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ASSESSMENT OF THE PROSPECTS FOR HYDROCARBON TECHNOLOGY IN THE GLOBAL DOMESTIC REFRIGERATION MARKET

September 1996

Deloitte & Touche Consulting Group

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Contents
(Overview)

Contents
(Detailed)

1 FOREWORD TO THE GTZ EDITION - January 1997 -

Klaus Meyersen
Advisor to GTZ PROKLIMA CFC-Phase-Out-Projects

This is a reprint of the unabridged Worldbank Study by GTZ, one of the sponsors, contributors and originators of this study. It might be helpful for the reader to draw his attention to a few issues and give some additional references:

- The study was published by the Worldbank with support from the Swiss Development Cooperation (SDC)/ INFRAS and the Bundesministerium für Technische Zusammenarbeit (BMZ) / Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) in October 1996. It was presented at the „1996 International Conference on Ozone Protection Technologies“ in Washington, DC on October 22nd, 1996 in the section „Air Conditioning and Refrigeration“ with an own conference topic „Assessment of the Prospects of Hydrocarbon Technologies“

- Proceedings of the conference may be obtained from Mrs. Heather Tardel, International Conference on Ozone Protection Technologies, 312 W. Patrick St.. #2, Frederick, MD 21701 USA, T 001-301-695 3762, F 001-301-695 0175; Homepage: http:/www.ecoexpo.com/ecoexpo/company/opt.html or http:/www.fred.net/jan/index/html.
  The original Worldbank version of the study may be obtained from Mr Bilal Rahil, The World Bank, H Street, N.W. Washington, DC 20433, USA. T 001-202-473-7289, F 001-202-477-5752, 001-202-522-3258; internet: brahil@worldband.org.

- This GTZ reprint has reduced the size to DINA5 paperback book format to render a more comfortable reference and to treat the study - which consists of various contributions - as one single document for ease of access and retrieval of information. Therefore a detailed table of contents has been added as well as an index, allowing cross references to all papers in order to assist the reader in gaining full comprehension of the information and the various opinions expressed in this study.

- We would like to draw the attention of the reader to the fortunate fact that the Workshop held in June 1996 in in a monastry in Schaffhausen / Switzerland, with the attendance of over 60 experts form all over the world representing a cross section of the various stakeholders, turned out to have been an essential forum of discussion, creating perhaps something like „the Spirit of Schaffhausen“. Since it became - in more then one way - the centrepiece of the study, we recommend to anyone deeply interested in the issues of Hydrocarbon Technology, to carefully study the proceedings of this Schaffhausen Workshop. Particularly the group sessions contain a wealth of ideas, suggestions, recommendations which can not be fully transcribed in proceedings or minutes, nor could they be indexed completely. In case you want more background information, we recommend to contact Mrs. Jessica Irvine, Deloitte & Touche, London, for e.g. readable copies of the original charts from the group work, or you may contact any of the participants on reference for their particular field of interest and their contribution during the course of the Workshop (addresses are given in the list of participants, see Section 9, THE WORKSHOP PAPER). Parts of the Workshop are on amateur-quality video; the material is unedited, but could be copied on special request to GTZ, Proklima.

- The Section TECHNOLOGY; MARKET; COSTS AND ENVIRONMENT describes the Hydrocarbon Technology in relation to HFC- / HCFC-Technology in detail and depth. This is an updated, deepened and widened version of earlier studies done by FKW, in cooperation with Infras and GTZ, sponsored by Swiss Development Cooperation (SDC) and Bundesministerium für Technische Zusammenarbeit (BMZ). Again, this allows in-depth study of the various aspects related to all of the CFC-free technologies. GTZ and SDC are planning to issue this paper as an individual publication to make it available to an wider group of interested readers.

- Since the entire study is documented in Word processing format we would make the document available on request as data file (WINWORD7.0 file 3,8 MB, or WORD text file). For arrangements please contact Mr. Dirk Legatis, HEAT, Consultant to GTZ PROKLIMA, T 0049-06174-964077, F 0049-06174-61209, Internet: heatinternational@t-online.de or 100102,330@compuserve.com
  GTZ also maintains a databank on Hydrocarbon Technology, which can be di-aled into via 0049-6196-79 7396, where this document can be downloaded as well. A WorldWideWeb page is under preparation, via GTZ:T 0049-6196-792179.

- Finally, we are deeply interested in keeping the Domino effect of the Hydro-carbon Technology running. Therefore we will appreciate any inquiry, request, feed back, suggestion, recommendation you may have in this respect. Avail-able for contact are Peter Stoermer, GTZ Proklima, T: 0049-9196-792179, Dirk Legatis, HEAT Consultant to GTZ Proklima, T: 0049-6174-964077 / F 0049-6174-61209, Internet: 100102,330@compuserve.com. Klaus Meyersen, Advisor to GTZ Proklima, T 0049-6131-995491, F 0049-6131-995492, Inter-net: klaus.meyersen@t-online.de or 101526,2742@compuserve.com. Thanks in advance for your interest and support.

Klaus Meyersen
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2 EXECUTIVE SUMMARY -- September 1996-

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The Study

Sponsors and Study Team

This is the executive summary of the results of work undertaken under the leadership of the World Bank to assess the prospects for hydrocarbon technology, in particular for refrigerants, in the Global domestic refrigeration market. The studies were sponsored by GTZ (the German technical co-operation agency) and SDC (the Swiss Agency for Development and Cooperation) and were undertaken by FKW (the Research Centre for Refrigeration and Heat Pumps Ltd. based in Hannover, Germany), INFRAS based in Zurich, Switzerland, and Deloitte & Touche Consulting Group based in London, England, which also managed the project.

Purpose

The hypothesis underlying the work is that, although hydrocarbon technology for refrigerants is a technically proven alternative to HFC technology and is claimed to have technical advantages over HFC technology, particularly in the manufacturing and servicing environments found in developing countries, and is also claimed to have cost and environmental advantages over HFC technology, it has not so far been adopted as the refrigerant of choice in developing countries.
If this hypothesis can be confirmed, then there must be barriers operating in the market place which are inhibiting the adoption of HC technology for refrigerant.
The work programme therefore sought to:

- cost comparisons between HC and HFC technologies
- to examine the evidence for the claimed environmental advantages of HC technology; and
- to investigate the existence of market barriers to the uptake of HC technology.

Structure of the Work Programme

Three separate studies were carried out in parallel:

- a 'technology and cost' study
- a 'market' study
- a 'barriers' study.

Draft reports were prepared and presented at a workshop of interested parties which was held in Switzerland from 5 - 7 June 1996. The workshop provided an opportunity for the findings of the studies to be presented and discussed, for the validity of the barriers to be examined, and for possible action to be explored. The workshop provided many useful inputs.

This report presents the following documents:

- a review of the technology, market, costs and environment issues of hydrocarbon technology in comparison with HFC and HCFC technologies (*Technology, Market, Costs and Environment Study: Hydrocarbon Technology in Relation to HFC/HCFC Technology).* This study has been undertaken by FKW and INFRAS and it takes account of many useful inputs from the Workshop
- a study of the non-technical barriers affecting the rate of adoption of hydrocarbon technology (*The Barriers Paper)* undertaken by Deloitte & Touche Consulting Group, together with a number of country case studies written by various authors. This paper was prepared as an input to the Workshop and has been edited only lightly since the workshop
- *The Workshop Paper* describes workshop methodology and presents the results and findings. The workshop was hosted by SDC, organised by INFRAS, moderated by GTZ and chaired by the World Bank and Deloitte & Touche Consulting Group. This paper has been prepared by Deloitte & Touche Consulting Group
- an integration of the findings from the workshop with the Barriers Paper (*Technology Transfer Issues Paper).* This paper was prepared after the Workshop by Deloitte & Touche Consulting Group with inputs from the members of the study team and presents the results of the studies and the Workshop in the context of the challenge of transferring appropriate technologies to developing countries.

All the papers have benefited from the inputs of various experts in a peer review.

Technical, Environment, Costs and Market

A comparison has been made of the technical, market, cost, and environmental features of:

- cyclopentane (a hydrocarbon) and HCFC-141b used as blowing agents for the rigid polyurethane foam in a domestic refrigerator;

- isobutane or a blend of butane and propane (hydrocarbons) and HFC-134a used as a refrigerant.

Technical Comparison

Both HC and non HC technologies have been shown to be technically feasible for large scale domestic refrigerator production in developed countries. Each technology has advantages and disadvantages in converting from CFCs, in manufacturing and in servicing.

As a **foam blowing agent**, HCFC-141b has good insulation values and the equipment is easy to convert. However, incompatibilities between HCFC-141b and materials used in refrigerators can cause problems. Cyclopentane has no such incompatibilities with refrigerator materials, but the foam has slightly lower insulation values compared to the foam blown with 50% reduced CFC-11, and the foaming equipment has to be converted because of the flammability of cyclopentane.

In comparing the alternative **refrigerants**, isobutane shows an energy efficiency at least equal to HFC - 134a, with a slight tendency to an efficiency advantage under moderate climatic conditions and an advantage at high ambient temperatures. Isobutane is compatible with the oils and materials used with CFC-12 in the refrigeration cycle, and the handling of the components and oil is similar to the handling of CFC-12. As isobutane is flammable, factories need to meet safety precautions which involves increased investment, and in some cases, design changes to refrigerators, consisting usually of a change in location and protection of electric components to ensure that accidents are avoided. A disadvantage of isobutane - its lower volumetric capacity compared to CFC-12 - may lead to larger compressor housings with similar sized motors as for CFC-12. A blend of isobutane and propane can use similar sized compressors, but in most cases this is only suitable for single temperature appliances or for those which have been redesigned for the needs of a blend.

HFC-134a can use the same size compressor as CFC-12 and is not flammable. However, there is a disadvantage with the ester oil which has to be used with HFC-134a. It is expensive, highly hygroscopic and forms acid with water. Its use requires very strict workplace discipline in the manufacturing process. A refrigeration cycle containing ester oil which has been contaminated with moisture, for example from ambient air, will almost always result in a total compressor breakdown within a period of a few months up to two years. The combination of HFC-

134a and ester oil is a partial solvent, capable of gradually dissolving leftovers from the manufacturing or servicing process, in particular those oils used for machining. Usually, these substances are deposited in the capillary tube of the refrigeration cycle, causing anything from a decreasing capacity to a break down of the system. In order to avoid this, a specially adapted production process must be followed with strict workplace discipline for all components which are used in the cycle.

There have been indications for quite some time that there have been major problems in the **mass production** of refrigerators and their components with HFC-134a. In one reported case at one medium sized manufacturer close to 10,000 warranty cases had to be dealt with as recently as 1995, three years after market penetration. Experts from large compressor manufacturers state that these compressor related problems have now been overcome in developed countries after some five years of extensive research and development. However, there is a concern that developing country manufacturers lacking this expertise may run into the same or similar problems, which are more likely in less stringent quality control situations.

In the **service** sector, service engineers need additional training to enable them to master the requirements of both refrigerants. The variation in necessity for training in the use of isobutane or HFC-134a in developing countries has not been established yet. Training in the handling of hydrocarbons is necessary to avoid any risk of explosion. However, as refrigerator manufacturers have not used flammable substances for several decades, there are serious reservations. The handling of HFC-134a and its oil requires a strict working discipline, and the ability and the will to recognise mistakes and unfavourable circumstances and act accordingly, which usually means disposing of significant quantities of the oil.

In developing countries, there are significant numbers of CFC-12 refrigerators in use which will continue to be serviced with CFC-12 and mineral oil. While isobutane or a hydrocarbon blend will work with the mineral oil used for CFC-12, this is not true for HFC-134a. If the wrong oil type is used in servicing an HFC-134a refrigerator, a subsequent breakdown is very likely. In addition, HFC-134a requires different charging equipment to CFC-12 but CFC-12 and hydrocarbons can be used in parallel without major problems.

Environmental Comparison

For **environmental** reasons, the blowing agent HCFC-141b is not favoured as it contains chlorine, it is ozone depleting and restricted under the Montreal Protocol. In addition, it also has a significant greenhouse effect. But due to the possibility of a relatively cheap and easy conversion of existing CFC-11 foaming equipment, HCFC-141b facilitates an almost tenfold reduction in ODP terms in comparison with CFC-11. New fluids, HFC-245ca and HFC-365mfc, are presently being developed, but quantities and experiences are not available yet. It is not known if these fluids will actually be produced and supported as a blowing agent. Cyclopentane, as HC blowing agent, has already gained wide market acceptance.

HFC-134a has no **O**zone **D**epleting **P**otential (ODP), but a relatively high **G**lobal **W**arming **P**otential (GWP), while hydrocarbons have zero ODP and a negligible GWP.

Information that HFC-134a degradation causes formation of trifluroacetic acid (TFA), causing TFA-concentration in rain water, or that hydrocarbons in refrigerators could contribute to low level smog do not seem to be significant enough to be considered as negative for either of the fluids. If TFA does turn out be an environmental problem, it will be a long-term, global one, which should be avoided from the viewpoint of the precautionary principle and the sustainable development principles set out in Rio.

The **T**otal **E**quivalent **W**arming **I**mpact effect, combining energy consumption related emissions of carbon dioxide and their effect on global warming with the direct effect caused by emissions of the fluids used in a refrigerator, signifies the impact on global warming caused by an appliance over its lifetime. There is hard evidence that for the given costs, HFC/HCFC technology could achieve a greater TEWI reduction by improving energy efficiency, thus being more environmentally efficient. Without being able to provide exact numbers, the investigation showed that the direct GWP of the fluids contributes significantly to the TEWI. In addition, from a certain point of energy efficiency onwards, a TEWI reduction is achieved more cost effectively by using hydrocarbons, rather than by further decreasing the energy consumption. In addition, the minimum TEWI can only be achieved using hydrocarbons.

Cost Comparison

Comparable **cost** information is not available for **conversion** costs for refrigerator and compressor manufacturing plants. Comparable information on estimated costs is available from conversion projects of refrigerator manufacturing plants submitted to the Multilateral Fund. In an evaluation undertaken by the Multilateral Fund, the incremental investment costs for hydrocarbon technology needed for safety precautions are 27% compared with the 35% eligibility threshold for financial assistance. It is often cited that investment costs increase from 10% to 90% for the conversion of a refrigerator factory in comparison with the costs arising when converting to HFC-134a.

The **unit costs** of those refrigerators using hydrocarbons as a refrigerant were higher in the past because of the small numbers produced, but there is no reliable information about whether the unit costs will change in the future compared to HFC technology. In general, a decrease in the cost of hydrocarbon refrigerant technology has been experienced on the European market and it is expected to become more significant if the technology continues to spread. Cyclopentane as a blowing agent turned out to be the most cost effective solution for the phase-out of CFC-11 as a blowing agent.

From a lifetime cost perspective, the use of hydrocarbon technology in the production of refrigerators is very likely to provide **higher cost effectiveness** than the use of HFC-134a as a refrigerant or HCFC-141b as a foam blowing agent under developing country conditions.

Market Issues

The first non-ODS technology available for refrigerator manufacturing was HFC/HCFC. These technologies, which have been used since 1990/1991, have gained a world-wide **market** share of approximately 40% (early 1996). Around 10% of the refrigerators produced use hydrocarbons as a refrigerant, roughly 15% as a blowing agent; a market share achieved since 1993. In some areas, cyclopentane foam was combined with HFC-134a as a refrigerant. At present, slightly less than 50% of world-wide refrigerator production is done using CFCs as refrigerants and blowing agents. In most countries, customers do not seem to have any preference for a specific technology and it is not known if customers are willing to pay for the benefits associated with a particular technology, and if so how much they are willing to pay. However, consumer safety acceptance is not really an issue because the consumer (correctly) assumes that the manufacturer will address the safety issues. At the same time it is not possible to estimate the value of safe, cheap and reliable servicing or general reliability to the consumer at the time of purchase.

The study provides evidence that the use of hydrocarbon technology as a refrigerant and blowing agent offers some advantages over HFC/HCFC alternatives, particularly in meeting the requirements of sustainable development in developing countries:

- HC technology is an old and relatively simple technology which, when the necessary safety precautions are taken, is well suited to production in developed as well as in developing countries. Even though HFC-134a appliances may be produced successfully in the conditions prevailing in developing countries, by manufacturers with technology tie-ups to multinational companies, it is doubtful whether the same is feasible for independent manufacturers. They have to rely on the technology transfer facilities offered under the procedures of the Multilateral Fund. Furthermore, an appropriate service infrastructure for HFC 134a based appliances has not yet been established, particularly in rural areas in developing countries. On the other hand evidence from countries with established LPG servicing practice for CFC 12 appliances (e.g. Cuba /INFRAS&ECOZONE 1996/) tells us that no serious hazards have been reported.

- The choice of hydrocarbons offers the advantage of independence from high-tech manufactured or patented substances such as HFCs, HCFCs and the synthetic oils. These substances would have to be imported from industrialised countries or a production license would have to be purchased while hydrocarbon fluids, sometimes at insufficient purities, can be procured from refineries located in most major developing countries. HCs are not patented.

- Hydrocarbons have excellent thermodynamic and thermophysical properties for their application as refrigerants in domestic refrigerators and freezers. This makes hydrocarbons superior to HFC-134a, especially in consideration of the warm and humid climate of most developing countries.

- Hydrocarbons are environmentally benign fluids and are degraded within a few days into nature-identical substances whereas HFC-134a and HCFC-141b contribute significantly to global warming, although at present there is no scientific consensus about further possible environmental damage caused by their degradation. Therefore restrictions on production and the use of HFCs might be expected and HCFC-141b is already controlled through the Montreal Protocol. However, limitations in the use of hydrocarbons are not likely to come about and would require, if they did, the same techniques to avoid emissions already used for HFC-134a. Those manufacturers converting to hydrocarbons choose a long term alternative to CFCs.

Barriers

The possible existence of barriers depends on the hypothesis that there are technical, cost, and other criteria on which HC technology could be preferred in specific situations and these barriers inhibit the adoption of such a technology.

In parallel with the technology, market, cost and environment studies, we interviewed a wide range of parties with vested interests in these issues, to establish what kind of barriers to HC technology adoption were perceived.

These interested parties recognised that cyclopentane is accepted as a foam blowing agent and therefore responses focused on HC as refrigerant.

A full inventory of these barriers, as reported by interested parties, were presented at a workshop. A sample of these barriers is as follows:

Technical and Cost Issues
A number of technical and cost barriers were cited, including:

- the investment costs for changing a production line to HC technology are higher than those for HFC -134a, on account of safety measures
- manufacturers do not have sufficient know-how for managing safety risks associated with the storage of large quantities of HC refrigerant/foam blowing agents
- there are increased cost implications for the servicing of HC refrigerators - engineers need to be trained and additional equipment is required, although the costs might be lower than for HFC - 134a.

Market Issues

Market barriers which were cited included:

- a parent company's technology is often transferred from developed to developing country manufacturers through commercial agreements such as joint ventures and licensing agreements, thus leading to a preference for HFC -134a
- there is a lack of consumer demand for HC refrigerators, based on ignorance of refrigeration technology and poor labelling of products
- HC technology is viewed as just a "German" technology and information is scant on other countries' positive experiences.

Policy and Institutional Issues

Barriers cited in relation to policy and institutional issues included:

- the costs of conversion to HC technology are only partially funded by the Multilateral Fund;
- the consultants employed by the implementing agencies have at best limited experience of using hydrocarbon technology;
- insufficient resources are devoted to demonstration and pilot projects by the Multilateral Fund;
- procedures for new technologies and approvals for new projects are subject to time delays.

Significance of the Barriers Cited

In presenting the inventory of reported barriers to the workshop, no attempt was made to evaluate their significance or to describe the mechanisms underlying the barriers. However, those present at the workshop were able to “vote” and select those barriers that they felt were important and worthy of further investigation. The following six barriers received the most votes:

- Through commercial agreements e.g. joint ventures, licensing agreements etc., between developed and developing country manufacturers, the parent company’s technology is transferred which, in most cases, is HFC technology
- Consumers are more interested in the price of their refrigerator than the ecological benefits
- There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry as a whole and especially to developing countries
- The investment costs for changing a production line to HC (costs for safety measures) are higher than for HFC-134a

- There is widespread ignorance about the disadvantages of synthetic replacements (e.g. 134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries)
- Manufacturers fear misinformation campaigns and adverse publicity against HC from the multinational chemical industry as well as from competing manufacturers

Through the workshop, it was clear that:

- there was no consensus amongst interested parties on which barriers exist there was conflict in relation to some of the barriers suggested
- some barriers were based on the incorrect or the unsubstantiated perceptions by interested parties
- some barriers reported, reflected the incompleteness of available information on which to make judgements, a problem which affects all decision-makers in this area
- some reported barriers were based on a lack of knowledge of the interested party (although the information is available), therefore the barriers thus cited are incorrect.

The Workshop

This stakeholder workshop had 73 participants and was held in Schaffhausen, Switzerland from 5 to 7 June 1996.
The aims of the workshop were to provide an opportunity for interested parties to:

- react to, comment on, and connect the papers on Technology and Costs, on Markets, and on Barriers, which had been sent to all participants in advance;
- discuss, clarify, and add to the inventory of reported barriers;
- consider possible ways of overcoming these barriers.

