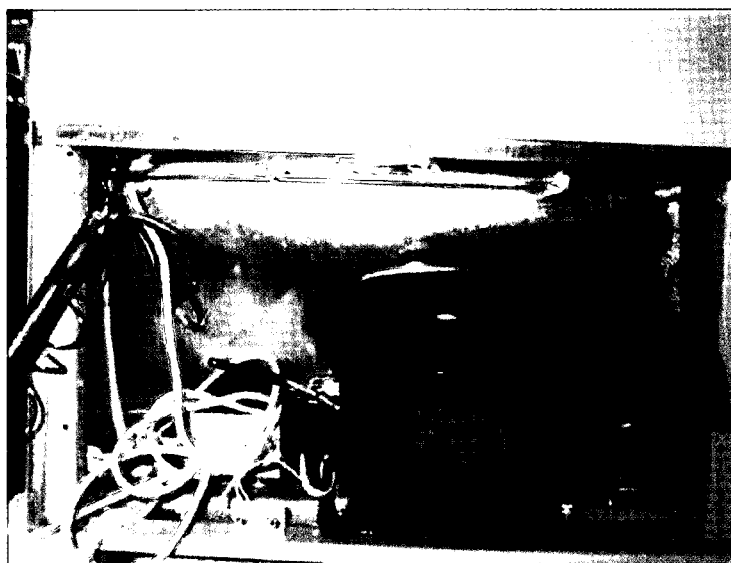


Fig. 7: Locally made isobutane compressor by UNIDO-assisted  
Jiaxipera Co., fitted in Huari refrigerator

## *Converting domestic refrigerator production: Pars Appliance Manufacturing (Iran)*

Sector: Domestic Refrigeration

Company: Pars Appliance Manufacturing Company (PARS)

246, Taleghani Ave, Tehran, Iran

Project No.: MP/IRA/94/403

Project title: Conversion of domestic refrigerator production facilities to phase-out CFC-11 and CFC-12

### ***Background***

Pars is a private 100 per cent Iranian-owned enterprise, originally established and operated in 1975 by General Electric, United States. The most developed manufacturer of home appliances in Iran, it manufactures approximately ten models of domestic refrigerators (including a no-frost refrigeration model) as well as freezers in various sizes. The company employs around 700 people in one shift. When project formulation started in 1993, its annual production of all models amounted to 160,000 units.

Prior to the start of the project, CFC-12 was used as a refrigerant and CFC-11 as foaming agent for the insulation of the refrigerators and freezers. Its three production lines for refrigeration appliances are supported by a well-established workshop within the company premises where most of the refrigerator components are produced.

### ***Alternative technology selection***

Approved at the 11<sup>th</sup> session of the Executive Committee in November 1993, Pars was the first MLF project to apply the long-term hydrocarbon alternative as a foam-blowing agent, i.e. cyclopentane to replace CFC-11. Pars decided on cyclopentane following the technical advice received from UNIDO and the endorsement of the Government. It selected HFC-134a as the refrigerant after taking into consideration the various safety aspects of isobutane and the lack of information on its application at the time of project approval.

### ***Services provided***

Following project approval, the company was reconstructed. A second production hall was established where the assembly of cabinets is now concentrated. The new facilities and layout thus offered excellent possibilities for the sensitive HFC-134a and cyclopentane technologies. There were substantial financial inputs from the counterpart without which the project could not have been successfully implemented.

New production leak detectors, charging stations and recovery pumps—all designed for use with HFC-134a—were installed through the UNIDO project. Because redesigning the two old foaming machines would have been too costly, they were replaced by a new cyclopentane foaming machine along with a mixing unit and cyclopentane storage facility.

Reflecting the flammability and explosiveness of cyclopentane, several safety measures were taken: installation of a gas detector system, an exhaust and ventilation system and a fire protection system in the foaming area. All equipment in the hazardous parts of the foaming lines was made explosion proof. All foaming jigs and plugs were equipped with good earth connections to avoid the appearance of static electricity. Nitrogen was provided in the whole piping system for neutralization. After the conversion, the complete



manufacturing line was inspected and certified by TÜV Germany for its conformity with latest industrial safety standards.