The workshop used the "Metaplan" technique which proved to be highly successful in helping interested parties holding radically differing views to address the issues in groups.
An extensive and illustrated description of the "Metaplan" process followed during the workshop is included in the workshop paper, together with transcripts of the closing remarks made by Fraser Morrison (Deloitte & Touche Consulting Group) and Ken Newcombe (the World Bank).
The Workshop served to clarify many of the issues and their interrelation.

The results are discussed in the "Technology Transfer" paper, which is summarised below.

Technology Transfer Issues

The Technology Transfer Issues Paper integrates the findings of the workshop with the Barriers Paper in the context of the challenge of transferring appropriate technologies to developing countries. The paper elaborates the key issues - technical appraisal, cost issues, consumer issues, environmental benefits, institutions and information issues - that emerged during the Workshop. We also consider the developmental issues that arise from technology choice. By developing a “market model”, we analyse the positions of the interested parties and show how some of the barriers presented in the Barriers Paper fit into this model. In addition, we provide some clarification and correction to those barriers that require amendment.

As the hypothesis upon which this initiative was tested and explored during the workshop, a number of points emerged:

- the technical argument for the advantages / disadvantages of HC technology caused controversial discussion with little consensus as to how to assess the pros and cons, which go far beyond the differences in their respective costs of production
- HC technology, at present does not offer any overwhelming cost advantages and, because of the safety issues, may incur higher refrigerator manufacturing costs. In the longer term, however, it is possible that the differences in the relative costs for HC and HFC technologies may be reduced or become mere favourable for HC technology on a *lifetime* basis.

Furthermore, three clear groups emerged as being the most important players within the market place - consumers, manufacturers and institutions - and, that in making their respective decisions, they face a number of issues as demonstrated in summary form below:

DECISION MAKERS	CONSUMERS	MANUFACTURERS	INSTITUTIONS
The decision	Which refrig-erator?	Which technology?	Intervention?
Issues	Price lifetime owner-ship cost	Technology production costs Marketing	Environmental benefits not captured else-where

From the workshop it became clear that most participants thought that purchase price is the key factor in **consumers'** purchasing decisions in developing countries. This contrasts with the German-speaking markets where consumers appear to place a higher value on environmental benefits. It also became clear that consumers are not aware of, or do not value, the lifetime ownership cost i.e. cost of servicing, energy efficiency savings etc. of a refrigerator in making their purchasing decisions. The selection criteria (price, operating costs, reliability, useful life, serviceability, functionality features, safety and environmental benefits) that a consumer might consider in purchasing a refrigerator are often proxies by brand name. Safety issues in the home might also be an issue in ownership, misinformation and a lack of clear information may contribute towards uncertainty, particularly in the purchase of an HC refrigerator.
The major issue that emerges in examining the role of consumers is that their purchasing decisions are constrained by a lack of information.

Manufacturers have decisions and choices to make between alternative technologies in order to meet the CFC phase-out requirements. In doing this, they need to understand the priorities of consumer choice in their market, the regulations concerning substances and components, and undertake a technical and cost appraisal of the options and risks involved. If, as in the case of the German-speaking markets, there is an overwhelming demand for non-CFC/non-HFC refrigerators, there would be signals to encourage manufacturers to produce them. However, there are other issues that the manufacturer needs to incorporate into his technology choice decision. As technical assessments *will* give different results in different environments, particularly when comparing developing and developed country manufacturing processes, the manufacturer needs to weigh up the risks that either technology might involve.

Production cost is clearly important as it is the main determinant of the refrigerator price and therefore strongly affects consumers' purchasing decisions. However, there are difficulties in assessing what the relative production costsare for HFC and HC technologies as these are dependent upon economies of scale, on location and on the local infrastructure. The key production cost differences that emerge between the two technologies are, for HC, investment costs in manufacturing are needed to ensure safety aspects are dealt with and, for HFC's, the production process requires strict workplace discipline and some adaptation to working procedures to prevent ester oil contamination by moisture.

Similarly in **servicing,**the manufacturer should be aware of the post production implications his technology choice might impose; with HFC-134a there may be risks if the servicing of refrigerators is not properly undertaken and moisture is allowed to contaminate the ester oil. For HCs, there may be safety risks in servicing, which will impose the need for training of engineers.

The risk implications in both production and servicing will be made manifest to the manufacturer through loss of market share and damage to brand name. Manufacturers require information therefore, on the "best" technology choice to make under local conditions and the technical support needed to minimise the associated risks.

Since technical and cost issues do not provide definitive justification for technology choices, the **environmental** benefits should to provide a lead. During the workshop there was no agreement on the relative environmental merits or disadvantages of either HCs and HFC-134a. There was consensus that the environmental benefits HC technology provides compared to other non-CFC alternatives are symbolic and not very significant,.
The major issue that emerged was for appropriate environmental measures to assess the environmental benefits and for means to influence the consumer if interventions are justified to capture any externals.

Information emerged as being very important for both consumers and manufacturers and the complexity of the decision making process became apparent. It became clear that in many cases the available information is not seen to be applicable to developing countries. However, it is not clear whether information on ownership costs and the environmental implications of technology choices would be sufficient to change the purchasing decisions of consumers in developing countries and override the importance of purchase price. For the manufacturer, information is available in part, yet concerns were expressed at the workshop that it was inaccessible and often there was an imbalance information, between information available for HFCs and that of HCs.

This imbalance of information can be attributed to the superior technical support network offered by compressor manufacturers to manufacturers using HFCs; this support informs manufacturers in making their decisions that they will be supported in the transfer of the technology.

The role of the **institutions,** and particularly the institutions under the auspices of the Montreal Protocol which concerns itself with CFC phase-out, is to assess which interventions are required to ensure that most, if not all, environmental benefits are taken into consideration. Some of the barriers in the Barriers Paper related to the role and work of institutions. In many cases, these barriers were ones of perception of individual interested parties and were based on inaccurate information or an incorrect understanding of the issues. Following the workshop, guidance was given to correct perception of these barriers where appropriate.

The technology transfer mechanism that operates through the Multilateral Fund seeks to correct any cost bias against converting to HC technology. Notwithstanding this, HC proponents retain some basic concerns that there are specific technology transfer issues affecting HC technology and that, in particular, there are some development implications in the current trends in the spread of HFC-134a in developing countries.

These **development implications** relate to the considerable differences in the economic and market conditions under which CFC-free technologies were developed compared with those prevailing in developing countries. At the Workshop it became clear that a sound information base for making informed technology choices according to local conditions has not yet been established - either by the implementing agencies or by developing countries themselves.

Conditions in developing countries affect technology choice decisions for a variety of reasons; rapidly expanding markets and increasing demand for consumer goods are providing attractive opportunities for manufacturers. However, tropical climatic conditions, the lower skill level of workers and a lack of discipline in the workplace (especially in servicing) need to be incorporated in manufacturers' decisions. Evidence suggests that HC technology offers a number of advantages over HFC technology in developing countries on account of these issues. Even so, manufacturers in developing countries complain that the information they need to assist them in appraising these issues is incomplete, inaccessible or biased.

With indications that there have been major problems in the manufacture of refrigerators and their components with HFC-134a in mass production, there is concern that developing country manufacturers that lack the necessary expertise, may run into the same or similar problems, which are more likely to arise under less stringent quality controls.

The servicing of appliances also has a development dimension - as appliances tend to have a longer life, servicing is very important, particularly when poor power conditions adversely affect compressors. For HFC-134a compressors, the service situation is more critical due to the strict discipline needed to prevent contamination with moisture, whereas the technology standard for HC appliances is closer to CFC-12 if the safety aspects are dealt with.

The **technology transfer** process as it currently stands has a number of weaknesses; the introduction of HFC-134a technology in domestic refrigeration in developing countries requires a "*technology leapfrog*" to a high quality production system and the establishment of a highly qualified service network, extending to rural areas. As servicing is typically undertaken by the informal sector in developing countries, their late conversion to CFC alternatives could be an important barrier to CFC phase-out, particularly as the infrastructure and policy framework for this sector is not yet in place in many developing countries. Technology transfer needs to address this important economic and developmental issue of upgrading skills and capabilities outside the formal sector.

In addition, technology transfer is currently linked to corporate strategies as essential refrigeration technology is typically made available to developing country manufacturers through joint ventures and technology collaboration agreements. This know-how is available only from a few international players and often not under the conditions suggested by the Multilateral Fund.

It does seem that the corporate strategies determining technology choices are inconsistent with the vision of the Multilateral Fund and with the concept of fair access to technology on a commercial, national or international scale. On this basis, and because of the risks and uncertainties outlined in the previous sections, it would appear that HC technology is not readily available to manufacturers in developing countries and they are therefore unable to include it in making informed decisions. Such informed decisions, however, can satisfactorily be made much more due to sufficiently available accurate information concerning HFC-134a technology.

3 GUIDE TO THE PAPERS

- September 1996-

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The Sponsors of the Study

This initiative, *"An Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market"*, has been sponsored by The World Bank, the German technical co-operation agency (GTZ) and the Swiss Agency for Development and Cooperation (SDC).

The study has comprised a number of elements which have been undertaken by the following organisations:

- a review of the technical case, the market opportunities, costs and environmental implications of hydrocarbon technologies in relation to HFC/HCFC technologies. This study has been undertaken by FKW (Hannover, Germany) and INFRAS (Zurich, Switzerland).
- A study of the barriers affecting the rate of adoption of hydrocarbon technology. This study has been undertaken by Deloitte & Touche Consulting Group (London, England).
- A workshop, hosted by SDC, organised by INFRAS, moderated by GTZ and chaired by The World Bank and Deloitte & Touche Consulting Group.
- Reports on the workshop and the findings of the workshop, prepared by Deloitte & Touche Consulting Group, with inputs from the study team.

The Guide

Introduction

This document aims to guide readers through the various papers and process of the World Bank sponsored initiative *"An Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market"*. This initiative has been done in collaboration with the German technical co-operation agency (GTZ) and the Swiss Agency for Development and Co-operation (SDC).

The goal of the initiative was to conduct an evaluation of the barriers facing hydrocarbon technologies; to determine whether or not they enjoy a level playing field relative to the alternatives; and to assess the comparative environmental benefits of the technology. The main aim was that enterprises, particularly those eligible for assistance from the Multilateral Fund, should be in a position to give full and fair consideration to hydrocarbon technology when considering their CFC phase-out strategy. The Terms of Reference for the initiative are presented at the end of this guide.

To achieve these goals, the initiative has comprised a number of elements which have been undertaken by the following organisations:

- a review of the technical case, the market opportunities, costs and environmental implications of hydrocarbon technologies in relation to HFC/HCFC technologies. This study has been undertaken by FKW (Hannover, Germany) and INFRAS(Zurich, Switzerland)
- a study of the barriers affecting the rate of adoption of hydrocarbon technology. This study has been undertaken by Deloitte & Touche Consulting Group (London, England)
- a workshop, hosted by SDC, organised by INFRAS, moderated by GTZ and chaired by The World Bank and Deloitte & Touche Consulting Group
- reports on the workshop and the findings of the workshop, prepared by Deloitte & Touche Consulting Group in consultation with the study group and with peer reviewers.

The non-technical assessment has focused on refrigerant technologies (HFC and HC), rather than insulation and foam blowing agents. In the foam sector, HC technology (cyclopentane) has proven to be technically and commercially viable throughout the world and is in wide use.

The papers presented in the following sections have been prepared by the organisations described above and they have benefited from the inputs of various experts during a peer review which was carried out between the workshop and the publication of this report.

Technology Transfer Issues Paper

The Technology Transfer Issues Paper draws together the findings of the study. This paper builds on the findings from the Workshop and the guidance received, and it looks at the technology transfer issues relating to refrigeration technology choice for manufacturers.

Chapter 1 recalls the hypothesis underlying the initiative at the outset and presents the decisions and issues facing the key players in the market - consumers, manufacturers and institutions.

Chapter 2 presents the key findings of the workshop by describing the issues affecting the consumer in purchasing decisions, the manufacturer in appraising technology options, their associated costs and risks, the importance of information in decision making, the role of institutions and the environmental issues. It also considers the development issues in technology transfer in developing countries.

A “market model” is then presented in Chapter 3 which shows the selection criteria of the stakeholders and their positions when characterised as either HC or HFC proponents.
In Chapter 4 we review the reported barriers presented in the Inventory of Barriers and seek to validate them, particularly in light of some of the guidance received from various stakeholders.
Chapter 5 summarises the findings of technology choice and cost, the conditions in developing countries and the technology transfer mechanisms.

The Barriers Study

The Barriers Study was undertaken by Deloitte & Touche Consulting Group, supported by the study group with respect to stakeholder interviews and country case studies to assess the barriers, if any, affecting the adoption of hydrocarbon technology in the domestic refrigeration market. The study findings were presented at the Workshop in Switzerland in June 1996, to inform participants of the views and perceptions of various stakeholders in the market place about hydrocarbon technology.
The study findings, which are summarised in the Executive Summary, have not been amended since the Workshop, although the report has been subject to some minor edits for clarification.
The Barriers Paper presents in Chapter 2 an introduction to the study, the hypothesis for the existence of barriers and an outline of our methodology.
Chapter 3, entitled The Rise and Prospects of Hydrocarbon Technology, describes the success of HC technology in Germany, some of the advantages of HC technology and an overview of the market structure of the refrigeration sector.

Chapter 4 presents a description of the barriers reported by various stakeholders. These include technical and cost barriers which cover alternative technologies, production, distribution and marketing costs, servicing issues, commercial relationships and product liability. The market barriers include technology transfer issues, consumer issues and environmental implications. The policy and institutional barriers cover institutional procedure, the OORG, policy failure, trade and technical standards.

In Chapter 5 some geographic issues are presented which cover regional issues and a summary of the reported barriers affecting developing countries. A summary of the country case studies is also provided (India, China, Argentina, Germany, USA, and UK).

In Appendix I an Inventory of all the reported barriers is presented.
A number of country case studies are presented which examine the prospects for hydrocarbon technology throughout the world and to highlight some of the barriers that have been cited in the Barriers Study. Case studies have been undertaken on the following Article 2 and Article 5 countries by the following organisations:

Country Case Study	**Author**
India	Ajay Mathur et al. Tata Energy Research Institute, New Delhi, India
China	Klaus Meyersen (advisor to GTZ), Germany, Song Xiaozhi, NEPA, Xu Dongsheng, CHEAA and NCLI, China
Argentina	Maria Lucia Gòmez, INTI, Argentina
US	The World Bank, Washington DC, US
Germany	Klaus Meyersen (advisor to GTZ), Germany
UK	Deloitte & Touche Consulting Group, London, England

The Technology, Market, Costs and Environment

Undertaken by FKW and INFRAS the Technology, Market, Costs and Environment Study aimed to assess the following:

- the present state of knowledge of the competing technologies for refrigeration market applications (HFC, HCFC and HC), including an assessment of each option
- the global market for domestic refrigerators and freezers and the general trends which influence technology selection. The study sought to identify if market opportunities exist in developing countries for a direct conversion from CFC to HC technology
- a comparative cost study of the technology options covering investment, production and lifetime costs
- the environmental benefits and disbenefits of refrigeration technologies.

The initial study findings were presented at the Workshop held in Switzerland in June 1996 and, following the guidance received, substantial amendments have been made to the report.

The first section of the study report looks at the technology and environmental issues related to CFC-free technology options for refrigerants and foam blowing.

Chapter 2 provides an introduction to domestic refrigeration, including an overview of recent technology history and the fundamentals of refrigerator technology. It goes on to give an explanation of insulation and foam blowing agents, refrigeration processes and refrigerants (including the technical principles of refrigeration processes, refrigerant options and an assessment of pure fluid and mixture refrigerants).

In examining the environmental issues, Chapter 3 assesses the ODP and TEWI of CFC replacement fluid options and examines the cost aspects. Other environmental aspects are also considered: TFA formation and photochemical ozone creation potential.

In covering foam blowing agents, Chapter 4 presents the technical requirements and options for polyurethane rigid foams and blowing agents. It goes on to examine cyclopentane foam properties, ageing phenomena, plastic liner interactions, energy consumption and safety measures, equipment changes and safety measures and looks at future developments.
The various non ODS refrigerants are examined in Chapter 5, covering both “natural” and synthetic refrigerant fluid options. The various options are assessed for energy efficiency, use of lubricants, material compatibility, quantity of charge, servicing, drop-in and retrofitting, recovery, safety and noise.

The second section of the report presents the findings from the market and cost study. It commences, in Chapter 6, with a review of global refrigerator production and looks at the present market situation, future developments and partnerships, associations and international ownership of manufacturers.

Chapter 7 goes on to consider hydrocarbon market development by looking at the development, and future trends, of refrigerator market shares in Western Europe and the developments in using cyclopentane as a blowing agent.

Chapter 8 provides an overview of the principal production costsof refrigerators and Chapter 9 looks at the component market for both refrigerants (HFC-134a/HCFC-141b and isobutane/cyclopentane production) and compressors.

Chapter 10 assesses the cost differences between hydrocarbon and HCFC/HFC technology by looking at the influencing factors, components, foam, production processes and after sales costs. Chapter 11 looks at the factors influencing the consumer market.

Conclusions are presented in Chapter 12 and all references are listed in Chapter 13.

The Workshop Paper

An important part of the initiative was the convening of a Workshop. This was held in Switzerland from 5 to 7 June 1996 and the preliminary findings of the Technology, Market and Barriers study were presented as background documentation.

The Workshop Paper aims to supply a link between the Barriers Paper and the Technology Transfer Paper by providing a detailed description of the process used by which guidance and amendments were received from the Workshop participants to the papers presented. It also presents the outputs of the working groups which show how additional issues emerged and were considered.

Chapter 1 provides an introduction to the Workshop and describes the preparation and format (Metaplan) used. It describes the processes for group work which allowed the key issues to be explored and it mentions some of the concerns that participants expressed about the approach.

In Chapters 2 - 7 the outputs of the six working groups are presented; this describes how a particular barrier was examined, how ideas emerged and how actions were proposed for taking appropriate steps to deal with some of the issues that arose.

The conclusions of each working group were presented to the other workshop participants and a summary of their presentations and the questions that were asked is given in Chapter 8.

Chapter 9 provides transcripts of the closing remarks made by Fraser Morrison (Deloitte & Touche Consulting Group) and Ken Newcombe (The World Bank). In Chapter 10 we have included the feedback we received from participants after the workshop.

Appendices I and II provide the workshop programme and list of participants respectively. In Appendix III the Inventory of Barriers is given; this was used as core working material at the workshop, it shows the additions made and how many “votes” each barrier received from the participants in selecting the key issues for discussion. In Appendix IV we provide photographs of the work of the Working Groups.

Acronyms

A2	Article 2 Countries (of the Montreal Protocol)
A5	Article 5 Countries (of the Montreal Protocol)
CFC	Chlorofluorocarbon
D&TCG	Deloitte & Touche Consulting Group
GTZ	German Technical Co-operation Agency
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HC	Hydrocarbon
HCT	Hydrocarbon Technology
HFC	Hydrofluorocarbon
MF	Multilateral Fund
MP	Montreal Protocol
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substance
OORG	Ozone Operations Resource Group
PUR	Rigid polyurethane foam
SDC	Swiss Agency for Development and Cooperation
TEWI	Total Equivalent Warming Impact
TFA	Trifluoroacetatic acid
VOC	Volatile Organic Compounds
HCFC-141b	HCFC foam
HFC-134a	HFC refrigerant
CFC-11	CFC foam
CFC-12	CFC refrigerant
HC-600a	Isobutane (hydrocarbon refrigerant)

Acknowledgements

In undertaking this assessment of the prospects for hydrocarbon technology in the global domestic refrigeration market, Deloitte & Touche Consulting Group, FKW and INFRAS have benefited from the contributions of a number of individuals and organisations. The issues involved in assessing a new technology are notoriously complex and the substance of information gathered has been particularly dependent upon the generosity and goodwill of a range of individuals and institutions. The scope of the study has demanded a very wide ranging information gathering exercise covering the whole spectrum of the refrigeration sector, including policy makers in government and other institutions, manufacturers, industrial associations and non-governmental organisations. Their assistance in providing information has been invaluable and much appreciated.

Whilst every effort has been made to ensure that the study has been undertaken with all due diligence and that the content of this report is accurate, the findings of this study should not form the basis of any investment decision.

4 TERMS OF REFERENCE for this Study sponsored by World Bank / BMZ-GTZ/ Swiss Development Cooperation

-January 1996-

The World Bbank

Terms of Reference

Background

1. As a result of recent technical developments, there is now a body of well-informed opinion which believes that hydrocarbon technology used in domestic refrigeration applications has economic, as well as environmental superiority over other technologies now dominating the post-CFC domestic refrigeration market. Although the use of hydrocarbons in foam blowing has found widespread use globally, the use of hydrocarbon in the cooling circuit has yet to break out from its European origin into the rest of the world, both developed and developing. There is therefore a concern that there are barriers in the market place which are preventing hydrocarbon technology from being considered on an equal footing with the prevalent technologies.

2. On the occasion of the Eighth Ozone Operations Resource Group (OORG) Meeting, in Washington, on October 26, 1995, the World Bank presented plans for a strategic study on the global hydrocarbon domestic refrigeration market. Through this undertaking, the Bank indicated its wish to identify the barriers which could prevent developing countries from the opportunity to fully assess the viability (advantages and disadvantages) of hydrocarbon technologies in their efforts to phaseout CFCs in refrigeration applications.

3. Whereas the OORG has previously undertaken a review of *technical* barriers in hydrocarbon supply, other market barriers may exist, and might usefully be assessed to establish whether there is indeed a levelplaying field for this alternative and its equally technically sound alternatives. Thus, the overall goal of this initiative is to conduct an objective evaluation of such barriers (market and others) and to assess the comparative environmental benefits the technology.

Goals

4. The goal of this initiative is therefore to conduct an evaluation of the barriers facing hydrocarbon technologies; to determine whether or not they enjoy a level playing field relative to the other alternatives; and to assess the comparative environmental benefits of the technology. If barriers are found which are unique to this technology, then we aim to develop an understanding of the options to undertake in order to reduce those barriers and establish a level playing field. The Bank's responsibility, and that of the study partners, will be to ensure that issues are addressed objectively and not biased in favor of any country or industry.

It is essential to be able to identify and clarify to clients what the alternative options are, and what their associated costs and benefits (economic as well as environmental) are in relation to their national policies in order to facilitate their informed choice of technology and minimize associated environmental impacts while considering all relevant economic factors. The main goal therefore is that enterprises, particularly those eligible for assistance from the Multilateral Fund, should be in a position to give full and fair consideration to hydrocarbon technology when considering their CFC phaseout strategy.

5. The intention of the study partners (World Bank, GTZ and SDC) is to convene a group comprised of all stakeholders, to meet in April 1996, and address and discuss the political, social, economic, as well as potential technical barriers to hydrocarbon use. The Bank is committed to spearheading the elaboration of the terms of reference (TOR) for this convocation, to mobilize the financing for this study and to manage the overall program.

6. While the key focus will be on understanding the market barriers affecting the domestic refrigeration market, the study will utilize this as a pilot case and attempt to draw more general conclusions on technology transfer and market penetration issues which may also be relevant to other emerging sectors such as hydrocarbon usage in commercial refrigeration application.

Participation

7. The format of the study will be such that all interested parties will have a chance to participate. One of the key activities of this initiative is the workshop which will be convened to discuss the draft reports of the three studies (detailed below). Participants will include stakeholder representatives from industry (hydrocarbon producers/distributors, compressor and refrigerator manufacturers, appliance certification laboratories, manufacturers liability insurers, market assessment/forecasting experts, etc.); government (both developed and developing countries); and non-governmental organizations (NGO's). OORG sector advisors, in particular, will be invited to participate in this study as well.

Proposed Work Program

8. A comprehensive work program has been developed which will, among other things, attempt to answer the following basic questions:

- What are the real environmental costs and benefits of hydrocarbon technology and other non-ODS domestic refrigeration technologies?
- What is the current status of global hydrocarbon technology use in terms of market share/penetration, present and future production commitments, etc.?
- What are the country and region-specific barriers and constraints to penetration of the technology such as regulatory policy, perceptions of risk, availability of information on technologically sound, commercially viable options?
- Who are the stakeholders, and what is driving the market towards either hydrocarbons or the alternatives?
- What are the basic requirements to support technology transfer?
- What are the basic costs to support technology transfer?
- What are the alternative demand scenarios?
- What is the capacity for technology transfer compared to demand prospects?

9. Preliminary discussions between the study partners and the Management Consultant have resulted in he identification of three basic studies needed to support the objectives of this initiative. Although the detailed TORs for each of these studies remain under preparation (and are a part of the Management Consultant's assignment), what follows is a brief overview of what these studies entail and how they will generate answers to the questions outlined above:

- A. **<u>The Market Survey:</u>** This study will assess the global market for domestic refrigerators and freezers and the general trends which influence technology selection. Items to be covered will include the following (Detailed TORs are under preparation):

(a) Determine the projected global demand for domestic refrigerators and freezers, to 2005; and

(b) Identify key stakeholders in the market and their perspective on hydrocarbon technology in domestic refrigeration applications such as: consumers, liability insurance providers, domestic refrigerator and freezer appliance manufacturers and service providers, domestic refrigerator and freezer manufacturers and service providers, manufacturing equipment and technology suppliers, HC and mineral oil processors and suppliers, HFC-134a and ester oil manufacturers and suppliers, Non-Governmental Organizations (NGOs) and others.

B. **The Technology Survey:** This second study will assess the present state of knowledge of the competing technologies for the refrigeration market application including an assessment of positive and negative attributes (actual and perceived) of each option. (Detailed TORs under preparation)

C. **The Barriers Study:** This study would assess the key barriers which are affecting the rate of penetration of the hydrocarbon technology and would include the following tasks:

- Literature search to identify and confirm key stakeholders, a preliminary view of the barriers and possible case studies.
- Preparation of an interview strategy and programme, covering stakeholders, and those with access to case materials.
- Based on discussions with key stakeholders, identify initial hypotheses.
- Preliminary interviews, to test initial hypotheses and interview formats.
- Remaining interviews.
- Draft report, including case studies, and circulation to key interviewees for comments.
- Redraft and circulate to all workshop invitees.
- Draft final report after consideration of draft findings by the Workshop participants.

D. The Workshop. The results of the three studies will be provided as background documentation to all workshop participants. The workshop will be informed by a set of draft reports which attempt to describe:

- The technological status of hydrocarbon technology use in refrigerators.
- A quantitative assessment of the world market for domestic refrigerators.
- A descriptive assessment of the barriers in the market place to the uptake of the hydrocarbon technology.

The hoped-for achievements of the workshop are:

- The data, analysis and findings of the three draft reports will be confirmed, or guidance would be given on appropriate improvements and corrections.
- The reported market barriers will be discussed in detail, with stakeholders explaining perceptions of the validity of barriers.

- Exploration of possible interventions and actions which would contribute to overcoming these barriers, including whether a global initiative to facilitate the introduction of hydrocarbon alternatives would appear justified.

- Commitments from the relevant stakeholders to leading these interventions and preparation of an action plan.
- Arrangements will be explored for continuing to direct and manage the initiative.

Administrative Arrangements & Assignment of Responsibilities

10. The study will be managed by a Steering Group consisting of representatives of the study partners. The proposed organisational structure of the Study is provided in Attachment 1. The main areas of responsibilities are as follows:

<u>The World Bank will</u>:

- Finalize the study terms of reference (TOR).
- Mobilize the resources for the study.
- Run the business of the Steering Group and manage the day-to-day business of the study with the Management Consultant.
- Establish the modalities and arrangements for the project.
- Take overall responsibility for the achievement of the work programme.
- Manage the work of the Steering Group and the Management Consultant.

<u>GTZ will:</u>

- Undertake the Market Study.
- Assist in the preparation of the Terms of Reference for the Market Study.
- Take part in the Steering Group.
- In cooperation with the Management Consultant and the study partners, identify, recruit and invite key stakeholders to the Workshop.
- Obtain commitments to background papers.
- Provide resources, facilities and staff support for the Workshop.

<u>The SDC/INFRAS will</u>:

- Undertake the Technology Assessment study.
- Assist in the preparation of the Terms of Reference for the Technology Assessment study.
- Take part in the Steering Group.

- Host the workshop.

The Management Consultant will:

Take the lead in developing the Terms of Reference for each of the three studies and then operationally coordinate and supervise the work of the teams to ensure that the work programs of the three studies are well integrated and delivered in time.
Undertake the "Barriers" study.
Attend the SDC/GTZ sponsored workshop in Delhi to assess the effectiveness of the main technology transfer efforts now underway for hydrocarbon technology in domestic refrigeration application.
Design, in consultation with the study partners, the workshop.

- Monitor the progress of the study teams and ensure coordination and consistency between the studies.
- Review the draft reports of all the study teams and ensure coordination and consistency between the studies.
- Review the draft reports of all the study teams in order to achieve a consistent presentation format and depth of coverage of key issues.
- Facilitate the workshop.
- Prepare the final report, including the reports of the three studies and the follow-up actions developed in the workshop.

Proposed Schedule

11. The proposed schedule for this initiative is as follows:

January	• Terms of Reference (overall and for specific studies) are finalised. • Study partners exchange letters confirming study modalities and funding. • Contractual arrangements (where necessary) in place.
January-April	• All studies are undertaken and draft reports prepared for end of March • Key stakeholders identified and interviewed. • Arrangements for Workshop finalised and • Draft reports issued to all stakeholders.
May	• Workshop. •
May-June	• Prepare and circulate draft final report. •
July-August	• Finalize report. •
September	• Issue final report.

12. These revised Terms of Reference provide for a longer period of study prior to the Workshop.

Funding

13. The World Bank has undertaken to mobilise the funding for this study. The proposed funding arrangements are as follows:

- The World Bank will cover its own expenses (staff and travel) and provide a small start up contract to the Management Consultant in order to get the initiative off the ground while final financial arrangements are being made.

- The SDC will fund the work of INFRAS who will undertake the Technology Survey study.

- GTZ will fund the work of key consultants and its own expenses in carrying out the Market Survey and will also fund the bulk of the Management Consultant contract.

14. Time permitting, the Bank will pursue the participation of no more than one more study partner.

5 TECHNOLOGY TRANSFER ISSUES - September 1996 -

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Context

This paper is part of a series of four papers which give an overview of the conclusions and findings of a study programme initiated by the World Bank and sponsored by Germany's GTZ and the Swiss Agency for Development and Cooperation (SDC), under the title "Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market". The study programme has had a number of components:

- a review of the technology, market, costs and environment issues of hydrocarbon technology in comparison with HFC and HCFC technologies (*Technology, Market, Costs and Environment Study: Hydrocarbon Technology in Relation to HFC/HCFC Technology).* This study has been undertaken by FKW and INFRAS
- a study of the non-technical barriers affecting the rate of adoption of hydrocarbon technology (*The Barriers Paper)* undertaken by Deloitte & Touche Consulting Group, together with a number of country case studies undertaken by various authors
- a workshop, which provided an opportunity for the findings of the study to be presented and discussed, for the validity of the barriers to be examined, and for possible actions to be explored (*The Workshop Paper).* The Workshop was hosted by SDC, organised by INFRAS, moderated by GTZ and chaired by the World Bank and Deloitte & Touche Consulting Group. This paper has been prepared by Deloitte & Touche Consulting Group
- an integration of the findings from the Workshop with the Barriers Paper (*Technology Transfer Issues Paper).* This paper has been prepared by Deloitte & Touche Consulting Group.

All the papers have benefited from the inputs of various experts during a peer review.

Introduction

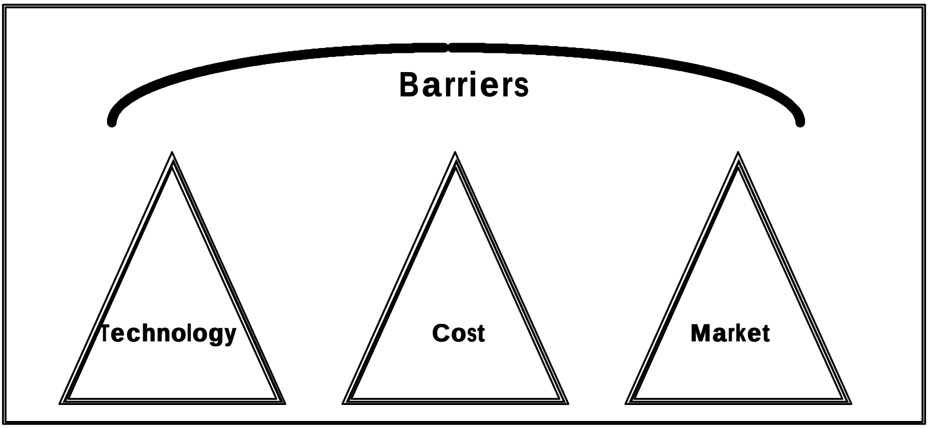
The Hypothesis

This paper builds on the Barriers Study Paper by integrating the findings that emerged from the Workshop and by incorporating the guidance and amendments received. The main source of input for the reporting and analysis of this paper is the Workshop Paper. This paper aims to consolidate the findings derived from the Workshop.

The initiative for the whole study programme was founded on a hypothesis that had three "pillars" as illustrated in Figure 1:

- that hydrocarbon technology used in the refrigeration cycle may have a number of *technical advantages* over HFC based refrigeration technology in the CFC-free domestic refrigeration market; HC technology used in foam blowing is already considered to be a technically feasible option
- that hydrocarbon technology, as a refrigerant, may be *cost-effective* (perhaps even have a cost advantage) when compared with other refrigeration technologies on a lifetime basis (i.e. when all the ownership costs are included e.g. servicing costs, energy efficiency savings); HC technology used in foam blowing is already considered to be commercially viable
- that hydrocarbon technology, as a refrigerant, may be appropriate for the *market opportunities* that exist, particularly in developing countries *OR* that it may be opportune to convert directly from CFC to HC refrigeration technologies in developing countries; HC technology used in foam blowing is already being used throughout the world.

Figure 1: The "Pillars" of the Hypothesis



If all three "pillars" are in place, then it is reasonable to argue that there may be market barriers operating to prevent the uptake of HC technology in the refrigeration cycle, particularly in developing countries. The hypothesis was based on observations that HC technology (used as a refrigerant) has had limited market acceptance outside Germany and a few other northern and central European countries. HC foams, it is noted, have had wider acceptance throughout the world. To examine and test this hypothesis the following studies have been undertaken;

- **a technology and cost study:** the purpose was to examine the technical case for HC technology (in particular HC-600a) and to review the cost implications of a conversion to HC technology, particularly in comparison with HFC-134a technology. The study sought to establish evidence for the technical advantages. The study focused on refrigerant technology as HC technology used for foams (cyclopentane) has achieved widespread acceptance with manufacturers
- **a market study:** this study sought to examine the global domestic refrigeration market and to identify where conversion from CFCs has not yet taken place, and where, therefore, there may be significant opportunities for hydrocarbon technology. The study sought to identify areas where a "double" conversion (as in the case of Germany where manufacturers converted from CFCs to HFCs and then to HCs) could be avoided
- **a barriers study:** its purpose was to identify barriers which may affect the rate of adoption of HC technology, particularly in developing countries, if the technical and cost superiority could be demonstrated.

The barriers cited in the Barriers Study Paper were, in effect, the interpretations and views of various stakeholders of the situation in the market place. The reported barriers covered a range of issues, some of which were perceptions or were based on an incorrect understanding of the situation where the barrier was perceived to apply.

As the hypothesis was tested and explored during the Workshop, a number of points emerged:

- the technical argument for the advantages of hydrocarbon technology against its disadvantages caused controversial discussion with little consensus as to how to value its pros and cons
- hydrocarbon technology, at present, does not offer any overwhelming cost advantages and, because of the safety issues, may incur higher refrigerator manufacturing costs. In the longer term,

however, it is possible that the differences in the relative costs for HC and HFC technologies may narrow or be advantageous for HC technology on a *lifetime* basis (i.e. including servicing costs and energy efficiency savings)

Furthermore, three clear groups emerged - consumers, manufacturers and institutions - as being the most important players within the market place. During the Workshop, the main issues that were raised and the suggestions for recommended actions, related to each of these three groups.

It emerged that each of these groups plays an important role within the market place and, in making their respective decisions, they face a number of issues as demonstrated in summary form in Figure 2 below:

Figure 2: The Players in the Market

DECISION MAKERS	**CONSUMERS**	**MANUFACTURERS**	**INSTITUTIONS**
The Decision	Which refrigerator?	Which technology?	Intervention?
Issues	Price Lifetime ownership cost	Technology Cost Marketing	Environmental benefits not captured elsewhere

From the Workshop it became clear that most participants thought that purchase price is the key driver in **consumers'** purchasing decisions in developing countries, in contrast with the German-speaking markets where consumers appear to place a higher value on environmental benefits. It also became clear that consumers are not aware of, or do not value, the lifetime ownership cost i.e. cost of servicing, energy efficiency savings etc. of a refrigerator in making their purchasing decisions.

Manufacturers have decisions and choices to make between alternative technologies in order to meet the CFC phase-out requirements. In doing this, they need to understand the drivers of consumer choice in their market and to undertake a technical and cost appraisal of the options. If, as in the case of the German-speaking markets, there is an overwhelming demand for HC refrigerators, there would be signals to encourage manufacturers to produce them.

The role of the **institutions**, and particularly the institutions under the auspices of the Montreal Protocol which drives CFC phase-out, is to assess which interventions are required to ensure that any environmental benefits are captured.

Structure of the Report

In the following section, we elaborate upon the key issues - technical appraisal, cost issues, consumer issues, ownership costs, environmental benefits, institutions and information issues - that emerged during the Workshop which relate to each of these players in the market place. We also consider the developmental issues that arise from technology choice. In Section 3 we go on to develop a “Market Model” which provides a framework for an analysis of the issues that lie behind technology choice and we outline the positions of some of the stakeholders. The positions of the stakeholders show how some of the barriers presented in the Barriers Study Paper fit into the Market Model. However, some of the barriers require amendment and correction and so in Section 4, we provide a validation of the barriers. In the concluding section, we summarise the findings.

Findings from the workshop

The Consumer

As one of the key players in the market place, the consumer plays an important role. Understanding the drivers of consumers’ purchasing decisions and the extent to which they can influence manufacturers’ technology choice decisions needs to be established. Consumer issues were addressed by working groups B and E.

Purchase Price: in developing countries particularly, purchase price is the primary consideration for consumers in their buying decision, especially in making their first refrigerator purchase.

Ownership Costs: as well as the initial purchase price of a refrigerator, there are other costs involved e.g. servicing costs and energy efficiency savings. These costs may potentially have an influence on consumers’ purchasing decisions, although they tend not be known or fully understood by the consumer. Consumers will not have access to information on the comparative reliability of an HFC and HC refrigerator in a developing country, and so the servicing costs are also unclear. Information about energy efficiency for HC technology in developing countries is only beginning to emerge, although HC-600a shows an energy efficiency at least equal to HFC - 134a, with a slight tendency to an efficiency advantage under moderate climatic conditions and an advantage at high ambient temperatures. Safety issues in the home might also be an issue in ownership, and misinformation and a lack of clear information contributes towards uncertainty, particularly in the purchase of an HC refrigerator.

Environmental Impact: if the environmental impact of a particular technology is known and understood, it may be incorporated in purchasing decisions, although in developing countries there is little evidence at present to suspect that consumers will value environmental benefits.

The major issues that emerge in examining the role of the consumer is that their purchasing decisions are constrained by a lack of information.

Technical Appraisal

It is well established that both HFC-134a and hydrocarbon technologies are technically feasible and can be commercially viable in the production of domestic refrigerators in developed countries. Developing country manufacturers have choices, therefore, as to which technology they will employ as they phase-out CFCs and they need to have criteria for making such decisions.

However, there are a number of areas that remain in controversial debate:

- both technologies are accepted as proven. However, a clear technical *superiority* cannot be established through debate, but only through the market place. The pros and cons of either technology extend beyond the differences in their respective costs of production
- technical assessments *will* give different results in different environments, particularly when comparing developing and developed country manufacturing processes.

The influences on a manufacturer in making a technology choice are complex and various and the manufacturer needs to weigh up the risks that either technology might impose.

Production: the production cost is clearly important because it is the main determinant of the refrigerator price and therefore strongly affects consumers' purchasing decisions. Manufacturers need, therefore, to undertake an appraisal of production costsThere are, however, a number of difficulties in assessing what the relative production costs are: there is no definitive benchmark for the costs of conversion from CFCs to HFCs or HCs, the costs are changing as economies of scale are realised and the costs are highly dependent upon location and the local infrastructure. They key production cost differences that emerge between the two technologies are, for HCs, the investment costs in manufacturing needed to ensure safety aspects are dealt with and, for HFCs, the production process requires strict workplace discipline and some adaptation to working procedures to prevent ester oil contamination with moisture.

Servicing: similarly in servicing, the manufacturer should be aware of the post-production implications his technology choice might impose. With HFC-134a there may be risks if the servicing of refrigerators is not properly undertaken and moisture is allowed to contaminate the ester oil. For HCs, there may be safety risks in servicing, which will impose the need for training for service engineers.
The risk implications in both production and servicing will be made manifest to the manufacturer through loss of market share and damage to brand name. For a manufacturer's decision making process to be enhanced, information is required on:

- the "best" technology choice to make under local conditions
- technical support to minimise the risks associated with that technology choice.

These issues were addressed in some of the Workshop working groups (Groups F and A).

Environmental Benefits

Since the technical and cost issues do not offer definitive justification on technology choices, the environmental benefits might provide direction. From the Workshop, the available information seemed to indicate that HC technology does not offer significant environmental benefits over the non-CFC alternatives, but that they are symbolic. There was no agreement among stakeholders on the relative environmental merits and disadvantages of either HCs and HFC-134a.
Interventions can be made if there is a clear need to change consumers' purchasing decisions to capture the externality. Therefore, an appropriate measure for environmental benefits is needed so that technology choice decisions can be changed accordingly. The major issues that emerged were the need for appropriate environmental measures, as discussed by Group C, and means to influence the consumer, as discussed by Group E.

The Information Issues

In the foregoing sections, the importance of information to both consumers and manufacturers - and the complexity of decision-making based on available information - has become very apparent. It is worth mentioning that in many instances, information is incomplete, unknown and not definitive. Some of this could be rectified by additional research but there are some information needs which may never be fulfilled. In other areas, information that is available is not trusted because of the information sources and the motivations of those supplying it.