UNIDO contracted experts to assist the company in development, redesign, prototype manufacture and testing of the refrigerators and freezers using HFC-134a refrigerant. Personnel from Pars received training on the use of the new equipment both on the job and in Europe. Company management was trained in production control, functionality, performance testing and quality assurance taking into account the new safety requirements. Close cooperation, active participation and full involvement of the management of Pars and the support of the government enabled UNIDO to complete the job with significant results.

### *Impact*

The converted plant phased out 193 tons of ODP. The use of environmentally friendly technology increases the international market potential of the products manufactured. At the time of project formulation, the company had reported no exports. Exports have meanwhile started.

Productivity increased by approximately 20 per cent, annual production achieved the designed capacity of 195,000 units per year.

Well-trained staff, increased safety measures, better production processes and enhanced research and development facilities all contribute to a better and more competitive business.



Fig. 8: ODS experts in South Asia network evaluate foaming area at Pars Appliance Manufacturing, Teheran (Iran)



Fig. 9: UNIDO and Government representatives check Pars Appliance Manufacturing production lines

*Converting compressor production for domestic refrigerators: Jiaxipera Compressor Factory (China)*

Sector: Refrigeration (compressor)

Company: Jiaxipera Compressor Factory,  
Wangdian, Jiaxing, Zhejiang Province, P.R. China

Project No.: MP/CPR/96/032

Project title: Conversion of compressor production for domestic refrigerators from CFC-12 to hydrocarbon refrigerant at Jiaxipera compressor factory

***Background***

Jiaxipera is a 100 per cent Chinese state-owned company with a factory built in 1992 and compressor production going back to late 1992. Its main products are hermetic reciprocating compressors for use in domestic refrigerators. Six different models cover the range from 70 to 200 W. Its total staff is 900 (700 in production and 200 in service). In 1994, the year before project formulation, annual production of compressors amounted to 600,000 units, representing a 10 per cent market share in China. There were no exports.

Prior to the start of the project, compressors were designed to be used with CFC-12. Major compressor parts were produced in a factory housing a foundry line, 8 machining lines, a motor line, an assembly line and a pressing and welding line. They were assembled into final compressor products, and the product quality was tested either at the assembly line or in a test laboratory. Compressor performance (capacity and efficiency) was measured in the laboratory.

***Alternative technology selection***

Based on the company's technical capacity and market conditions, together with technical advice received from UNIDO, Jiaxipera pioneered the use of long-term hydrocarbon alternatives in China, i.e. isobutane refrigerant technology. Its selection of hydrocarbon refrigerant was supported by the technical advantages and innovative nature of this latest technology. Jiaxipera, as the producer of good quality refrigeration compressors, followed the demand of its main customers (the more advanced refrigerator manufacturers), which understood the strong marketing potential of fully environmentally benign and energy efficient products. Calculations showed that the compressors could be produced with hydrocarbon technology at lower cost than with the environmentally less friendly HFC alternative.

***Services provided***

As a first step, a technical partner was selected for the redesign of products and re-engineering of the technological process according to the requirements of the new refrigerant. The first batch of hydrocarbon compressors was redesigned with the assistance of an Italian consulting firm contracted by UNIDO. During this activity, plant engineers were also trained in redesign techniques. UNIDO organized a study tour for core design engineers of Jiaxipera to European compressor manufacturers. Jiaxipera engineers, with assistance of the Italian consulting firm, reduced the noise and vibration and improved the efficiency of the compressors through design modification of several compressor parts (suction valve leaves, fixtures of motor and other changes) to meet latest standards and

customer requirements. After completion of the work, the products met all international specifications and were accepted by customers.

In the mechanical workshop, machine tools were installed to produce newly designed crankcases and other compressor parts. New jigs, fixtures, gauges, tools, moulds (including casting moulds) were also commissioned.

A calorimeter and some other instruments specially designed for measuring basic performances of hermetic compressors with hydrocarbon refrigerants were installed in the laboratory. They are fitted with the safety equipment required to mitigate the hazards of the flammable refrigerant.

Training of operators and maintenance staff in best operating and maintenance practices as well as up-to-date safety philosophy and methods were carried out on site.

### ***Impact***

Jiaxipera is one of the first companies in developing countries to start production of the most modern and environmentally benign hydrocarbon compressors. Some 200 tons of CFCs were phased out at refrigerator factories that used the company's new hydrocarbon compressors. Environmental impact, occupational health and safety were improved at Jiaxipera itself.

Annual production was increased by 40 per cent so that in 2000 Jiaxipera produced 1,000,000 hydrocarbon compressors. Quality assurance procedures and quality of the products were strengthened and the company was certified to National safety standard.

Long-term employment of Jiaxipera's staff was secured through better business opportunities and human resource development in a very competitive business climate (i.e. despite the extensive industrial consolidation in this sector of China). UNIDO worked hand in hand with the Government and the industry to reach a balance between the compressor supplier and refrigerator manufacturer end-users with regard to the various refrigerant alternatives selected. Thus, Jiaxipera could establish long-term, mutually beneficial strategic partnerships with its major customers, offering a stable market on one hand and reliable core component supply on the other. Since Jiaxipera could easily find isobutane compressors users in the local market, its sales are increasing.

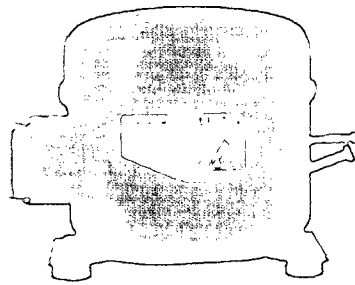
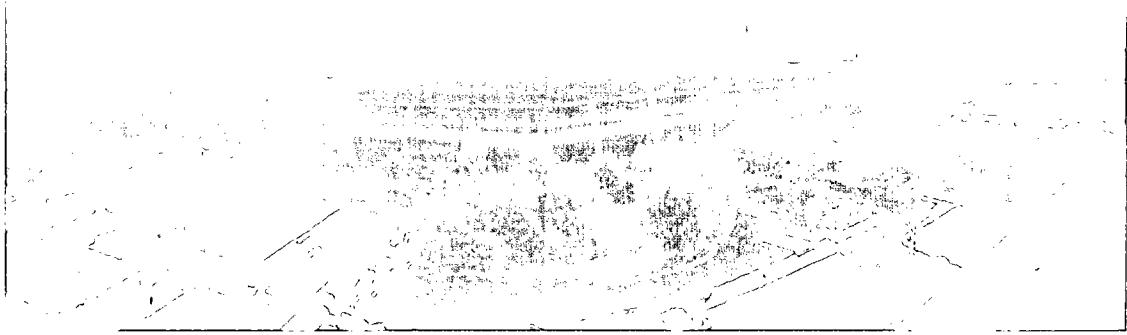


Fig. 10: Jiaxipera compressor factory (P.R. China) and typical isobutane compressor

## Alternative technologies for domestic appliances

### Refrigerants

Table 7 compares the main technological options available to replace CFC-12 refrigerant in domestic refrigeration.

**Table 7** Alternative refrigerants to replace CFC-12

Refrigerant	Assessment	Consequences
Isobutane (R-600a)	<ul style="list-style-type: none"> <li>• Inflammable and explosive in certain limits of mixture with air.</li> <li>• ODP = 0</li> <li>• High coefficient of performance (COP) which means lower energy consumption.</li> <li>• GWP near zero</li> </ul>	<p>Special infrastructure needed. Technology and specific know-how required to guarantee safe conditions during manufacture, repair and service. Special service technology must be applied. Changes in product design and manufacturing technology are necessary (smaller refrigerant volume, larger compressor, hazard prevention).</p>
HFC-134a	<ul style="list-style-type: none"> <li>• ODP = 0</li> <li>• Lower coefficient of performance compared to CFC-12 and isobutane, resulting in higher energy consumption</li> <li>• GWP = 1,300</li> </ul>	<p>Product design (except the cooling circuit) can remain the same. Increased manufacturing process control: high cleanliness and dryness required. Components affected by the refrigerant must be free of mineral oil, chlorine, water, wax etc.</p>

Source: U.S. Environmental Protection Agency (USEPA).