During the Workshop it became clear that in many cases the available information is not seen to be applicable to developing countries, particularly relating to HC technology; much of the positive HC information relates to Germany's experience and comes from the proponents which have been involved with it there.

The following issues emerge with respect to the importance of information for both consumers and manufacturers in their respective decisions:

- for the developing country consumer, whilst information is lacking on ownership costs and the environmental implications of technology choices, it is unclear whether this would be sufficient to change their decision and override the importance of purchase price. In addition, consumers have concerns that information of this nature, provided by manufacturers, is biased
- for the manufacturer, information is available *in part*, yet manufacturers and others at the Workshop expressed concern that much of the information is *inaccessible.* Furthermore, there seems to be an *imbalance* between information available for HCs and HFCs.

The imbalance of information can be attributed to the superior technical support network offered by multinational suppliers of synthetic fluids; this support gives comfort to manufacturers in developing countries that they will be supported in making their decisions.

The Institutions

The role and influence of institutions, such as the Multilateral Fund and its Implementing Agencies, must also be considered alongside the decisions of the producers and consumers.. The primary role of the Multilateral Fund is to ensure the successful, and early, phase out of CFCs in developing countries alongside other institutions (the World Bank, governments etc.) which are concerned with climate change and other issues. Institutions are able to make appropriate and necessary interventions in the market to endeavour to ensure that any environmental externalities can be captured and internalised by the manufacturers and/or the consum-

ers. For institutions to make the appropriate interventions in the technology choices of manufacturers, they need, therefore, to have information on the pricing/cost mechanisms so that the externalities can be captured by consumers and manufacturers and incorporated into their technology choices.
For developing countries, the role of the Multilateral Fund is of critical importance as it exists to pay the “eligible incremental costs” associated with the phase-out of CFCs. To correct any cost bias against converting to HC technology, the Executive Committee has approved a discount of 35% in the numerator (i.e. the total incremental cost) when calculating cost-effectiveness. For refrigerator manufacturers, this includes one-off costs and, for HC technology, a contribution to the incremental operating costs relative to HFCs. Hence, in the short term at least, HC technology is assisted in being cost neutral with HFCs and may not be at a cost disadvantage.

Notwithstanding this, the HC proponents retain some basic concerns that there are technology transfer issues affecting HC technology, driven by the following:

- HFC-134a has superior technical & marketing support
- only Germany and a few other developed countries have changed to HC technology, so there must be some factors inhibiting the rest of the developed world
- safety issues in manufacture, use and servicing are widely debated for HC technology, but the development implications of the current trends in HFC-134a (which may lead to a concentration of the global domestic refrigeration business in a few multinational companies within the next decade) are not receiving the same level of attention.

These concerns seem to quite understandably point manufacturers towards HFC-134a.

Development Issues

In addition to issues underlying technology choice for consumers and manufacturers, together with the role of institutions, there are also specific issues for developing countries in phasing out CFCs. The economic and market conditions under which CFC-free refrigeration technologies were developed and are being used in developed countries differ considerably from those prevailing in developing countries. Indeed, the conditions within many developing countries vary considerably.

At the Workshop, technology transfer issues were assessed by working group A and it became clear that an information basis for making informed technology choices according to local conditions has not been established - either by the implementing agencies of the Multilateral Fund or by developing countries themselves. Workshop participants proposed that developing countries should develop local expertise for appraising technology options independently of developed country partners. A number of Workshop participants viewed the Indo-Swiss-German ECOFRIG project as a model case for local capacity building. Technology transfer through this means is a more interactive process than the more traditional process via a technology partner although this has not yet been fully acknowledged by the Multilateral Fund. The ECOFRIG project builds on know-how transfer supplied by technology partners in the North and in particular develops a partnership with industry and laboratories in India, rather than as a client relationship. Suggestions at the Workshop included rethinking the technology co-operation mechanism and the possible establishment of a global independent body to support the technology transfer process.

There is also a development dimension in the servicing of appliances and this plays a role in technology choice. In developing country conditions, the servicing of appliances is very important due to their longer useful life. Warranty aside, refrigerators in developed countries typically are not serviced and they are replaced by more advanced and more energy efficient models when they do fail in service. However, power conditions in developing countries (frequent power cuts and voltage fluctuations) adversely affect longevity of compressors. Compressor burn-out is likely to occur within the lifespan of a significant proportion of refrigerators. For HFC-134a compressors, the service situation is more critical in terms of avoiding moisture contamination, whereas the technology standard needed for HC appliances is closer to CFC-12, if the safety aspects are dealt with. It was noted that there is an insufficient body of experience shared with the public even in developed countries on service operations of conversions to HFC-134a and that this experience should be assessed in a neutral and fair manner, although it is unclear which institutions/organisations should do this.

In evaluating the proceedings of the Workshop, there is ample evidence for weaknesses in the technology transfer process as it currently stands: the introduction of HFC technology in domestic refrigeration in developing countries requires a *"technology leapfrog"* to a high quality production system and the establishment of a highly qualified service network, extending to rural areas. The servicing of refrigeration appliances in developing countries is largely undertaken by the informal sector which lack skills and capital in undergoing a substantial change as demanded by CFC phase-out schedules. The informal sector is currently an important consumer of CFCs and their late conversion to new technology could be an important barrier to CFC phase-out, particularly as the infrastructure and policy framework for this sector is not yet in place in many developing countries. Technology transfer needs to address this important economic and developmental issue of upgrading skills and capabilities outside the formal sector.

A second aspect of the inappropriate nature of the technology transfer process is linked to corporate strategies. Essential refrigeration technology expertise is typically made available to developing country manufacturers through joint ventures and technology collaboration agreements. This know-how is available only from a few international players and often not under the conditions offered by the Multilateral Fund.

The Stakeholders

A Market Model

In seeking to identify and develop our understanding of what the real concerns are, we have developed a simple framework that presents the issues in the market place and the decisions to be made by the various stakeholders as shown in Figure 3.

Figure 3: A Market Model for the Choice of Refrigeration Technology

DECISION MAKER	***Producer*** (i.e. refrigerator manufacturer)	***Consumer***
SELECTION CRITERIA	i) Production cost (including the "cost to market" and the profit margin) ii) Risks (in production and in use) which may affect brand name iii) Regulations concerning substances and components	i) Purchase price ii) Operating costs iii) Reliability iv) Useful life v) Serviceability vi) Functionality and features vii) Safety viii) Environmental benefits (e.g. as seen in Germany)often proxied by the consumer by choice of "brand name"

Evidence suggests that *both* HFCs and HCs are technically feasible alternatives to CFCs and so the issue is one of *technology choice* by manufacturers and consumers. For manufacturers, their technology decisions are based on cost and ease of production; the Workshop showed that all the technological issues flow through into relative cost differences and so manufacturers' criteria tend to exclude specific technological criteria. Consumers' decisions would be expected to be based on the purchase price and lifetime costs of owning a refrigerator - which are, in turn, influenced and affected by manufacturer's decisions. However, these criteria are rarely supported by information, and therefore the consumer is obliged to make decision based on proxies, often represented by the quality of the brand name in the market.

Our "market model" describes the market place for alternative refrigeration technologies and shows how the producer needs to decide between technologies by assessing both consumer needs and preferences and production issues.

The Stakeholders' Positions

In the Barriers Study Paper, we set out the reported barriers identified by key stakeholders in the refrigeration sector. The stakeholders included domestic refrigerator and freezer manufacturers, compressor and equipment manufacturers, HC and mineral oil processors and suppliers, HFC-134a and ester oil manufacturers and suppliers, governments and institutions, and non-governmental organisations (NGOs).

The reported barriers relate, therefore, to the different interests, information requirements and incentives of the stakeholders. For example, manufacturers of HFC and HC equipment will typically produce whatever is acceptable and demanded in the marketplace, whereas governments/institutions and NGOs are seeking the "right" decision so that they can promote one option. All groups often request more information and protest that information relating to technology choices is either inaccessible or biased.

It is also possible to characterise many of the stakeholders as either HC-proponents or HFC-proponents, and the following two tables, Figures 4 and 5, summarise their respective positions:

Figure 4: HC Proponents - Summary of their Position

	CONSUMER ISSUES	*PRODUCTION ISSUES*	*ENVIRONMENTAL ISSUES*
HC-proponents claim that:	HC has lower running costs (energy efficiency) and better servicing potential	HFC-134a is difficult to work with reliably in developing countries. HC technology is the same as R12 technology if safety measures are taken	HC technology is environmentally superior over the life of the refrigerator
The barrier to acceptance of HC technology	Consumers are not aware of, and so can not explicitly value the lifetime ownership costs. Developing country consumers are primarily concerned with the initial price	Refrigerator manufacturers in developing countries are unaware of the problems and the resulting risks	The environmental benefits are not reflected in current regulations or relative costs
To overcome barriers, these actions will be necessary	Consumers should be informed of the lifetime ownership cost advantage so that they can make well informed choices	Support needed to ensure manufacturers' technology appraisal is fully informed of HFC-134a risks	Institutional interventions to capture the externalities in relative prices or through regulation
Current position	Limited information from reliable sources with which to inform consum-	The available information on HFC-134a manufacturing standards and	HC environmental advantages are not significant in domestic refrig-

	CONSUMER ISSUES	*PRODUCTION ISSUES*	*ENVIRONMENT AL ISSUES*
	ers	quality requirements has not yet been projected to developing country manufacturing and servicing conditions. HFC-134a manufacturers admit to having spent a number of years solving problems but now they claim they can make it work in developing countries	eration (as only a small charge is required)

Figure 5: HFC-134a Proponents - Summary of their Position

	CONSUMER ISSUES	***PRODUCTION ISSUES***	***ENVIRONMENTAL ISSUES***
HFC-proponents claim that:	Purchase price of HFC refrigerator is lower than HC refrigerator	HC production requires costly safety measures due to its flammability	TEWI is similar between HFC and HC products. No consensus on any adverse environmental impacts of HFCs
The barrier to acceptance of HC technology:	Initial price advantage for HFC refrigerators. HC refrigerators may have servicing risks	HC refrigerators are inevitably more expensive than HFC refrigerators and carry risks in production	There are no grounds for institutional intervention because HCs do not have a proven environmental advantage
Current position	HFC producers are able to compete effectively against alternatives	HFC producers can emphasise the production risks of HCs	HFC producers are able to exploit the information gap

The Barriers

The barriers cited in the Inventory of Barriers can now be looked at from the perspective of the decision makers i.e. the refrigerator manufacturer and the consumer, in the Market Model. By undertaking a broad classification of the barriers presented in the Inventory of Barriers it is possible to understand their potential effect and the extent to which they are valid. The majority of the reported barriers in the Inventory of Barriers are ones that directly affect the refrigerator manufacturer.

Barriers Affecting the Producer

Barriers Involving Production Cost: approximately one third of the reported barriers relate to production cost; these barriers include the cost involved in developing a product for the market and the profitability of the product:

Barrier No. 2: the investment costsfor changing a production line to HC (costs for safety measures) are higher than for HFC-134a.

Barrier No. 10: the payback on the investments in CFC to HFC conversion in developed countries prevents major changes in the short term.

Barrier No: 13: the costs involved in setting up servicing facilities for the three refrigerants (CFC-12, HFC-134a and HC-600a) are seen as prohibitive.

Barriers Involving Risk: another third of the reported barriers related to the risk a manufacturer incurs in producing/selling a certain type of product; the risks arise both in production and in use. Examples include:

Barrier No 6: there are safety risks associated with the storage of HC foam blowing agents and HC refrigerant in large quantities in manufacturing plants.

Barrier No. 18: there are potential product liability issues in the event of an accident.

Barrier No. 20: there are perceptions of safety hazards in the home.
Manufacturers also incur a **marketing risk** i.e. in deviating from the perceived global mainstream; for example:

Barrier No. 19: through commercial agreements e.g. joint ventures, licensing agreements etc. between developed and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology.

Barriers Involving Regulation; only eight barriers in the Inventory of Barriers relate to regulations and the policies of institutions/governments that the producer may consider and many of these are dealt with in the next section:

Barrier No: 41: safety standards in many countries do not include provisions for the use of flammable fluids in domestic refrigerators.

Barriers Affecting the Consumer

Of the reported barriers, only very few explicitly involve consumers and their decision making as described in the Market Model. Examples of barriers, which cover most of the criteria consumers used in selecting a refrigerator, include:

Barrier No. 26: the labelling of refrigerators is still poor and consumer-unfriendly in many countries

Barrier No. 27: the information made available to consumers from manufacturers is often distrusted; they are not given adequate information on the effects of their technology choice on operating costs (energy consumption) and on the environment

Barrier No: 28: consumers are more interested in the price of their refrigerator than ecological benefits.

Validating the Barriers

Some forty nine barriers were reported by the various stakeholders interviewed, covering a range of technical, cost, market, institutional and environmental issues. Some of the reported barriers covered more than one issue and many of them related to similar points. Many of the barriers can be observed within the Market Model but many are the *perceptions* of individual stakeholders and some of the barriers are based on *inaccurate information* or an *incorrect understanding* of the issues.

The Workshop sought to focus stakeholders' attention on those issues that were most important (see Workshop paper for a description of the process) and six of the barriers were identified in the Workshop as the most important ones:

- Through commercial agreements e.g. joint ventures, licensing agreements etc., between developed and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology
- Consumers are more interested in the price of their refrigerator than ecological benefits
- There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry as a whole and especially to developing countries
- The investment costsfor changing a production line to HC (costs for safety measures) are higher than for HFC-134a

- There is widespread ignorance about the disadvantages of synthetic replacements (e.g. 134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries)
- Manufacturers fear misinformation campaigns and adverse publicity against HC from the chemical multinationals as well as from competing manufacturers

Many of the forty nine reported barriers were also covered by the six working groups, but in some instances insufficient attention was given to correction of those barriers which are based on perceptions and inaccurate information. Many of the barriers which fall into this category relate to the "Institutional Barriers" and this section attempts to clarify the situation. The Technology and Cost Paper corrects, where necessary, those barriers that relate to technical, cost and environmental issues.

Barrier No. 35: The Multilateral Fund and Implementing Agencies are not well-informed about alternative refrigeration technologies in general and have failed to inform clients in time and in an unbiased manner.

The Multilateral Fund points out that only three years ago there was no widespread commercial use of HC technology in refrigeration and foam blowing. They have already funded 54 HC projects in 20 Article 5 countries over the past three years which demonstrates technology transfer over an extremely short time frame.

Barrier No 36: The Multilateral Fund does not devote sufficient funds to adaptive research and development and for demonstration or pilot projects.

It should be noted that, in the Fund's eligibility criteria, the most mature and transferable technology should be considered by Article 5 countries as a first priority and so, funds for adaptation and development could be expected to be minimal. The Multilateral Fund makes efforts to ensure that project approvals do contain some allocation for R&D in various ways.

Barrier No 38: The project rules for HC conversion projects funded by the Multilateral Fund are based on the rules used for synthetic fluids - this is an illustration of their inability to cope with emerging technologies.

The Multilateral Fund has responded by pointing out that 71% of their total allocation to the domestic refrigeration sector is for projects with either partial (foam part) or complete (foam and refrigerant part) HC technology which demonstrates that their policies are proving successful in addressing the choice of Article 5 countries in adopting new HC technologies.

The Multilateral Fund also pointed out that with respect to cost-effectiveness, the average cost-effectiveness of projects using either cyclopentane foam or complete HC technology is only 27% greater than the cost-effectiveness of HCFC/HFC based projects. This is well within the 35% discount established by the Executive Committee for projects using HC technologies.

The Multilateral Fund is also aware of a general misunderstanding of the cost-effectiveness thresholds and a belief that they cannot accommodate the choice of HC technologies for combined foam and refrigerant conversions. By way of example, a project approved for conversion of a large enterprise in China to isobutane and cyclopentane demonstrates that conversion to HC technologies is very cost-effective. The cost-effectiveness of this project without discounting for safety costs was US$5.84/kg ODP. After discounting by 35% the cost-effectiveness of the approved project was US$2.74/kg ODP which is much below the cost-effectiveness threshold value established at US$13.76/kg ODP.

Barrier No. 39: The eligibility criteria for the funding of incremental investment costs for HC-600a conversion projects are inadequate.

As with Barrier No. 38, this barrier can not be substantiated as all 8 projects submitted to the Executive Committee for approval using isobutane as a refrigerant have been approved. There are no eligibility criteria which distinguish between HC-600a and other refrigerants, except for the calculation of the cost-effectiveness where HC-600a is given an advantage as addressed in the preceding barrier.

The Multilateral Fund has also commented on other reported barriers: firstly, that there is a time delay in approving new technologies and funding new projects is not seen to be valid as the processes for the review, approval and funding of all projects accord with the rules and policies in operation under the Multilateral Fund and do not vary with the choice of technology. They were not able to cite any instances of specific delays relating to projects involving the use of HC technologies. Secondly, with respect to perception that recurrent costs of conversion to HC technology are only partially funded under the Montreal Protocol, the Multilateral Fund advises that incremental operating costs have been claimed in the majority of projects using HC technology so far. In some instances enterprises have chosen not to claim operating costs in order to present projects which were more cost-effective and similar situations have occurred in projects using non-HC technologies.

Technology Transfer Issues

Summary of Findings

In presenting our analysis of the findings of the Workshop, a number key issues have emerged for consideration:

- as both HFC and HC technologies are feasible and the technical superiority of either cannot be demonstrated, manufacturers have **technology choices** to make in the context of their CFC phase-out decisions
- manufacturers need to assess the **cost issues** associated with both technologies in making technology choice decisions
- the **conditions in developing countries** amount to an important influence in determining technology choice and in the adaptation and adoption of the technology.

Each of these issues is linked by the **mechanisms of technology transfer** which influences how a technology (be it HFC or HC) is transferred from a developed to a developing country manufacturer.

Technology Choice and Cost Issues

In choosing between HC and HFC technology options, manufacturers need to assess the relative costs and risks of each. However, comparative cost information is not widely available for conversion costs for compressor and refrigerator manufacturing plants. It is clear that the investment costs for HC technology are higher than for HFC technology because of the necessary safety precautions and that unit costs of HC refrigerators are higher because scale economies have yet to be captured. The Multilateral Fund points out that the average cost-effectiveness of HC technology projects is only 27% greater than the cost-effectiveness of HCFC/HFC based projects, and this is well within the 35% discount established for HC projects.

Manufacturers also have to assess any environmental implications of their technology choice in the context of the regulatory regime and in terms of the marketability of their product. That HC technology is environmentally superior to

HFC technology is not established, and there is no consensus on any adverse impacts of HFCs.
These selection criteria were presented in the Market Model.

Conditions in Developing Countries

Conditions in developing countries affect technology choice decisions for a variety of reasons; rapidly expanding markets and increasing demand for consumer goods are providing attractive opportunities for manufacturers. However, tropical climatic conditions, the lower skill level of workers and a lack of discipline in the workplace (especially in servicing) need to be incorporated in manufacturers' decisions. Evidence suggests that HC technology offers a number of advantages over HFC technology in developing countries on account of these issues. Even so, manufacturers in developing countries complain that the information they need to assist them in appraising these issues is incomplete, inaccessible or biased. The "information vacuum" might be attributed to the industry structure (i.e. four global players in compressor manufacturing and the influence of MNCs in shaping the perceptions of mainstream technologies in the market place).

The initial purchase price is central to consumers' purchasing decisions in developing countries and, unlike consumers in German-speaking markets, they are unlikely to pay more for a refrigerator that offers environmental benefits.

Technology Transfer Mechanisms

In understanding how manufacturers can make informed decisions about technology choices, the mechanisms of technology transfer need to be examined. Evidence from the Workshop suggests that many developing country manufacturers are not yet involved in a joint venture or licensing agreement with a developed country manufacturer. And, given the investment in R&D by developed country manufacturers in HFC technology, they are committed to promoting their products. It appears, therefore, that the transfer of refrigeration technologies is dependent upon the corporate strategies of the major manufacturers, as well as upon the relative capacity of developing country manufacturers of compressors to adopt this technology.

In making their technology choices, developing country manufacturers seek to manage, or reduce, the risks involved by looking at the evidence in the market place based on the experience of other manufacturers. However, there does not seem to be any consolidated information about manufacturers' experiences in developing countries of either technology. It is important, therefore, to look at the process which accompanies the technology choice and the role of corporate strategies in decision making.

It does seem that the corporate strategies driving technology choices are inconsistent with the vision of the Multilateral Fund and with the concept of fair access to technology on a commercial, or government-to-government, or country-to-country basis. On this basis, and because of the risks and uncertainties outlined in the previous sections, it would appear that HC technology is not readily available to manufacturers in developing countries and they are unable to consider fully it in their decision making process with a base of information which is as complete or as trusted as for HFC-134a.

6 THE BARRIERS STUDY
- September 1996 -

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Context

This paper is part of a series of four papers which give an overview of the conclusions and findings of a study programme initiated by the World Bank and sponsored by Germany's GTZ and the Swiss Agency for Development and Cooperation, under the title "Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market". The study programme has had a number of components:

- a review of the technology, market, costs and environment issues of hydrocarbon technology in comparison with HFC and HCFC technologies (*Technology, Market, Costs and Environment Study: Hydrocarbon Technology in Relation to HFC/HCFC Technology).* This study has been undertaken by FKW and Infras
- a study of the non-technical barriers affecting the rate of adoption of hydrocarbon technology (*The Barriers Paper)* together with a number of country case studies. This study has been undertaken by Deloitte & Touche Consulting Group
- a workshop, which provided an opportunity for the findings of the study to be presented and discussed, for the validity of the barriers to be examined and, for possible actions to be explored (*The Workshop Paper).* The Workshop was hosted by SDC and Infras, moderated by GTZ and chaired by the World Bank and Deloitte & Touche Consulting Group. This paper has been prepared by Deloitte & Touche Consulting Group
- an integration of the findings from the Workshop with the Barriers Paper (*Technology Transfer Issues Paper).* This paper has been prepared by Deloitte & Touche Consulting Group.

All the papers have benefited from the inputs of various experts during a peer review.

Executive Summary

Deloitte & Touche Consulting Group were appointed by The World Bank in January 1996 to assess the barriers, if any, affecting the adoption of hydrocarbon technology in the domestic refrigeration market. We conducted desk research and a series of interviews with key stakeholders within the refrigeration sector including manufacturers, policy makers, and non-governmental organisations. The study has been done in conjunction with GTZ and SDC which have funded complementary studies on Technology and Market issues.

It should be stated that the barriers reported in this paper are the interpretations and views of the stakeholders interviewed. Some of these are perceptions, some are based on an incorrect understanding of the issues and some are demonstrably untrue. Deloitte & Touche Consulting Group and other members of the study team do not necessarily agree with all of the views expressed in this paper.

This report sets out the findings of this study that were presented to the participants at the Workshop in Switzerland from June 5 - 7 1996. This Executive Summary focuses on the key issues which arise.

Hydrocarbon Technology

Hydrocarbon technology has been successfully used in the domestic refrigeration market in Germany and other northern and central European countries, for both refrigerants and foams. It has become a proven technology and has demonstrated a number of benefits over other prevailing technologies; in particular, it offers environmental benefits since it is neither ozone depleting nor does it contribute towards global warming.

The main drawback to the use of HC technology is its flammability; for refrigerants this poses potential safety hazards both in the production process and in usage, whereas for foams (cyclopentane), flammability is only an issue in production. Cyclopentane is increasingly accepted as the global standard for foams.

Alternative Technologies

As countries phase-out their use of CFCs under the terms of the Montreal Protocol, they are having to make choices about the alternative refrigerants and foaming agents. Commonly used alternatives are HFC-134a as a refrigerant and HCFC-141b for foam, although the latter is an interim solution in view of its phase-out in the medium term. The main advantage of HFC-134a as a refrigerant is its similarity with CFC 12 and the relative ease of conversion, however, it does have a significantly different material compatibility, and it requires a different compressor oil which imposes strict cleanliness and moisture control standards in production and servicing.

Understanding the Barriers

Whilst hydrocarbon technology and the alternatives each offer benefits and suffer from disadvantages, HC technology has not had the same degree of commercial success and acceptance in the global market place. There is a need, therefore, to assess the barriers in the market place that are affecting its adoption and to enable decision makers, particularly those in developing countries, to give it full consideration in the CFC phase-out strategy.

In assessing whether this may be the case, we have gathered information on a number of barriers that have been reported to us. A full list of these barriers are presented in the Appendix to this report. These barriers may appear at a **technical and cost** level and affect all the cost issues involved in bringing a product to market. Examples of the barriers that were reported to us are:

- the investment costsfor changing a production line to HC technology are higher than those for HFC-134a, on account of safety measures
- manufacturers do not have sufficient know-how for managing safety risks associated with the storage of large quantities of HC refrigerant
- there are cost implications for the servicing of HC refrigerators - engineers need to be trained and additional equipment is required over that for HFC-134a.

Barriers have also been cited at a **market** level which include issues such as the price of the product in the market, the product itself and the merits upon which it is sold, and the promotion required to make the product successful in the market. For example:

- a parent company's technology is often transferred from developed to developing country manufacturers through commercial agreements such as joint ventures and licensing agreements
- lack of consumer demand for HC refrigerators; this is based on ignorance of refrigeration technology and poor labelling of products
- hydrocarbon technology is viewed as just a "German" technology and information is scant on other countries' positive experiences.

Stakeholders have reported barriers at a **policy and institutional** level which concern the interventions that are made by governments and institutions, and the information made available in the market place. Examples include:

- the costs of conversion to HC technology are only partially funded by the Multilateral Fund
- the consultants employed by the Implementing Agencies have at best limited experience of using hydrocarbon technology

- insufficient resources are devoted by the Multilateral Fund to demonstration and pilot projects
- procedures for new technologies and approvals for new projects are subject to time delays.

Geographic Issues
As well as barriers operating at a technical, market and institutional level, there are also some significant geographic factors that need to be considered. In developed countries, manufacturers have already converted from CFCs and have made choices to either HFCs or HCs. It would appear that those that have opted for HFCs are unlikely to convert again in the short term unless there is overwhelming pressure either from government or consumers for them to do so.

In developing countries technology choices are less clear cut as CFCs and, increasingly, HFCs are readily available. We have undertaken case studies of India, China and Argentina as representative, and significant, markets. It is possible to observe that as their economies are liberalising, opportunities for foreign investors are increasing and technology choices can be influenced by commercial agreements.

The Workshop
One of the aims of the Workshop was to discuss the findings of this study, examine the validity of the barriers and to explore possible actions. In addition, it sought to gain agreement in areas where there is considerable divergence of opinion.

Introduction

Background to the Study

As part of a World Bank initiative, Deloitte & Touche Consulting Group (D&TCG) were commissioned to undertake an assessment of the barriers affecting the adoption of hydrocarbon (HC) technologies (i.e. refrigerants and foams) in the domestic refrigeration market. This study was undertaken in collaboration with the Swiss Agency for Development and Co-operation (SDC), the German technical co-operation agency (GTZ), and consultants Infras and FKW. Infras/FKW and GTZ have undertaken supporting reviews of the technical case for HC technologies and of the market development of hydrofluorocarbon (HFC) and HC refrigeration respectively. The outputs of these reviews are presented separately.

The initiative has concentrated on the domestic refrigeration market and has considered refrigerants, foams and end products; where possible we have examined the application of HC technology to other markets.

Plans for this initiative were proposed by the World Bank at the Eighth Ozone Operations Resource Group (OORG) Meeting in Washington on October 26, 1995. The effort was initiated in view of the perceived potential environmental benefit of adopting HC technologies. This initiative aims to supplement work already undertaken by the OORG on the technical barriers to HC technology by providing an objective evaluation of other barriers affecting the adoption of this technology. The objectives of the initiative are:

- to provide decision makers (particularly those eligible for assistance from the Multilateral Fund) with appropriate information about HC technology so that they can give it full and fair consideration in their CFC phase-out strategy
- to develop an understanding of the possible options needed to reduce those barriers and establish a level playing field.

The initiative also involves the convening of a workshop with participation by key stakeholders in the refrigeration sector; this draft final report serves to inform the workshop participants of the perspective of many of the key stakeholders and it reports on the barriers that they have identified.

In the following sections of this report we describe the hypothesis for the existence of non-technical barriers to HC technology and provide an outline our methodology for undertaking this study. In Chapter 2 we give a synthesis of the emergence of HC technology in Germany and some of the actual and perceived advantages associated with this technology. Chapter 3 describes the barriers that have been reported to us and provides a brief summary of how each barrier is seen to operate. Chapter 4 provides a geographical perspective and Chapter 5 examines the significance of the barriers. Appendix I presents an inventory of the reported barriers.

In separate volume, we present a collection of country case studies which highlight some of the key issues facing HC technology in both developed and developing countries.

The Hypothesis for the Existence of Barriers

As a result of recent technical developments, it appears that HC technology used in domestic refrigeration may have economic as well as environmental superiority over other technologies now dominating the post-CFC domestic refrigeration market (i.e. it is the best zero-ODP technology available). Although the use of HCs in foam blowing applications has found widespread use globally, the use of HCs in the cooling circuit has yet to break out significantly from its European origin into the rest of the world, both developed and developing.

This study was commissioned on the basis that there is a concern that there may be barriers in the market place which are preventing HC technology from being considered on an equal footing with the prevalent technologies and which are preventing the full environmental benefits of the technology from being captured.

Over the course of the study, we have noted a number of dissenting views from this hypothesis; in particular, some of the major refrigeration manufacturers do not believe that HC technology is environmentally superior to other refrigeration technologies, notably HFC-134a. Such manufacturers go on to assert that since there are no advantages there are, therefore, no barriers to HC technology as it does not require any special promotional effort.
Taking these views into account, we observe that whilst HC technology has one distinct disadvantage over other refrigeration technologies i.e. its flammability, it does have main advantages:

- it has no Global Warming Potential
- it does not contain any fluorine and it is not persistent in the environment
- it can operate with mineral oil which is preferable to the ester oils that HFC-134a requires (ester oil being hygroscopic and requiring high standards of cleanliness in production)

In addition, there is a theoretical energy efficiency associated with the use of HC technology which warrants an examination of its application to the refrigeration sector.

To understand the barriers facing HC technology we have, therefore, undertaken a comparative assessment of HC and HFC refrigeration technology and examined benefits and disadvantages of each.

In the following sections of this report we examine whether there are barriers that are unique to HC technology and we determine whether or not HC technology enjoys a level playing field relative to the other alternatives. By examining the different stakeholders and their interactions within the refrigeration market, we aim to provide an objective and impartial assessment of the global prospects for hydrocarbon technology in the domestic refrigeration market.

Our Methodology

In undertaking this study we adopted the following approach:

- a literature search and a networking programme to identify and confirm the main stakeholders in the refrigeration market, to gain a preliminary view of the barriers and to identify possible case studies
- an interview programme covering stakeholders and those relevant to the case studies
- the collation of an inventory of barriers (both real and perceived).

Further information on the reality of the barriers was sought from stakeholders present at the Workshop.

The discussions and outputs from the Workshop have assisted in this exercise and have been incorporated in the subsequent sections of this report - namely the Technology, Market, Costs and Environment Study and the Technology Transfer Issues Paper.

A key objective of our information gathering and reporting was to provide an *objective and impartial* exposition and analysis of the main issues surrounding the adoption of HC technology in the domestic refrigeration market. We have sought to be neutral in our reporting style and to provide a thorough and detailed presentation of the barriers described to us.

We have drawn upon the complementary studies undertaken by Infras and FKW on technology and market issues and on their programme of information gathering which has also sought to identify barriers. In addition, a number of country case studies reinforce and highlight some of the barriers facing HC technology; case studies have been undertaken on India, China, Argentina, the US, Germany and the UK.

The Rise and Prospects of Hydrocarbon Technology

The Success of HC technology in Germany

Hydrocarbon technology in the domestic refrigeration sector is probably best known from its success in Germany. The success of a small manufacturer, Foron, based in former East Germany, in identifying and pursuing the production possibilities and a market niche for HC refrigerators was brought about by a number of factors. This in turn assisted the spawning of a, hitherto unpredicted, new approach to refrigeration production and one which occurred at a rapid pace.

The changes came about within an industry that had accepted HFC-134a as the replacement choice for CFCs; however, using research undertaken at the Dortmund Institute for Hygiene on ecological CFC phase-out solutions, and with the interest and initial investment of Greenpeace, a small ailing company was persuaded to look at a new technology.

In a bold move and risking its chances of survival, the management of Foron decided to enter into the production of refrigerators using propane/butane blends. Taking advantage of the growing market for "green" consumables, a mail order company, Neckermann, ordered 20,000 refrigerators whilst they were still at prototype stage and before the required approvals had been issued by the German safety institution, TÜV.

The product gained almost immediate acceptance in the market place from ecology-conscious German consumers, and the marketing success was strongly influenced by the Greenpeace "GreenFreeze" campaign. Other refrigeration manufacturers soon identified opportunities in this area; Liebherr decided to convert directly from CFCs to hydrocarbons and pioneered the use of cyclopentane as a blowing agent. Bosch-Siemens also saw the opportunities in the green market and, using their market power, were able to influence and bring about changes in the compressor market towards HC technology.

To date some five million HC refrigerators are in use in Germany (produced by Bosch-Siemens, Liebherr, AEG, Zanussi, Foron and Whirlpool); HC technology (both for refrigerants and foams) is used in 95% of all refrigerators produced for the German market. No-frost HC refrigerators are also being produced and their market share (currently less than 10%) is expected to increase gradually. It is estimated that 50% of the models produced in Germany for the European export market are based on HC, whereas those produced for the rest of the world are predominantly HFC-134a.

There have not been any reported accidents resulting from HC refrigerants, either from manufacturers, the service sector or from normal domestic use. There have been 5 reported accidents resulting from cyclopentane in the manufacturing process; one recent accident (March 1996, although without any casualties) is currently being investigated by TÜV. This has puzzled the industry as it happened at one of the most safety-conscious manufacturers where all the necessary precautions, including inertisation with nitrogen, were being observed; this accident may serve to caution the industry since it may indicate dangerous situations beyond the present stage of knowledge and in areas where there is insufficient experience with flammable foaming materials.

Under German law there are no manufacturer product liability issues as long as the goods fall under the jurisdiction of safety standards set by the official institutions and existing regulations are sufficient for household refrigeration. The forthcoming European regulations will supersede these standards although they will focus on commercial use; they may, however, cause some uncertainty in the future.

The refrigeration market in Germany is still highly competitive and because HC units are slightly more expensive than other models (some of the component parts are not mass-produced), this may encourage retailers and wholesalers to reconsider HFC-134a, even though "CFC-free + HFC-free" is now a common standard. However, at present the main focus of the German refrigeration industry is energy efficiency. In the longer term, this may mean considerable design changes, such as thicker insulation although as yet the market is resisting models of larger dimensions.

The German success story is being replicated in other parts of the world through commercial agreements and acquisitions, however, the major manufacturers are taking a pragmatic approach in their technology transfer decisions. Their policy is to use totally CFC-free technology i.e. a conversion at minimum to cyclopentane and HFC-134a (e.g. Bosch-Siemens' acquisitions in China). The economics of conversion is also of key importance as is system reliability (e.g. Liebherr in China). In addition, Germany has funded the introduction of HC technology as part of its contribution to the Multilateral Fund of the Montreal Protocol, in e.g. India and China, and will continue to do so under the present GTZ/PROKLIMA-Project.

To conclude this brief examination of the German success story, we can observe the following:

- success arose in a unique political and economic environment resulting from reunification and this was supportive of former East German enterprises
- HC technology is accepted by the consumer
- the flammability issue never came under intensive public discussion as consumers accept safety standards as a quality guarantee
- energy efficiency issues are now receiving most attention in the refrigeration sector.

Germany is an established and unique situation in the world market for HC refrigeration technology and at present only Switzerland, Austria, the Scandinavian countries and recently Spain bear any resemblance. As HC technology has "matured" between 1992 and 1995, the situation in 1996 is best characterised by fading public and political interest; this might make it more difficult to obtain additional public support on the issue of ozone layer protection in the future. On the other hand, mass production of R600a compressors has taken off outside Europe in 1996 (in Brazil, Malaysia/Singapore, Egypt).

The Advantages of HC Technology

As identified and discussed in the Technology Study, HC technology has a number of key characteristics which explains its introduction into the German refrigeration market and which warrants its further investigation.. In this section we provide a brief summary of the advantages and positive influences that could encourage and persuade institutions, governments, enterprises and consumers to opt in favour of HCs as refrigerants and foam blowing agents. Alongside these advantages we also cite some of the key disadvantages associated with HFC-134a.

These can be summarised as follows:

Technical Factors: One of the key advantages of hydrocarbon refrigerants and foams is their *simplicity*; HCs are derivatives of the petrochemical process - pentane and isobutane are by-products of a synthetic process - and require purification before use. HC refrigerants have excellent thermodynamic and thermophysical properties that are particularly well suited to the warm and humid climates of most developing countries. HFC-134a, by contrast is produced by synthetic chemistry.

HC refrigerants are *compatible* with CFC technology; they can use the same mineral oils, which are not easily contaminated by chemicals in the production process. HFC-134a requires ester oils which are expensive and incompatible with those used for CFC-12. Ester oils are highly hygroscopic which imposes a strict cleanliness and moisture control discipline in production and servicing. For example, HFC-134a compressors have to be stored in hermetically sealed containers prior to use. In servicing, all the oil must be removed from an HFC-134a refrigerator; again care must be taken with respect to moisture levels and a special vacuum pump oil is required.

HC blends can use the same compressors as used with CFC-12, and those compressors manufactured for pure isobutane offer *energy savings* in the order of 5% over CFC-12, and similar savings over HFC-134a at higher ambient temperatures. Isobutane refrigerators are *lower noise* refrigerators compared with other types. Drop-in conversions with HC refrigerants are possible with CFC-12 compressors if an isobutane/propane blend is used; this technique has been used by Foron in Germany and Elstar Manufacturing Ltd. in the UK.
Cost Issues: the *cost* of hydrocarbon refrigerant available in Europe is lower than other types and less is required in weight per unit charged.

For developing countries, the safety-related costs for converting a CFC refrigerator production line are in the same order of magnitude as those for changing to the production practices (cleanliness and moisture standards) required for HFC-134a.

The *recurrent costs* for cyclopentane foams in the manufacturing process are lower than HCFC-141b and there is no requirement for an inner liner material as is the case with HCFC-141b. Using hydrocarbons as the blowing agent (i.e. cyclopentane) means that there is no *corrosion or abrasion* of machinery as compared with HCFC-141b.

There are fewer *customer returns* reported with HC-600a refrigerators compared with HFC-134a.

Economic Factors: In addition to the technical benefits, HC technology can offer developing countries *independence* from synthetic fluids and synthetic oil supplies. Manufacturers adopting HC technology may need a technology transfer agreement but do not necessarily need to undertake joint ventures or licensing agreements. Furthermore, the use of HC technology in the production process does not require patents or licences.

A number of refrigerator manufacturers in both developed countries (e.g. the UK) and developing countries (e.g. Turkey) have identified *export markets* for HC refrigerators, mainly Germany and some other northern European markets.
For developing country manufacturers, converting to HC technology in the first instance rather than to HFC-134a as a "stop-gap" will avoid a *second conversion* in the longer term. Complying with the necessary safety requirements for HC technology will cost less than the technical requirements of HFC-134a such as checking cleanliness and low moisture in the circuit

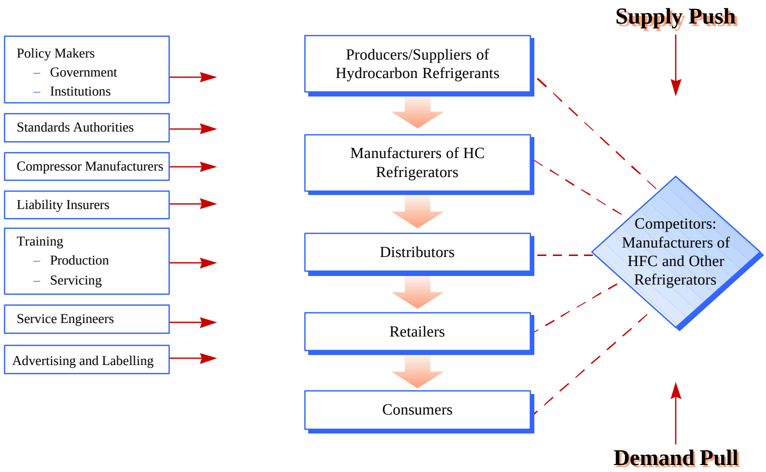
Perhaps the most overriding advantage of HC technology for an developing country is the *developmental benefit* it offers: an initial investment in the necessary safety infrastructure means that cooling devices can be manufactured and maintained within the present work culture. The skills acquired from compressor manufacturing can also be used in servicing.

Environmental: An important advantage of hydrocarbon technology is the environmental benefits it offers; HC technology has zero ODP, negligible GWP and theoretical enhanced energy efficiency compared with HFC-134a and cyclopentane.

The Market Structure of the Refrigeration Sector

In assessing the use of HC technology we have examined the structure of the domestic refrigeration market and the key players and stakeholders involved. A market model, which broadly applies to both developed and developing countries, is presented in diagrammatic form overleaf. Our interview programme and data gathering exercise have sought to gain representative coverage from each stakeholder group.

Hydrocarbon Technology in the Domestic Refrigeration Market
A Market Model: The Players and Stakeholders



The Barriers to HC Technology

The Barriers

Over the course of our information gathering, stakeholders have reported a number of barriers affecting the adoption of HC technology. In the following section we have classified the barriers into some broad categories:

Technical and Cost Barriers: these include all the cost issues involved in bringing a product to market. The barriers cover issues such as:

- HFC vs. HC comparisons
- the initial capital investment in HC technology and the subsequent operating costs
- ancillary issues such as compressor designs, maintenance, working practices and investment to meet safety regulations

Market Barriers: these include issues such as the price of the product in the market, the product itself and the merits upon which it is sold, and the promotion required to make the product successful in the market.
Policy and Institutional Barriers: these barriers concern the interventions that are made by governments and institutions and the information made available in the market place.

We discuss how the barrier operates, the stakeholders who have cited it, how other stakeholders are affected by it and whether it is a barrier that is unique to hydrocarbon technology. In Appendix I we provide a full inventory of the barriers.