Fig. 11: Relative refrigerator performance:  
Coefficient of Performance

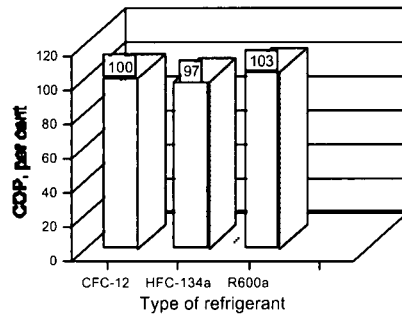
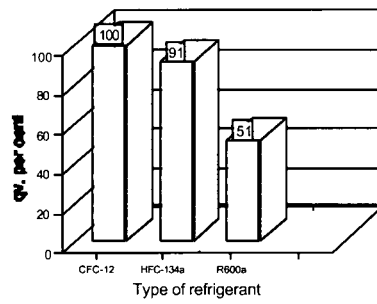


Fig. 12: Relative Refrigerator Performance:  
Volumetric Cooling Capacity



## HFC-134a

### Advantages:

- Many major international manufacturers of domestic appliances and compressors have already selected HFC-134a as the replacement for CFC-12 in domestic refrigerators and freezers. The option is therefore commercially available to manufacturers in developing countries.
- HFC-134a is considered an appropriate alternative by the technical advisory bodies of the Fund and it is recommended as a long term substitute of CFC-12 in the domestic refrigeration sector. HFC-134a refrigerant is in line with several countries' phase-out strategies.
- Since many refrigerator and compressor manufacturers in developing countries have also decided to use HFC-134a refrigerant for their conversion strategy, the producers of this refrigerant and of the matching compressors are well represented in most countries. Thus, not only the refrigerant and the compressors but also the necessary technical assistance can be obtained locally on reasonable terms.
- Investment cost of this technological option is relatively low.

### Drawbacks:

- Sensitivity of the technology: to avoid clogging of the capillary tube when using HFC-134a, a much cleaner and dryer cooling system is required compared to CFC-11. It means that dry and clean conditions are also required in the production area,
- The charging equipment and vacuum pumps must be used solely for HFC-134a and any contact with CFC-12 must be avoided. Both this and the previous conditions apply to the after-sale servicing of the appliances. These are difficult to maintain in certain factories and during service conditions.
- High global warming potential (GWP): HFC-134a refrigerant is in the basket of greenhouse gases of the Kyoto Protocol.
- HFC-134a is relatively expensive.
- Cooling efficiency (COP) of HFC-134a is lower than the COP of CFC-12 (see fig. 11).

### Conversion projects should include the following steps:

- Existing refrigerant charging boards designed and used for CFC-12 must be replaced by boards suitable for HFC-134a.
- New leak detectors designed for use on HFC-134a systems are required. The currently used CFC-12 leak detectors are based on a reaction with chlorine molecules which will no longer be present; these can therefore no longer be used.
- The new refrigerant requires more stringent evacuation of the appliances to meet the stricter dryness and cleanliness requirements prescribed for polyolester oil/HFC-134a systems. This requires some modifications, installation of new pumps, vacuum gauges and control.
- To avoid an increase in the energy consumption of appliances, it is necessary to adjust the performance of the cooling system and to determine the new specification for cooling circuit components to compensate for the lower efficiency of the new refrigerant and for the slightly reduced insulation value of the new polyurethane foam.
- Redesign of models requires performance tests in air-conditioned test rooms providing standardized climate conditions. Even if the company has such test rooms and some testing equipment, generally they are not fully adequate and sufficient for fast redesign of all existing models according to current

requirements. Thus, additional testing facilities have to be procured and assistance from an outside consultancy company is required to carry out redesign of at least one model, and to train the laboratory staff to continue the model redesign work on their own.

- The technical specifications of components have to be in line with established international standards such as DIN 8964, i.e. new and very strict rules for dryness and cleanliness need to be applied. Production techniques for in-house manufacture of components must therefore be modified. The cooling system must contain zero or only extremely small amount of chlorine, fat, paraffin, mineral oil, water, soluble residues and a maximum of 1 per cent non-condensable gases;
- The capillary tube of the appliances has to be optimized for increased resistance at low evaporating temperatures;
- Adequately sized filter driers containing 3 angstrom pore desiccants have to be applied in the refrigerators.

### R-600a - Isobutane

Advantages:

- Hydrocarbons are natural refrigerants with zero ozone depleting potential;
- Isobutane has very low global warming potential (GWP);
- Isobutane has higher cooling efficiency—coefficient of performance (COP),
- Savings accrue because the amount of refrigerant in the appliances can be reduced by 60 per cent because isobutane is cheaper than any other refrigerant;
- Good energy efficiency ratios can be achieved in compressors designed for R-600a;
- Hydrocarbons permit the use of mineral oil similar to that used in CFC-12 compressors, thus avoiding the technical difficulties and the additional cost of HFC-134a technology;
- The availability of compressors is secured world-wide (in China even from local producers);
- Hydrocarbon technology is gaining acceptance in international markets; in Europe it is becoming the only acceptable one.

Drawbacks:

- Isobutane, like all similar hydrocarbons, is inflammable in a given concentration range;
- Appliances need safety redesign and modifications;
- Safety measures at the work places and better training of workers are essential;
- Increased investment cost;
- Adequate training of service technicians, some special tools and service techniques have to be introduced.

Conversion projects should include the following steps:

- Application of isobutane calls for stringent safety measures to avoid explosions during the manufacturing process. The isobutane storage charging and recovery areas should be well equipped with gas detectors, safety control and exhaust systems. Charging equipment must be explosion-proof and specially designed for isobutane equipment.



- The integrity of the components and joints in the cooling circuit must be extremely good since the new refrigerant is explosive, and a significantly lower amount of it is used in appliances.
- Leak detectors must be replaced by new ones designed for detection of isobutane;
- To minimize refrigerant leaks, thorough leak prevention techniques must be introduced;
- The refrigerant charging boards must be replaced by boards suitable for isobutane;
- On the repair line, special hydrocarbon refrigerant recovery machines should be used;
- The refrigerant storage should be placed in a designated building of special construction, as required by safety authorities;
- Traditional flame soldering in the area of charging is clearly unacceptable due to the explosive nature of isobutane; this must be replaced by ultrasonic welding techniques;
- The volume of components such as tubes, condensers, evaporators, capillary tubes must be reduced in proportion to the smaller charge;
- The design of the appliances has to be changed, with electrical switches mounted on the outside of the appliances, in order to avoid explosion or fire ignited by sparks in the event of a sudden leak of refrigerant. All remaining electrical components and connections inside the refrigerator compartment should comply with increased safety standards. It is also important to place all possible joints outside of the cabinet.
- Safety inspection and certification of the whole installation must be carried out by reputable independent safety surveyor institution.

### ***Foam blowing agents***

Several alternatives to CFC-11 have been tried during the recent years as indicated in table 8. However, although these new alternatives have decreased or have zero ozone depleting effect, none of them proved to be technically as good as the traditional blowing agent. Their major disadvantage is that the insulation properties of the foam produced with these alternatives are worse than at the pre-conversion stage. Coupled with other differences, this means that the selection of alternatives most appropriate for the given project represents a compromise between the technical parameters, price and commercial availability of the alternatives, cost and feasibility of the investment required to introduce the alternative, cost increase of other components (inner liner) of the refrigeration appliance caused by the selected alternative, and other factors.

**Table 8 Environmental properties of foam blowing agents**

Foaming agent	Ozone depleting potential (ODP)	Other features
CFC-11	1	Non-toxic, non-flammable, good insulation properties. Its price is increasing. To be phased out in the short term.
HCFC-141b	0.11	Has been the blowing agent of choice until recently in North and South America and some other developed and developing countries, but will be phased out by 2003 in the EU, Japan and U.S.A. In developing countries can be applied latest until 2040. Therefore it is a transitional solution, requiring second conversion to a final alternative. Non-flammable, non-toxic, insulation properties: slightly worse than CFC-11. Price: more than CFC-11, or cyclopentane, less than HFC-134a. Requires application of special and high priced plastic or metallic inner lines. Easy and relatively cheap conversion process.
HCFC-142b	0.065	Not proven as viable alternatives commercially. Transitional solution, as for HCFC-141b.
HCFC-142b + HCFC 22	0.06	
HFC-134a	0	Non-toxic, non-flammable. Due to its high global warming potential it is in the basket of Kyoto Protocol greenhouse gases. Difficult technology requires new equipment and good skills, therefore used only by a few companies. Price: more expensive than HCFC-141b
Cyclopentane	0	Non-toxic, natural product with almost no global warming effect. Flammable, thus requires expensive new foaming equipment and safety and ventilation system. Final solution, no second conversion is required. Insulation properties: slightly worse than HCFC-141b. Price: comparable to CFC-11 and lowest among all alternative blowing agents. No change of inner liner necessary.