It should be stated that the barriers reported in this paper are the interpretations and views of the stakeholders interviewed. Some of these are perceptions, some are based on an incorrect understanding of the issues and some are demonstrably untrue. Deloitte & Touche Consulting Group and other members of the study team do not necessarily agree with all of the views expressed in this paper.

Technical and Cost Barriers

Alternative Technologies: One of the most significant barriers identified by stakeholders is that CFC-12 continues to be available in developing countries. The continued use of this technology, plus the broad dissemination of information about HFC-134a combine to form an effective barrier against alternative technologies.

Production, Distribution and Marketing Costs: Manufacturers commonly cite a number of technical barriers relating to the cost implications arising from the safety precautions necessary for HC technology. This occurs in both the production process and in domestic usage, and it impedes their willingness to consider HC technology.

The overall cost implications of changing a *production line* to HC technology are typically considered to be a considerable barrier to manufacturers and this primarily relates to safety-related investment and acquiring the relevant know-how. Many of the barriers are also linked to the cost and safety implications discussed under Market Barriers and include:

- as will all *new technology developments,* the benefits of scale economies have yet to be fully exploited in HC refrigerator production, particularly for component parts (all manufacturers did not agree on this issue)
- higher investment and recurrent costs for frost-free HC refrigerators (agreement)
- safety risks and related precautionary measures associated with the storage of HC refrigerant in large quantities in a *manufacturing plant* (varying views about the importance of this issue)
- perceived safety risks associated with the storage of HC refrigerators in *warehouses* (considered a barrier by a minority of stakeholders)
- developing countries may not be in a position to produce HCs of appropriate *quality and purity* at a competitive price; the same may also be true for HFC-134a
- different compressors are required for HC refrigerators; this imposes additional R&D costs and can involve higher recurrent costs (additionally, if HFC compressors are used for HC refrigerants, the *guarantee* will be invalidated.) Stakeholders have also said that there is a *shortage* of some types of HC-600a compressors at competitive prices in some regions of the world (widespread agreement by manufacturers)

- developing country manufacturers may lack adequate facilities and sufficient personnel for research and development for the redesign of models using HC technology
- developing countries may lack a local compressor production capability (both for HCs and HFCs), so there is a tendency for increased imports (broad agreement)

In the case of those developed manufacturers which have recently converted from CFCs to HFCs, a commonly quoted barrier is the fact that the *payback* on their investments necessary for CFC conversion is still awaited. In Germany, manufacturers had to write off their investment in HFC-134a within two years. Other manufacturers are reticent, however, to undertake new investments.

It is often assumed that developing countries are able to *"leapfrog"* technologies; however, the operating environment is often more complicated than anticipated on account of their weak implementation capacity, different working practices and a cautious approach to adopting new technologies.

Servicing Issues: In the servicing of HC refrigerators, developed manufacturers have stated that there are cost implications involved in the servicing of HC refrigerators (for the distribution of the refrigerant, staff training and charging equipment) if HFC-134a has already been adopted. There are concerns that *service engineers* are unfamiliar with HC refrigerants which also can cause safety issues. In developed countries, the costs involved in establishing servicing facilities for three refrigerants (CFC-12, HFC-134a and HC-600a) are seen as prohibitive. In addition, the enforcement of appropriate servicing is acknowledged as difficult to monitor or observe, even in countries where such standards exist.

In developing countries imported compressors using synthetic oils may lead to *servicing problems* if they can not be serviced locally. This can be the case for HC and HFC compressors - servicing problems for HFC-134a can be acute, especially in humid coastal areas on account of its moisture sensitivity. Servicing issues may be compounded if only a few manufacturers adopt HC technology as HC-600a may not be readily available.

Commercial Relationships: The commercial relationships that exist between manufacturers, both on a competitive basis and between suppliers of component parts, can generate barriers. developing country manufacturers (and some small manufacturers in developed countries) have mentioned their *dependence* on compressor manufacturers as a barrier to HC technology. The *availability* of HC compressors and the degree of innovation within the compressor industry impacts strongly on manufacturers.

The *vested interests* of manufacturers of HFC refrigerators and US-based appliance manufacturers have been cited as a considerable barrier by NGOs; the commercial weight that large manufacturers and multinational firms could have in undertaking adverse publicity and misinformation campaigns against HC technology is claimed to be a barrier that could affect the sales of HC refrigerators in markets with competing refrigerants.

An additional barrier that faced the proponents of HC technology (mainly those from non-governmental organisations), was their initial lack of *commercial respectability* and the unwillingness of manufacturers to give their arguments credibility; this barrier has been cited by non-governmental organisations and governments as well as the suppliers of HCs.

Developed countries have cited the *economic recession* as a barrier that has restricted new investment and has affected consumer demand. The recession has reduced the diffusion of technology within developed markets. Conversely, in developing countries, it has been reported that the high economic growth rates do not create sufficient pressure for innovation by refrigeration manufacturers. New technologies are not adopted because consumer demand is easily satisfied with products produced from existing equipment.

Product Liability: the issue of product liability is seen as the main barrier in the United States of America and in some developing countries. The actual risks and the scale of any claim are unknown A US-style HC refrigerator has yet to be produced and tested by Underwriters Laboratory.

Market Barriers

The stakeholders that have cited barriers in the market-place have predominantly been the manufacturers and retailers of domestic refrigerators. Market barriers include the effects of competition, technology transfer and investment decisions; it is possible to distinguish between the barriers facing developed country manufacturers, which have already converted from CFCs to HFCs, and developing countries, which have yet to invest in alternatives to CFC refrigerants. Some of the barriers are reported to exist at a political level and operate within both developed and developing countries.

Technology Transfer Issues: in developing countries, many of the larger refrigerator manufacturers are undertaking joint ventures or have licensing agreements with companies based in developed countries with no experience of HC technology (e.g. US and Japan). These arrangements are viewed by some stakeholders as a barrier to HC technology because the parent company typically guides *investment decisions* and imposes their technology on the manufacturer. This can also have an impact on the export markets that manufacturers can access.

Safety Issues in Domestic Usage: Many manufacturers have expressed concerns about safety issues relating to the use of HC refrigerators in the home. These barriers largely stem from consumers' *perceptions* of safety hazards and from their *ignorance* of refrigeration technology. By contrast, other manufacturers counter this as they believe that the consumer assumes the manufacturer will address safety issues before bringing a product to market.

Manufacturers have pointed out that many refrigerators are damaged by consumers *tampering* with them, often in the process of defrosting. With HC refrigerators there is a concern that consumers could be exposed to a greater risk by puncturing the hermetic circuit and then causing the ignition of the refrigerant.

A variety of market barriers operating at a *political* level have been reported; these barriers originate and operate in both developed and developing countries. These barriers have been cited by non-governmental organisations, institutions and manufacturers:

Developed Countries: Some widely differing barriers with a political dimension have been identified from within developed countries; for example, there is a view that HC technology is considered as a *"German"* technology and, because of this connotation, it is difficult to promote with any political neutrality. In addition, developing country manufacturers cite that they have scant information from other European manufacturers about their use of HC technology and this implies that HC technology is not accepted by other developed countries.

By contrast, in the USA, *nationalistic interests* and commercial leadership are cited as barriers affecting developing countries; by promoting HFC technology over HC technology, developing countries are unable to gain independence from developed country know-how.

Developing Countries: A barrier noted within developing countries is the misuse of the *CFC phase-out issue* as a means to demand support from developed countries. This action is seen as a means to delay tackling the issue and creating an unnecessary demand for and reliance on external resources.
Consumers: the ignorance of consumers of refrigeration technology has been cited as a barrier and this is compounded by the *poor labelling* of products which are considered to be too technical and consumer-unfriendly. The costs required to educate consumers, for example through *advertising*, are also deemed to be a barrier. Information on safety issues is considered to be inadequate; it is considered that consumers are not presented with sufficient *information on flammability risks* of HC refrigerators particularly in comparison with other devices that use flammable substances.

Some stakeholders have raised the issue of the *quality and source* of the information made available to consumers; information published by manufacturers is perceived to be biased and partial and is distrusted by the consumer.

The lack of *consumer demand* for environmentally-friendly products and their unwillingness to pay any premium for such products (on account of safety costs) is typical of most developed (except Germany) and developing countries. The barrier cited by manufacturers is that consumers place price above ecology in their purchasing decisions.

Environment: A number of stakeholders have expressed concern that HCs are not a panacea for the environmental problems they aim to alleviate and that HCs themselves also have environmental disbenefits. The barriers often relate to an absence of hard data or are not based on scientific fact and those cited include:

- HCs have high *VOCs* which may lead to low level ozone
- HCs are not *"natural"*; they are a by-product of an intensive refining process
- there is a lack of coherent and credible evidence on TEWI for both HCs and HFCs; different manufacturers hold conflicting views on this issue within developed countries and this in turn sends confused messages to

the industry as a whole and especially developing countries

- HC refrigerators are not necessarily more *energy efficient* on account of the larger size of the compressor required.

Some stakeholders have suggested that there are a number of technology issues that have been overlooked or for which there is *insufficient knowledge*; for example, some manufacturers assert that there are practical problems for drop-in HC blends (CFC-12 retro-fitting) and that developing countries would be unlikely to accept a practice that is not employed in developed countries. There are concerns that blends might be used without following the appropriate safety standards; if accidents then occurred, there would be a loss of *consumer confidence* in HC technology. Another example is that the issue of appropriate blends of hydrocarbons for retrofitting has not been devoted sufficient attention for developing countries.

There is also widespread ignorance about the disadvantages of synthetic replacements for CFCs (e.g. HFC-134a is unsuitable in some countries and would require substantial changes in working practices in manufacturing operations). Other manufacturers have raised questions about the *toxicity* of HC technology which has not been fully tested.

Policy and Institutional Barriers

It appears that there is often some confusion and misunderstanding of institutional policy and implementation procedures by many of the stakeholders interviewed and this can be evidenced by the barriers reported in this section.
A number of barriers have been cited that affect the adoption of HC technology at an institutional level (e.g. the Multilateral Fund and the Implementing Agencies - UNEP, UNDP, the World Bank and UNIDO) and through government interventions. The institutional barriers primarily affect developing countries and are always not unique to HC technology because they often reflect bureaucratic weakness and financing constraints. The barriers have been cited by non-governmental organisations, consultants, manufacturers and the institutions themselves.

A lack of information within institutions, or the dissemination of inaccurate or misleading information by institutions, is acknowledged by manufacturers, governments, institutions, non-governmental organisations and consumers as exerting a considerable barrier against HC technology.

Institutional Procedure: barriers cited include the *time delay* involved in approving and adopting new technologies and developing procedures for approving funds for new projects. The time delay is often caused by general institutional inertia and the institutions being described as being poorly informed about new technologies. However, the accumulated delays in project implementation need not necessarily be viewed as barriers to HC technology because instead, this has offered an opportunity to fill information gaps. In addition, *insufficient funds* for demonstration or pilot projects have also been cited as a barrier. Another barrier is the length of time it takes for information dissemination of new technologies to reach the field, the Ozone Units in particular, from the institutions.

The *project consultants* used by the institutions to advise the Ozone Units in developing countries have also been described as barriers; they are often biased towards synthetic fluid technologies and insufficiently informed about HC technologies. The layers of consultants are perceived by developed and developing country manufacturers involved in the technology transfer process to contribute to financial waste and a loss of time.

The OORG: The role and operation of the Ozone Operations Resource Group has been cited by various stakeholders as a barrier to HC technology. In particular, the OORG is reportedly *biased* towards HFCs and synthetic refrigerants and this is deemed to result from the strong positioning of multinational chemical companies within the group.

Institutional Policy Failure: The Multilateral Fund policy is to phase out ODS in a cost effective manner; however, there is a perception by some stakeholders that phase-out is to be undertaken at the lowest possible cost. The cost effectiveness thresholds do not always take economies of scale into consideration and as a result small countries/manufacturers have a higher per unit ODS cost. In addition, as the recurrent costs of conversion to HC technology are not fully eligible for funding, this policy favours technology with lower investment costs. To correct this bias, in calculating the cost-effectiveness value of projects converting to HC technology, the MF recommends that the numerator should be discounted by up to 35%. These eligibility criteria are cited to be inadequate for meeting the incremental investment costs required for HC technology. Another barrier attributable to institutional policy failure is that the social and environmental costs of transitional and high GWP alternatives are not sufficiently taken into account.

A number of economic barriers have been reported relating to developed and developing countries - affecting manufacturers and consumers.

Trade: the lobby of multinational chemical companies in applying *protectionist influences* for the continued use of HCFCs and HFCs has been cited as a barrier by many stakeholders.

Technical Standards: Technical standards that govern the use of refrigerants in production and in servicing often *prohibit the use* of hydrocarbons for domestic refrigeration; this is the case in the US and France where regulations are not yet specified in the regulatory framework for the use of flammable refrigerants in refrigerators. The absence of appropriate standards is cited as a barrier by manufacturers in developed and developing countries.

Standards for the *servicing and maintenance* of HC refrigerators are also absent and manufacturers cite this as a barrier. Even where they do exist, such standards are difficult to enforce and monitor.

How do these Barriers Work? Many of these barriers would seem to be generic within institutions, reflecting bureaucratic weakness and financing constraints, and operate at various stages of the project cycle. It would appear that HC technology can be overlooked because of a lack of concrete information on technical and cost grounds. The rules and procedures for approving project funding have been created for *in-kind* technologies (e.g. HFC-134a) but these often do not pay full justice to the *not in-kind alternatives* such as HC. In addition, the incremental investment costs required for safety reasons for HC technology are only partially funded under the Montreal Protocol.

Geographic issues

Regional issues

The geographic focus for this study is broad and we have sought to ensure representative global coverage in our data gathering and analysis. The focus is necessarily wide for there are a number of issues facing HC technology that require an examination of specific in-country characteristics that have determined the success or otherwise of HC technology. In particular, it would appear that the market evidence of HC technology is unevenly distributed between refrigerants and foams, and between developed and developing countries. By undertaking a number of country case studies, we have gained an insight into some of the relevant issues of HC technology throughout the world.

The history of HC technology and its "birth" in Europe require us to examine those factors which have contributed to its success in the West and so we have looked at the case of Germany which has seen the commercial success of HC technology and its acceptance by both manufacturers and consumers alike in the domestic refrigeration market. In other developed countries, HFC-134a continues to be the replacement refrigerant for CFC's and so we have considered the case of the United Kingdom which is largely ambivalent to HC technology, and the USA which uses some strong arguments against the technology.

As one of the main goals of the study is to provide developing countries with the ability to make informed decisions about the use of HC technology in their CFC phase-out strategies, we have looked at some developing countries - India, China and Argentina. These are countries that are experiencing rapid economic growth and present significant market opportunities for domestic manufacturers and importers. However, refrigerants replacing CFC's (HC-600a/HC blends and HFC-134a) have yet to achieve acceptance in the marketplace. Both SDC/Infras and GTZ have been involved in programmes promoting HC technology in India and China.

As for foams, cyclopentane (including related hydrocarbons) is an accepted technology for the replacement of CFC's in both developed and developing countries, and is the current option to HCFC-141b. It is also emerging as the dominant option in non-compliant developed countries.

Summary of barriers affecting developing countries

One of the objectives of the study is to provide decision makers in developing countries with appropriate information about HC technology so that they can give it full and fair consideration in their CFC phase-out strategy. It is useful, therefore, to summarise some of the barriers reported in the previous section that relate specifically to developing countries:

Technical and cost barriers

- continued availability of CFC-12

- production of HC refrigerants of an appropriate quality and purity
- poor availability of HC compressors and dependence on compressor manufacturers
- inadequate R&D facilities for redesign of HC models
- weak implementation capacity/different working practices
- servicing problems for imported compressors
- lack of pressure for innovation

Market barriers

- commercial agreements with developed countries influence technology decisions
- focus on seeking financial support from developed countries for CFC phase-out rather than active commitment to phase-out actions
- lack of consumer demand for "green products"
- lack of information/knowledge on use of HC blends
- conflicting signals on energy efficiency and TEWI from developed countries

Policy and institutional barriers

- time delay in approving new technologies and funding new projects
- insufficient funds for demonstration and pilot projects
- bias of the OORG towards HFC and synthetic refrigerants
- recurrent costs of conversion are only partially funded under the Montreal Protocol; HFC and HCFC-based technology benefits with respect to cost-effectiveness (N.B. this statement holds true for all technologies, but since the recurrent cost of HFC134a and HCFC141b are higher than those of HC, their cost effectiveness improves on paper
- absence of technical standards for production and servicing of HC refrigerators.

Country Specific Issues

The Case Studies that are presented in the collection of Country Case Studies highlight the relevance of some of the barriers and demonstrate some of the lessons that can be learnt from the adoption of HC technologies. The following sections provide some of the key points from each of the case studies.

India

India presents the case of a rapidly expanding developing country market. The domestic refrigeration sector is dominated by 3 large manufacturers and 4 smaller producers. All manufacturers, bar one, are opting for cyclopentane, but HFC-134a is seen as the conventional choice for refrigerant. The majority of manufacturers have chosen HFC 134a for a number of reasons: non-flammability and because of the advice and support they receive from their technology partner. There are also competitive pressures as there is a perceived lack of demand for environmental products if they cost more.

The poor availability of components for refrigerators using HC refrigerants is seen as a barrier and three manufacturers are establishing new production lines for HFC compressors. Ease of servicing is increasingly seen as a key issue for either HFC or HC refrigerants. Manufacturers are more concerned with reducing the cost of producing non-ODS no-frost refrigerators as this is the fastest growing market segment.

China

Of all developing countries, China represents the largest and one of the fastest growing markets for domestic refrigerators. Eight of the top twelve manufacturers have decided to invest in cyclopentane for foams, which represents about 60% of the Chinese market. The situation for refrigerants is not as clear but it appears that approximately 40% of the market is being given over to isobutane.

The speed with which China has adapted towards HC technologies is an important outward sign to developed and developing countries. The interest in HC technology has, to date, been mainly driven by companies wanting to gain know-how that will make them more competitive internationally; this is having a knock-on effect on the refrigerators produced for the domestic market.
Whilst there has been a considerable conversion towards HC, China still produces some 4-5 million CFC refrigerators each year. The market opportunity for HC technology is, therefore, the largest in the world.

Argentina

Like India and China, the market for domestic refrigerators in Argentina is rapidly expanding. Seven manufacturers currently dominate the production of refrig-

erators, of which only one is a multinational, although as the market is becoming more liberalised and opportunities for foreign investment increase, this is likely to change.
When the Country Programme for ODS phase-out commenced in 1993, HFC-134a and HCFC-141b seemed to be the preferred technology choices; however, cyclopentane is now favoured by manufacturers as they fear a second conversion from HCFC-141b and because of lower operating cost and ease of availability.
HC refrigerants are not popular largely because information on HFCs has been readily available and it is seen as a proven technology. HC refrigerants are viewed with some uncertainty on safety grounds and because as their use appears to be limited to the German market. However, two manufacturers have chosen HC refrigerants; one has an agreement with Liebherr and the other has changed to HC to benefit from easier working practices and lower costs.

The main barriers would seem to be a lack of information on HC technology and inadequate facilities for R&D. There is uncertainty over handling safety issues and concerns about the cost of conversion especially as the funding rules for HC technology under the Multilateral Fund only partially cover recurrent costs.

Germany

Hydrocarbon technology "started" in Germany; and its success in the domestic refrigeration market can largely be attributed to consumer pressure. German consumers are well-informed about environmental issues and, together with a strong campaign from Greenpeace, a risk-taking enterprise was able to give commercial credibility to HC technology. Other manufacturers also recognised the market opportunities and quickly converted from HFC-134a refrigerants to HC technology.

Safety issues were never of importance in Germany as consumers seem to have confidence in the safety standards by which manufacturers must comply. "CFC-free and HFC-free" products are now regarded as the norm in Germany and manufacturers and policy makers alike are now concentrating on other issues, particularly energy efficiency.

USA

The US refrigeration market is predominantly based on HFC 134 and HCFC-141b and there is a widespread reluctance to change to alternative technologies (although it is acknowledged that HCFC-141b is a transitional substance). At present, US safety regulations prohibit the use of HC refrigerants and foams and manufacturers which have recently converted from CFCs are unwilling to make any further investments in an area where profit margins are already tight.

The US market is also characterised by the product liability issue and manufacturers are uncertain about how they would address any potential litigation claims. In addition, there are conflicting views on the merits of hydrocarbons particularly in terms of energy efficiency and TEWI.

UK

The UK presents a situation where consumers and manufacturers alike are rather ambivalent to HC technology. Even so, there have been recent changes in safety regulations that now permit the use of HC technology in the domestic refrigeration market. Manufacturers acknowledge the feasibility of HC technology, but are wary of the short term cost burden it would impose both in the production line and in servicing of appliances, as they feel it would be difficult to pass any additional costs onto the consumer. However, in view of export opportunities, many manufacturers are considering adopting HC technology in the medium term.