Source: UNIDO Refrigeration Unit

## **Transitional technologies**

HCFC-141b, HCFC-142b and HCFC-142b + HCFC-22 blends, all have ozone depleting effect, even though they are still tolerated by the Montreal Protocol in A 5 countries up to 2040. This deadline is under renegotiation and many developed countries have already taken voluntary measures to ban or strictly control and reduce the use of HCFCs. For this reason, HCFCs can only be accepted as transitional substances and therefore provide only a short to medium-term solution. Among them only HCFC-141b has become widely accepted.

HCFC-141b does not require substantial changes in the existing machinery, especially where the enterprise applies high-pressure foaming machines in the baseline situation. Only application of better foaming and curing machinery is a must. The production cost of the appliances produced with HCFC-141b is higher due to the high price of the blowing agent and of the more expensive inner liner required. Thus, HCFC-141b offers an interim solution for small-scale producers bearing in the high investment cost of zero ODP alternatives. This is also the case for companies situated at locations (e.g. densely populated areas) where cyclopentane cannot be applied due to its flammability.

Currently, intensive R & D is being undertaken in Europe and U.S.A. to bring zero ODP, non-flammable alternatives to the market. It is expected that two substances (HFC-245fa and HFC-356mfc) will be produced commercially in the U.S.A. and France. These products will be expensive (at least in the beginning) and their initial market will be North America, Europe and Japan where they will replace HCFC-141b, which has to be phased out almost immediately. These alternatives will not be commercially available to Article 5 countries in the coming years. However, in long term, they could provide a solution for those Article 5 countries that decide to select HCFC-141b.

## **Zero ODP alternatives**

Many companies have decided to avoid the use of any transitional substance and to introduce a long-term solution. At present the only non-flammable alternative is HFC-134a, but it is too expensive. Due to its price and the complexity of the technology it has been very unlikely that it would become the ultimate blowing agent for polyurethane foam in the domestic refrigeration sector. This is now confirmed by the forthcoming introduction of HFC-245fa and HFC-356mfc in industrialized countries.

Based on careful consideration of the ozone depletion and other properties of currently available alternatives, the only feasible zero-ODP foaming agent is cyclopentane. Cyclopentane technology is already well advanced, and equipment manufacturers from several countries are producing foaming machinery of inherently safe design. Currently all major European and most of the Far East manufacturers have already started using cyclopentane. Recognizing such advantages, UNIDO has been advocating its use since 1994 in all cases wherever it could be technically feasible and financially practical. Most medium and large scale domestic refrigerator manufacturers accept UNIDO advice to introduce it as the ultimate solution blowing agent—avoiding the use of transitional substances.

To enable the use of cyclopentane the following measures have to be taken:

- Low pressure foaming machines must be replaced with suitable high pressure machines designed for cyclopentane. If the company already uses high pressure machines, it is sufficient to replace only the polyol section and to install new mixing stations;
- Gas detectors and fire protection systems must be installed in the foaming departments around the foaming machines;
- Safety exhaust systems must be installed in all areas in the foaming department where cyclopentane is in use and could escape;
- All machinery and equipment which may come into contact with pure cyclopentane or cyclopentane/ polyol must be explosion-proof and/or encapsulated. Electrical contacts, switches, motors etc. must be replaced with specially designed explosion-proof ones. All foaming equipment must be fitted with good earth connections to avoid sparks generated by static electricity. Workers' clothes and shoes must be made of antistatic material and floors must be covered with antistatic paint;
- As a precaution against static induced explosions, it is necessary to inject nitrogen into the foaming cavity, immediately prior to the injection of the polyurethane material into the cabinet;
- It will be essential to train manufacturing and service technicians in the new foaming technology and operational safety philosophy and practices; this will be done by the equipment suppliers at their site. During the installation and initial operation of the new machinery and equipment the suppliers' engineers must train the company's technical staff;
- As a final step *in-situ* safety inspection and certification of the whole installation must be carried out by a reputable independent safety surveyor institution.

In conclusion, it should be noted that all these measures are expensive and require trained technical staff, both for operations and for equipment maintenance. Thus, cyclopentane can be recommended only to medium and larger manufacturers.

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