Appendix: Inventory of Barriers

Technical and Cost Barriers

1. Continued availability of CFC in developing countries
2. The investment costs for changing a production line to HC (costs for safety measures) are higher than for HFC-134a
3. The benefits of scale economies have not yet been fully exploited for the production of component parts for HC refrigerators
4. HC-600a compressors are not yet available at competitive prices in some regions of the world - creates dependence on imports
5. HC-600a compressors require a higher displacement volume compared with CFC-12/HFC-134a which may involve extra production costs
6. There are safety risks associated with the storage of HC refrigerant in large quantities in manufacturing plants
7. There are perceived safety risks associated with the storage of HC refrigerators in warehouses
8. Developing countries may not be able to produce HC refrigerants of appropriate quality and purity
9. Developing country manufacturers may lack adequate R&D facilities for the redesign of models to HC technology
10. The payback on the investments in CFC to HFC conversion in developed countries prevents major changes in the short term
11. Developing countries are not always able to "leapfrog" technologies due to weak implementation capacity/different working practices
12. There are cost implications involved in the servicing of HC refrigerators - distribution of the refrigerant, staff training and charging equipment
13. The costs involved in setting up servicing facilities for three refrigerants (CFC-12, HFC-134a and HC-600a) are seen as prohibitive
14. Manufacturers fear misinformation campaigns and adverse publicity against HC from the chemical multinationals as well as from competing manufacturers
15. HC technology promoters within non-governmental organisations have suffered from a lack of commercial respectability
16. The economic recession in Europe has restricted new investment in new technologies which is preventing a rapid second conversion to HC
17. The high growth rates in many developing countries do not create sufficient pressure for innovation by refrigerator manufacturers
18. There are potential product liability issues in the event of an accident

Market Barriers

19. Through commercial agreements e.g. joint ventures, licensing agreements etc. between developing and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology
20. There are perceptions of safety hazards in the home
21. There is a perceived risk of damage to refrigerators through consumers tampering with HC refrigerators in cleaning/defrosting
22. HC is marked as a "German" technology which implies German interests world-wide - this makes it difficult to promote with any political neutrality
23. US enterprises are reluctant to consider technologies they can not sell in their domestic market and this strongly influences developing countries
24. Some developing countries are more engaged in seeking financial support from developed countries for CFC phase-out than actively committing themselves to CFC phase-out activities
25. There is a lack of information/signals in favour of HC technology from the national/political level to manufacturers and consumers in developing countries
26. The labelling of refrigerators is still poor and consumer unfriendly in many countries
27. The information made available to consumers from manufacturers is often distrusted; they are not given adequate information on the effects of their technology choice on operating costs (energy consumption) and on the environment
28. Consumers are more interested in the price of their refrigerator than ecological benefits;
29. There is inadequate information on the actual risk and scale of safety issues (e.g. commonly used appliances such as lighters, spray cans, cooking gas, use larger quantities of flammable substances and are potentially more dangerous than HC refrigerators)
30. The potential for blends of HCs as a transitional option in developing countries has not been fully considered, and the possibilities for retro-fitting CFC-12 refrigerators have been overlooked
31. There is widespread ignorance about the disadvantages of synthetic replacements (e.g. HFC-134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries)

32. There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry as a whole and especially to developing countries
33. There is a lack of coherent information on the economic advantages of HC in developing countries
34. Cheap imports of HFC-134a refrigerators undercut HC refrigerators' market potential in some developed countries

Policy and Institutional Barriers

35. The Multilateral Fund and Implementing Agencies are not well-informed about alternative refrigeration technologies in general and have failed to inform clients in time and in an unbiased manner
36. The MF does not devote sufficient funds to adaptive research and development and for demonstration or pilot projects
37. The project consultants used by the Implementing Agencies are often biased towards synthetic fluid technologies and are insufficiently informed about HC technologies
38. The project rules for HC conversion projects funded by the MF are based on the rules used for synthetic fluids - this is an illustration of their inability to cope with emerging technologies
39. The eligibility criteria for the funding of incremental investment costs for HC-600a conversion projects are inadequate
40. The lobby of international chemical companies are able to apply protectionist influences for the continued use of HCFCs and HFCs
41. Safety standards in many countries do not include provisions for the use of flammable fluids in domestic refrigerators

7 COLLECTION OF COUNTRY CASE STUDIES - September 1996 -

Country Case Studies

A number of country case studies have been undertaken to examine the prospects for hydrocarbon technology throughout the world and to highlight some of the barriers that have been cited in the Barriers Study. Case studies have been undertaken on various Article 2 and Article 5 countries, and have been undertaken by the following organisations:

Country Case Study	Author
India	Ajay Mathur et al. Tata Energy Research Institute, New Delhi, India
China	Klaus Meyersen (Advisor to GTZ), Germany, and Song Xiaozhi, NEPA, and Xu Dongsheng, CHEAA and NCLI, China
Argentina	Maria Lucia Gòmez, INTI, Argentina
US	The World Bank, Washington DC, US
Germany	Klaus Meyersen (advisor to GTZ), Germany
UK	Deloitte & Touche Consulting Group, London, England

The Indian Refrigerator Market

Ajay Mathur et al.,Tata Energy Research Institute, New Delhi, India

Background

This case study examines the technological choice process for the selection of alternative refrigerants and foam-blowing agents by Indian domestic refrigerator manufacturers so as to identify barriers facing the adoption of hydrocarbon technologies in this market. It is based on interviews with the senior management of seven refrigerator manufacturers and two compressor manufacturers which sought their views on issues related to the non-ODS technological choice-making process; and particularly on their current impressions regarding Hydrocarbon (HC) technologies.

India has a low refrigerator ownership rate - currently only about 10% of households own a refrigerator - but a rapidly growing refrigerator market. Sales are in excess of 2 million units per year, and the annual growth rate is estimated at 12% to 15% in the years ahead. The share of larger and premium models in the sales-mix has been increasing in recent years, and frost-free refrigerators (first introduced only about five years ago) are currently the fastest growing segment of the market, .

The market is very competitive, and has traditionally exhibited marked price elasticity of demand. In terms of sales, it is dominated by three major manufacturers - Godrej-GE, Whirlpool (formerly Kelvinator of India) and Voltas (which recently acquired another independent manufacturer, Allwyn). Two large consumer electronics manufacturers, Videocon and BPL, entered the market about five years ago, both in technological collaboration with Japanese manufacturers, and are major players at the premium end of the market. Recently, Electrolux acquired a small Indian refrigerator manufacturer, Maharaja Appliances, and is setting up new manufacturing facilities. The Korean conglomerate, Lucky Goldstar is currently in the process of considering the establishment of refrigerator manufacturing capability with its Indian partner, the Birla group of industries.

The big-three Indian refrigerator manufacturers produce their own compressors; the others have been meeting their requirements through imports, though recently BPL has commissioned a new compressor plant, and Videocon is in the process of doing so. A small fraction of the compressor requirement has been provided by an independent compressor manufacturer, Kirloskar-Copeland, and a second compressor manufacturer, SIEL (which is in the process of conversion into a joint venture with Tecumseh) is also setting up facilities for the manufacture of compressors for domestic refrigerators.

ODS Phase-out

The Indian refrigerator manufacturers have been evaluating non-ODS technologies since 1992 when the India Country Programme for ODS phase-out was formulated. At that time, conventional wisdom dictated the adoption of HFC-134a as refrigerant, and HCFC-141b for foam-blowing. However, the rapid changes in refrigeration technology world-wide, and the relatively longer phase-out schedule allowable for India (and other developing countries) precluded early technological decisions.

Hydrocarbons, as technologically-viable alternatives, were introduced to the Indian refrigerator manufacturers largely through the Ecofrig programme, which promoted technical exchanges with German industry and research organisations involved in HC-refrigeration technology. The Ecofrig programme was initially launched by INFRAS, a Swiss consultancy organisation, with funding from the Swiss Development Co-operation. The programme is now a tripartite venture between the Governments of Switzerland, Germany and India, and is enabling pilot-scale evaluation of cyclopentane foaming technology, and technical assistance related to isobutane refrigeration technology. The programme has provided a channel for information-dissemination and exchange of experience related to HC-technologies.

Trends

Foam Blowing

All Indian refrigerator manufacturers, but one, are choosing cyclopentane technology for foaming. The reasons are the lower manufacturing costs associated with c-pentane technology (as compared with those with HCFC-141b technology), and the transitory nature of the alternative HCFC-141b technology. These reasons are cited for the relatively rapid diffusion, maturing and adoption of this technology internationally, despite the associated constraints of flammability and lower insulation. Both these constraints are being addressed through manufacturing process changes (enhanced safety features in the factory, and re-optimised insulation thickness), and the resulting higher capital costs are subsumed in the calculus of relative costs.

This rationale has lead one manufacturer to even move away from their initial choice of HCFC-141b. This initial choice was based on the advice and support of their technological partner, and planning investments were made for its adoption. However, subsequent international technological trends and the information dissemination through the Ecofrig programme lead them to decide in favour of cyclopentane technology, largely on the basis of the lower expected manufacturing costs. Technical support is now being provided by equipment and polymer-formulation suppliers. The one manufacturer who has not chosen c-pentane technology has done so on safety grounds; they recognise the transitory nature of HCFC technology, but believe that this itself would lead to the rapid development of non-inflammable zero-ODS alternatives. Internationally, this manufacturer has adopted both cyclopentane and HCFC-141b technologies; they prefer to introduce non-flammable technologies in India.

Refrigerants

In the case of refrigerants, HC (isobutane)-technology does not seem to enjoy the broad support that it does for foaming. Five manufacturers have decided on the adoption HFC-134a technology. Of these, one has chosen HFC-134a because of the constraints in the availability of isobutane-butane compressors; internationally, it has a stated corporate commitment to "green technologies", and has already decide to replace HFC-134a in the medium term because of its high global warming potential (GWP). A second manufacturer (who has chosen HCFC-141b for foaming) has done so for reasons of safety. As with foaming technology, some of its international plants utilise HC (isobutane) technology for refrigeration as well.

The HFC-134a decision for India is based on its preference to introduce non-flammable technologies in India, and the lack of a perceived demand for a low-GWP refrigerator in the Indian market. Two other manufacturers have chosen HFC-134a technology because of the advice and support of their technology partner. One of these two manufacturers has already moved away from its partners advice on the adoption of HCFC-141b technology for foaming, but does not believe that a strong case can be made for rejecting HFC-134a refrigerant technology. This manufacturer believes that the growth of isobutane technology is “an aberration"; isobutane refrigerators (particularly frost-free models based on quartz heaters which operate at temperatures in excess of the self-ignition temperature of isobutane) would not enjoy any cost advantage (as compared to similar models based on HFC-134a technology), and there is no perceived willingness in the market to pay higher prices for environmentally-friendly refrigerators. This manufacturer is currently in the process of setting-up a new refrigerator manufacturing facility, based on HFC-134a and cyclopentane, as well as a HFC-134a compressor manufacturing facility.

The fifth manufacturer currently prefers HFC-134a technology on competitive grounds. It believes that the adoption of this technology by the other four manufacturers (each with strong international technological collaboration), would lead to market structure that prefers this technology. This manufacturer has entered into an agreement for the establishment of a new HFC-134a compressor manufacturing facility with a Japanese company, but is configuring this facility so that it can be easily converted for the manufacture of isobutane compressors in the future. The company has also assessed the possibilities of converting its current CFC- 12 compressor manufacturing facility to either HFC-134a or isobutane-butane compressor technology. Their strategy reflects the market pressures on them that favour the convert adoption of HFC-134a technology (a domino effect), as well as the perceived technological uncertainties regarding HFC-134a that militate against its adoption as a long-term refrigerant option.

One Indian manufacturer is yet undecided. On the one hand, the manufacturing costs of isobutane refrigerators (particularly of frost-free models) would probably be more than that of HFC-134a refrigerators, and the availability of isobutane compressor manufacturing technology is yet unclear. However, on the other hand, this large Indian manufacturing corporation has, over the years, positioned itself as an environmental champion, and consistently supported citizen's groups working towards the improvement of environmental quality. Consequently, the corporate philosophy favours the adoption of isobutane technology.

For many manufacturers, the relative costs of non-ODS frost-free refrigerator is a major concern since this is the fastest growing segment of the refrigerator market. All models currently in the market are based on quartz heaters with a high surface temperatures (of about 600 C) to cope with quick frost-build-up in high-humidity conditions. This surface temperature is more than the self-ignition temperature of isobutane, and consequently, the cost of a HC-based frost-free refrigerator is expected to be much higher (by maybe as much as $30 to $60) since major design and tooling changes would be required. The problem of converting the European design of frost-free refrigerators is easier since they are based on electric tube heaters with surface temperatures (of about 230 C) which are less than the self-ignition temperature of isobutane.

Compressors

The two Indian compressor manufacturers foresee that an increasing fraction of refrigerator compressors would be provided by the independent compressor (non-refrigerator) manufacturers. Consequently, they seek to position themselves to supply any compressor that the refrigerator manufacturers may demand. Both the independent compressor manufacturers are currently in the process of establishing production lines for HFC-134a compressors (through support from the Multilateral Fund of the Montreal Protocol), and are actively involved in enhancing their capability to produce isobutane compressors as well. At present, therefore both the independent compressor manufacturers and two of the refrigerator manufacturers have established, or are establishing the capability to manufacture HFC-134a compressors. On the other hand, isobutane-butane compressor technology sourcing is still being negotiated.

Servicing

Surprisingly, all refrigerator and compressor manufacturers, but one, perceived servicing issues to be of secondary importance while deciding on the new refrigerant. It was felt that both options (isobutane and HFC-134a) would require a major upgrading of skills and facilities in the servicing sector, and that ODS-phase-out would probably lead to an inevitable restructuring of this sector. Three manufacturers stated their intent to move towards high-reliability manufacturing (so that refrigerator failures in the market are of the order of one-in-a-million) so as to decrease the need for infield servicing.

Driving forces

Relative manufacturing costs and corporate philosophy emerge as the major driving forces governing technological choice decisions, with technology availability (which might, in some cases, reflect the capability of technological partner) being the major secondary driving force.

Manufacturing Costs & Corporate Commitment

Relative manufacturing costs and one-time technological change seem to have largely favoured the adoption of HC (cyclopentane)- technology for foaming, even to the extent of overriding the technological partner's advice in one case. Corporate philosophy accounts for the only decision not to adopt this technology; in this case, there seems to be a corporate commitment to non-flammable technologies world-wide, except in European markets that preferentially demand HC-refrigerators.

On the other hand, relative manufacturing costs seem to work against HC (isobutane) technologies for refrigeration, and their adoption is largely driven by "green" corporate philosophy. The cost of the non-ODS frost-free refrigerator has become the de-facto criterion for the choice of the alternate refrigerant. This represents the fastest growing segment of the refrigerator market in India, and no manufacturer would like to lose their market-share because of higher costs. This carries with it, the perception that willingness-to-pay for environmental benefits is low in the Indian market.

Technology Availability

For at least two manufacturers, the technological choice of the partner is the stated main consideration for the adoption of HFC- 134a technology, but this has to be viewed within the context of the perceived cost advantage for this technology, and of no overriding corporate environmental commitment. The lack of availability of isobutane-butane compressor technology, however has constrained the adoption of this technology option by one manufacturer in spite of overriding corporate environmental commitment. These examples, together with the case of the adoption of HC-foaming technology despite the contrary choice of the technological partner, suggest that technology availability could be a constraining factor in technological choice, but not a driver of technological change.

Secondary Forces

Other secondary driving forces identified by manufacturers include a preference to adopt a common refrigerant, and availability of fluids and of components. Safety is a prime consideration, but is largely subsumed in the cost issue, except in the instance that it is an overriding corporate commitment. Finally, though servicing infrastructure upgrading is seen as a major task (irrespective of the alternate refrigerant adopted), it does not figure as an issue in the adoption of alternate technology.

The Introduction of Hydrocarbon Technlogy in China

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The Importance of China in Hydrocarbon Technology

In 1995, China produced 12.1 million household refrigerators and freezers, representing around 50% of the total production of all Article-5 countries eligible for Multilateral Funds from the Montreal Protocol. Approximately 60% of China's refrigerator production is manufactured by companies actively using or engaged in acquiring Hydrocarbon Technology (HCT). Given that all the Article-2 countries have already invested in their chosen technology and are now unlikely to change without ecological legislation or intense customer demands, it is likely that China will remain the prime area of HCT growth world-wide.

China ODS Phase-Out and Technical Initiatives

China signed the Montreal Protocol in June 1991 and, as an Article 5 country, is committed to phasing out CFCs by the year 2010, although according to NCLI and NEPA the target date might be 2005, five years ahead of the Montreal schedule.

A national development program was instigated to test and develop various substitute technologies. Tasks were assigned to groups made up of refrigeration companies and research institutions. For example, foaming was investigated by Shangling refrigerators, Haier Group and Xinfei Electric Group; 134a refrigerant was investigated by Beijing Snowflake and Tsinghua University and refrigerant mixtures by Changling Group, Haier and Xian University. According to NCLI, these and other studies resulted in the first 190 t. of ODS phase out being completed as early as 1993. This also resulted in applications with the Multilateral Fund for virtually all existing refrigerant technologies. Initially these applications were concerned with 134a, 152a although they rapidly expanded to include hydrocarbon based projects. There now total more than 25 approved or applied for

household refrigeration CFC phase-out projects with the Secretariat of the Multilateral Fund. These are described in detail below.
The government of China is not directing the industry on which technology is to be used, however, it recommends cyclopentane and 141b for foam, and 134a and hydrocarbons such as isobutane as refrigerants.

The Chinese Household Refrigeration Situation

The total national production of 12.1 million units is made up of 9.3 million refrigerators and 2.8 million freezers. There are around 70 manufacturing units with an approximate output of 15 million units per annum (double shift) and 18 compressor manufacturers with a capacity of 13 million units. There are 12 manufacturers with capacity greater than 300,000 units per annum, representing approximately 87% of the market. All of these manufacturers have projects for conversion to CFC-free production underway. Kelon and Haier lead production in terms of quantity and quality, with each producing in excess of 1 million units per annum. More market details are given in Appendix 2.

Recent Trends in Production and Consumption

Growth in production has been high, averaging 16% per annum in the years since signing the Montreal protocol. This is double the growth rate estimated in the original China Country Programme 91. There has also been a trend for larger units with increasing numbers of 300 and 400 litre capacity units although the 200 litre unit will continue to dominate the market in the coming years. The fastest growing sector of the market is reported to be the freezer market.

Of 240 million households in China, 43 million own a refrigerator, 55% of those in large cities and 22% of those in rural areas. There clearly exists considerable scope for expansion of the domestic refrigerator market and this will lead to an increase in CFC consumption. Estimates place growth in CFC consumption at 10% for 1995 and 6% per annum for the years 1995-2000. That corresponds with a total increase of around 60% in the next 10 years. It is here that the Chinese Government is focusing its attention.
Exports have grown rapidly from 220 T units in 1991 to 980 T units in 1995, but additional growth depends upon access to CFC-free technologies. The requirement to gain this know-how and so have greater access to global markets is one of the driving forces behind the rapid introduction of CFC substitutes including hydrocarbons. Companies like Kelon and Haier are now using all three refrigeration technologies, chloroflurocarbons (CFC), hydroflurocarbons (HFC) and hydrocarbons (HC) meet market demands almost all over the world. Manufacturers

driven to meet their customers' requirements are beginning to realise that green products can be more profitable.

National Technical Resources

State owned research institutions such as the Beijing Household Electrical Research Institute and Shanghai Design Centre are decreasing in importance however, the Chinese authorities wish to make more use of these resources. This would have interesting implications for hydrocarbon technology which is virtually patent and licence free. The leading manufacturers do not seem to want to rely upon national research institutions but rather would prefer to undertake direct international partnerships or undertake their own R&D at company level and this has been shown in the area of hydrocarbons.

International Links

Originally, in the 1980s, the Chinese government bought in refrigeration know-how from Italy, Japan and Germany. As an illustration, the technical market leader, Haier Qingdao, has had a technical support arrangement with Liebherr in Germany for more than 10 years (Liebherr built all the factories that China bought from Germany however, Haier’s new factory production line will be based on an additional contract with Hitachi), Kelon has also had an arrangement with Liebherr for many years, the Bosch Siemens group recently acquired a 70% stake in Yangzi’s refrigerator business, Electrolux is linked to Zhongyi, Whirlpool is reported to have linked up with Snowflake/Beijing and Xiling is building a new factory with Sanyo.

This last example may be used to illustrate the issues in relation to HC technologies. Whereas Xilings old factory lines are being converted to hydrocarbons, the new investment will be geared to refrigerators based on 134a/141b at the request of their Japanese partner.

State of Knowledge and Use of Hydrocarbon Technology

China chose isobutane for refrigerant and cyclopentane for foaming purposes as one of the two main technologies and opted for hydrocarbon technology quickly and decisively when compared with other Article-5 countries. Government institutions have been actively supportive of attempts to gain knowledge in hydrocarbon technologies as can be seen in the list of projects underway shown below.

NCLI and NEPA , the government institutions in charge of CFC phase-out, are actively educating the industry, starting with a seminar held jointly with Greenpeace in the China Appliances Exhibition 1993. Since 1993, NCLI has held three workshops on CFC phase-out. The last one, in September 1995, was the Strategic NCLI workshop held in Hefei/ Anhui in which hydrocarbon technology was prominently placed with contributions from Bosch Siemens, Plasttechnik Greiz and GTZ. There will be another workshop organised by NEPA/UNEP in May 1996 focusing on the safety issues of hydrocarbon technology.

One strong driving force behind the rapid move to CFC-free technologies has been the interest of individual enterprises in gaining know-how that makes them more competitive internationally. Although refrigerators are not normally thought of for exporting over large distances due to high freight rates, nevertheless, the current very low labour rates in China are making refrigerators manufactured in China more attractive in foreign markets.

In the home market in China, however, with its tendency towards larger models and so more frost free models, Chinese manufacturers are automatically using 134a as is the case with Shangling and Hualing, as only leading German manufacturers are producing hydrocarbon based frost free models.

Hydrocarbon Projects Underway

Eight of the twelve leading manufacturers are actively engaged in hydrocarbon technology, either in using cyclopentane for foaming or both, cyclopentane plus isobutane as the refrigerant:

1. The joint co-bilateral model project by GTZ and USEPA for one factory line (250.000 units) in the Haier factory in Qingdao was the first (!) full hydrocarbon project approved by the Executive Committee of the Multilateral Fund world-wide. The cyclopentane foaming part (GTZ Liebherr) has been running since July 95, the isobutane part (USEPA / Liebherr) is being installed and tested. The HC-refrigerator plant was visited in November 95 by Li Peng, Prime Minister of China, at the occasion of the state visit of Chancellor Kohl/ Germany. Haier on the basis of their own experience now provides technical support to the industry in China and also offered assistance in the Delhi HC Conference February 1996 to the leading Indian producers for their conversion, if they decide to go hydrocarbon.
2. Kelon/ Guangdong marketed the first full hydrocarbon refrigerator in China on their own initiative and costs in summer 1995 in some major cities (e.g. Guangzhou, Beijing, Shanghai) end of 1995, where they have sufficient factory based service stations in order to maintain

a high degree of safety in servicing. Kelon (supported by UNDP/ Liebherr) have now also a Multilateral Fund project approved for one factory conversion to cyclopentane / isobutane (CP/IB).

3. Xiling Holdings / Huangzhou hold an approved CP/IB Multilateral Fund (MF) project as well which is at present in the state of conversion; bidding went to dkk/Germany as the general contractor.
4. Xinfei is partially producing 134a/CP refrigerators
5. Changling / Shanxi has an approved cyclopentane project, which is being implemented.
6. Shuanglu/ Shanghai has a cyclopentane project in preparation.
7. Huari/ Huangzhou has an approved CP/IB UNIDO project (bidding ended May15th)
8. Bosch-Yangzi/ Chuzhou will be converting to CP/ 134a first by end of 1996 to get out of CFC quickly, later going to isobutane/ cyclopentane when the factory improvements allow safety precautions by German standards [BoSie3.96].
9. Wanbao /Guangzhou (WB/ GTZ expertise in 1995) was considering a switch to an already approved 152a project to isobutane as well as applying for cyclopentane foaming. The conversion of Wanbao CFC compressors to hydrocarbon compressors was under investigation by GTZ/dkk; expertise delivered 12.95

The estimated ratio of substitute technologies is estimated to be 60% cyclopentane and 40% 141b for foam and 60% 134a and 30% isobutane (with about 10% others, like 152a) as refrigerants. [CHEAA/NEPA5.96].
In general it is felt that hydrocarbon technology has additional requirements, such as own development capacity to adapt to this technology, safety precautions, trainings, e.g. which only the major companies, who have well trained technicians and a dependable service network of their own, are able to handle this technology, and that it is in total a more demanding management task which smaller companies are likely to avoid by choosing route that are perceived to be easier. Hence, this is considered a serious barrier in China [CHEAA/NEPA5.96].

The major drawback at the moment is the fact that neither the chemical raw materials, nor the equipment, in particular compressors, are available in the right quality from Chinese suppliers and must be imported. This causes higher operating costs also for Hydrocarbon Technology, as for all other technologies that depend on imports. This is seen as a general barrier to the introduction at present [CHEAA/NEPA5.96].

Safety Risks

Although China has general safety regulations, there are no specific regulatory or product standards for the use of hydrocarbon refrigerators. The government and industry are addressing this. Leading manufacturers which are investigating and investing in hydrocarbon technology are aware of the risks but are, it would seem willing to take some risks. For example, Kelon's cyclopentane foam production pilot ran over a weekend with specially trained crew using temporary exhaust alarm systems. German safety standards are applied at present including the TUV certificate awarded at the site in China before production starts.

In May 1996 there was a safety workshop for the entire refrigeration industry in Hangzhou, arranged by UNEP/NEPA.

With warranty coverage for 5 years, companies manufacturing HC refrigerators will have them repaired by their own network of technicians who are well trained in safety precautions. It is seen as a burden for smaller companies to conform to safety requirements needed for hydrocarbon technologies hence they may adopt cyclopentane for foam but shrink back from isobutane due to safety demands in servicing.

Consumer Awareness

Consumers have shown increasing interest in low-CFC or CFC-free products. All the leading refrigerator manufacturers point out the ecological advantages of their refrigerators in their advertising and the introduction of Kelon's first isobutane-cyclopentane model received much press coverage, however, in general consumer awareness is low and contrary to the case in Germany, would not allow for a price premium on non CFC refrigerators. Rather it would seem that stricter government regulation would be the major influence in the adoption of any CFC substitute.

NEPA and the industry focus on the rise in public awareness of the impact of CFCs on the ozone layer. Although this has an impact, ironically there are two effect which cancel one another out. At the beginning of the campaign the consumer would buy CFC-free products for two reasons - firstly, because they understood that CFC refrigerant does harm the ozone layer and secondly, because the perceived that CFC as a refrigerant would harm their health directly. With further education the consumer now has greater understanding of the need for protection of the ozone layer but they have also learned that there is no direct threat to their health from CFCs. As a result those consumers who had been in the second group who purchased CFC free products to avoid direct risk to their health are now more likely to reach their decision on the basis of price alone.

Support from Funding Agencies

After a period of reluctance and uncertainty towards hydrocarbon technology, although not on the part of China but rather from the international consultancy industry, support from funding agencies such as The World Bank, UNIDO and UNDP is now given mostly by using consultants from Germany. The introduction of hydrocarbon technology was definitely driven by leading enterprises rather than by the technology on offer through the agencies.

Policy and Institutional Issues - Payment for the Transfer of Know-how

As reported by some consultancy firms, the Secretariat of the Multilateral Fund appears to be refusing to fund know-how and technology costs on HC conversion projects on the basis that there will be only one payment per country per new technology. This is unusual under usual commercial conditions which apply to international know-how transfer between enterprises. At present there are only two companies that are experienced in the conversion process to HC technology and which are willing to share their know-how and experience. Since conversion know-how and experience is rendered by internationally active companies, there is a commercial interest in receiving payment for the transfer of conversion experience and their technical advice, especially since it is not patented.

Unless this situation is corrected and a solution is found that will keep those companies interested in transferring their technical expertise, it is likely that the know-how flow will come to a halt. This could create an unfavourable situation since this gap could be filled by the consulting engineers used by the Implementing Agencies of the Multilateral Fund which have limited practical experience of handling flammable materials in refrigeration production - essential to cut down on accidents. This is currently seen as one of the most important barriers to HC technology not only in China, but also in other Article 5 countries. China has taken up this issue at the 17t Meeting of the Executive Committee of the Multilateral Fund.

Conclusions

Eight of the top twelve leading manufacturers have decided to invest in cyclopentane as the HC technology used for foaming. These companies represent about 60% of the total Chinese market. Cyclopentane will dominate foaming in the future. However, the situation with refrigerants is not as clear. Of a national volume of 9.3 million refrigerator units in 1995, around 4 million units, over 40% of the market, was represented by companies adopting both isobutane and cyclopentane. This is very promising and makes China the leader among the Article-5 countries, even although these Chinese manufacturers at present only use HC technology to a limited extent and will try to keep other options open. Further development of HC technology will depend upon, for example, raw material supply, market development and especially on the success of those companies who have already adopted HC technology.

China has the largest market of the Article-5 countries and so has the greatest impact on the growth of these technologies world-wide. The speed with which China has adapted towards HC technologies is an important outward sign to Article-2 countries which have to take China seriously, and may force countries such as Japan to reconsider.

Interest in HC technology is at present mainly driven by companies seeking international markets. However, there may be some impact upon the internal market as companies who compete on quality present HC refrigerators as the most technologically advanced, thus putting their competitors under pressure to compete in this technology. Also, European manufacturers entering the market may show that producing ecologically friendly products pays.

The Chinese government has not yet focused with vigour on benefits to society of HC technologies such as additional energy savings and independence form foreign know-how, although they may do in the future.

Of the 12.1 million units produced, over 6 million are produced by companies that have acquired or are in the process of acquiring their own expertise in HC technology. This leaves around 4-5 million units from companies still using CFC only of which around 2-3 million units may be converted to HC, by far the largest potential market for HC technology in the world.

Appendices

Annual volume Refrigerators / Freezers / Compressors in China

Year	Refrigerators	Freezers	Total	Compressors
1993	6.2	1.9	8.1	5.9
1994	7.6	2.3	9.9	8.0
1995	9.3	2.8	12.1	

Source [CHEAA/NEPA5.96]

Major Refrigerator Manufacturers 1995

(Estimated total market ca. 9.3 mio units)

	Company	Known Technical Links	Prod. Est. 95 (000)	HC Project Status
1.	Kelon/ Guangdong	Tech. co-operation. Liebherr/ Germany	1222	CP/IB project approved; Test marketing from pilot production
2.	Haier/ Qingdao	Tech. Co-operation. Liebherr/ GTZ Germany/ USEPA/ University of Maryland; Hitachi/ Japan	1000	CP/IB project approved and executed; Cyclopentane manufacturing line operating since 7/95; Isobutane in test phase
3.	Shangling/ Shanghai	Tech. Co-operation. Mitsubishi/ Papan	853	134a project approved; 141b under preparation
4.	Meran/ Hefei	Tech. Co-operation. Ariston-Meerloni/ Italy	754	134a under preparation
5.	Yangzi/ Anhui	70% owned by Bosch-Siemens/ Germany 3/96	750	CP/134a conversion under preparation; IB to follow [Bo-Sie3.96]
6.	Xinfei/ He-		718	134a/CP under

	nan			preparation
7.	Changling/ Shanxi	Ariston-Meerloni/ Italy	626	R22/152a for refrigerant; cyclopentane for foam, project approved, conversion ongoing
8.	Wanbao/ Guangzhou		569	152a project approved conversion ongoing; 134a/141b for exports; HC compressor under study dkk/Germany
9.	Xiling /Hangzhou	Tech. Co-operation. Liebherr	505	CP/IB project approved and conversion ongoing
10.	Shuanglu / Shanghai		366	MP39 project approved and conversion ongoing; cyclopentane under preparation
11.	Hualing / Guangzhou		350	134a/141b under preparation
12.	Huari / Huangzhou		341	CP/HC project approved and conversion ongoing

Sources [CHEAA/NEPA5.96]; [Lieb5.96]

Estimated Proportion using HC or 134a for refrigerants and 141b or cyclopentane for foams

	Cyclopentane	141b	134a	Isobutane	Other
Refrigerant			60%	30%	10%
Foam	60%	40%			

Source: [CHEAA/NEPA5.96]

Major Freezer Manufacturers 1995

(Estimated total market ca. 2.84 mio units)

	Company	Known Technical Links	Production 95 Estimated (000)	HC Project Status
1	Acuma Qingdao		656	Under preparation
2	Xingxing / Zhejiang		333	
3	Haier Freezer / Qingdao	Derby	332	134a / cyclopentane project approved
4	Changshu		290	
5	X.X.X. / Suzhou		239	
6	Henan Freezer		180	134a / cyclopentane project approved
7	Huangzhou Appliances		176	Isobutane / cyclopentane project under preparation
8	Xiling / Hangzhou	Liebherr	171	Isobutane / cyclopentane project approved

Source: [CHEAA/NEPA5.96]

Sources

[CHEAA5.95] Strategic Study May 1995 by Office of Household Electrical Appliances Industry of China Household Electrical Appliance Association (CHEAA) / China National Council of Light Industry (NCLI) China

[MFS3.96] List of approved projects by Secretariat of the Multilateral Fund (MFS) status March 96

[BoSie3.96] Bosch-Siemens personal communication of company information

[dkk5.96] dkk Scharfenstein personal communication of company information

[Lieb5.96] Liebherr personal communication of company information

[CHEAA/NEPA5.96] Background Paper in Preparation for HC Study Workshop by Office of Household Electrical Appliances Industry of China Household Electrical Appliance Association (CHEAA) /China National Council of Light Industry (NCLI) and National Environmental Protection Agency (NEPA), China

Argentina Case Study

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Background

This case study presents an overview on the technologies selected in the refrigeration sector, mainly in the domestic area, to phase out the consumption of CFCs and the main barriers in Argentina to adopt hydrocarbons.

Industry Structure

The refrigeration sector, excluding air conditioning uses, is responsible for 51 per cent of CFCs consumption in Argentina, for refrigerants and foams.
The domestic sector produces refrigerators, freezers and little units for bottle coolers and foods display for small shops. It is basically composed of more than 17 enterprises, of which seven share approximately 72 per cent of the market. Of these seven enterprises, Whirlpool is multinational, Frimental of Chilean capitals and the other five are nationally owned.

The production of domestic refrigerators in 1992, base year of the Country Program, was equal to 761,000 units. This number grew by seven per cent in 1993, and six per cent in 1994. 1995 production figures were estimated in 871,00 units and production plans of the companies foresee for next years production of 1,000,000 units.

The sector was traditionally oriented to the internal market. Most of the companies developed their technology with the support of compressor and chemical suppliers. Today, only two companies Whirlpool and Autosal (Liebherr) have technology partners.

There are still two domestic compressor manufacturers, but they provide only to small producers and to service shops. Most of the compressors for the domestic sector come from Embraco and Sicom in Brazil.

To encourage industrialisation in some areas, the Argentine Government established a special tax exemption program in the 1980s. A lot of companies installed a second plant in this area, instead of concentrating the production in only one plant. Therefore, common production cells are around 50,000 units/year per plant.

The commercial refrigeration sub-sector is broadly developed in Argentina and provides self contained display cabinets and freezers up to complete installation for supermarkets, restaurants and small shops. Consumption in this sector has increased considerably, and far above the average of the rest, since new chains of hyper markets have begun operation in Argentina.

Evaluation of the Market

Significant changes are modifying the market structure, reasons are:

- liberalisation of the market, thus competition with European and American refrigerators, have lead to innovations and improvements of the national production and introduction of new models, especially no frost ones;
- increasing internal demand
- increase of exports under the MERCOSUR (Common market of the southern cone), mainly to Brazil;
- unexpected demand of small units for the display of beverage and food for small retail shops
- MERCOSUR possibilities are attracting foreign companies to invest in the sector. As a consequence, local companies could associate with Brazilian or multinational companies

Policy

The first activities for Country Program (CP) preparation begun around July 1993. In January 1994, a governmental *ad hoc* working group revised, completed and submitted the CP, which was finally approved by the Executive Committee (ExCom) of the MF in July 1994. Members of the Ministry of Foreign Affairs, of Environmental Secretariat, Industry Secretariat and of the National Institute of Industrial Technology took part in this group. The first three governmental bodies are in the Ozone Office and the fourth is responsible for the identification, preparation and implementation of re conversion projects.
A phase out target by the year 2,000 was considered possible, provided grants from the MF would be available for new equipment.

The following statements are subtracted from the CP:

- policy framework points out that the government will not impose any technological solution for the substitution and elimination of ODS consumption. The government's role will be to guide and inform on the fundamental aspects to be taken into account in adopting and adapting technology to local conditions;

- the government strategy sets, between others, for transition substances, to take into account the useful life of the facilities and possible changes in the timetable for elimination under the Montreal Protocol and therefore the use of transitional substances will not be encouraged for machinery with long useful life;
- priorities for the allocation of resources under the Montreal Protocol include the use of definitive solution, where available, as for example the use of alternative non fluorocarboned substances.

By June 1994 this Country Program was announced to the industry to begin formally the re-conversion program. It was then clearly explained to the industry that:

- the government is not able to impose a re-conversion technology within the context of the present free market economy. Each company has to decide which technologies will adapt. This is of course a market decision, based on the production facilities, the local conditions and market demand. Only in that way companies will complete the re-conversion successfully;
- in the case of transition substances, companies have to take into account that: if final technologies are available, the government does not see, in principle, reasons to adopt transition solutions that affect still the ozone layer, put the companies in front of a second re-conversion without financial assistance from the MF and will be at the end less cost effective;
- transition substances will not be limited or prohibited by the moment, since in some cases are the only available solution to get out of ODS, but the Government will strongly encourage projects with final solutions.

Current Situation

By the end of 1993, when the Country Program was under preparation, 10 companies belonging to the domestic and commercial sector requested assistance for project presentation to the Multilateral Fund of the Montreal Protocol (MF), HCFCs and HFCs were the technologies demanded in all those projects proposals. Only a few of them, foresaw a second re-conversion step to cyclopentane. The following table shows the situation today:

Notes to the following table: Project proposals for HCFC/HFC technology

(1) Domestic sector

Small: production capacity less than 20,000 units.

Medium: small; production capacities around 30,000 units to 50,000 units; Autosal, Briket and Neba.

Medium large: production capacities around 40,000 units to 70,000 units. All of them has two plants: Helamental, Fribe, MacLean, Aurora y Piragua.

Large companies: Production capacities more than 120,000 units in only one facility: Whirlpool and Frimental.

(2) Commercial sector:

Small: production capacity less than 1,000 units per year.

Medium: production of small units for retail shops, and display cabinets and little cold stores for supermarkets.

Large: Production of display cabinets, walk in coolers, and cold stores for supermarkets.

(3) Whirlpool, the other of the two largest argentine producers is in the process of project preparation, decision of technology have to be done in brief.

SECTOR	**TOTAL**	**HFCs/C5**			**HC/C5**		**HFC/141b**	
		Approved	for approval	under preparation	Approved	for approval	not approved	
DOMESTIC	17							(1)
Small	4	-	-	-	-	-	-	
Medium	11	5	1	1	3	-	-	
Large	2	-	-		-	1	-	(3)
COMMERCIAL								(2)
Small	20	-	-	-	-	-	-	
Medium	7	-	-	-	-	-	-	
Large	3	1	-	-	-	-	1	

Overview of Selected Technologies - Foam

For foams there is no doubt that pentanes are the option to substitute CFC-11 in domestic refrigeration and insulation panels. Water based system are today under consideration for display cabinets, building applications and spray foam.

Driving force in favour of adoption of HCs as auxiliary blowing agents (ABA)

Three companies took initially the decision to adopt cyclopentane by August 1994 and their projects were approved by the MF by December 1994. By then, even though production engineers of most of the companies had doubts about pentanes properties and were afraid of working with flammable liquids, managers decided for the cyclopentane solution for the following reasons:

- perspective of second re-conversion without financial assistance from the MF;
- country program framework;
- lower operational costs;
- pressure of the non governmental organisations;
- availability of pentanes in the market and possibilities of local supply of C5, once the market would be consolidated;
- domino effect, once two or three companies decided for C5, the rest of them wanted to follow without analysing the impact on their own production process.

Major barriers impeding the adoption of HCs as ABA

Only one company in the commercial sector has chosen HCFC-141b. This company has two plants, and a wide number of foaming machines and presses for production of a wide range of different models, therefore the re-conversion to cyclopentane would be extremely expensive. Funds coming from the MF would cover scarcely part of the investment costs, since for the commercial sector it is not possible to discount safety costs to calculate cost effectiveness.

Something similar occurs in the case of small companies demanding HC technology, following the global market decision. They can not afford the higher cost of this technology. In resume, barriers are:

- higher installation cost;
- differential MF treatment for the same technology in the commercial sector;
- uncertainty in the commercial sector, about the technology. For panel production some companies think that other technologies such as

CO_2technologies could be used in the future. For display cabinets, the question is put on water blown systems.

Support of driving forces

Stakeholders request the following support:

- establishment of safety standards, with clear minimum safety levels for production;
- training at all levels;
- development of local suppliers to lower cyclopentane costs.

Overview of Selected Technologies - Refrigerants

Adoption of hydrocarbon refrigerants has not been so popular because:

- HFC technologies has been broadly disseminated in the market during the last four years. HFCs suppliers and compressors manufacturers has provided to the market with enough information and this technology is considered broadly proven and available;
- HFCs have zero ODP and do not have any restriction under the Montreal Protocol. People do not understand the difference between the Ozone Depletion and Global Warming Potential. The limitations with respect to GWP are not clearly understood and a phase out schedule has not yet been established. Technicians in the sector do not consider it as a problem;
- hydrocarbons experience comes only from Germany. Engineers would like to hear about a great number of plants in different European countries using hydrocarbons. There are not a lot of experts in the field. This is also the situation with implementing agencies;
- presumptions against this technology were raised by different sectors creating doubts about the safety of the appliance in the houses;
- lack of enough information on redesign, performance and safety appliance contributed also to this;
- uncertainty of customers preferences.

To give a clear picture of the different opinions of manufacturers, two groups were identified:

<u>a) Companies which already have chosen HCs</u>

Two companies headed the introduction of hydrocarbons as refrigerant. Motivations are completely different.

One of them is closely related to Liebherr and would receive technology from this source.

The other company has wide experience in product development in its own facilities. It has been studying in its own laboratories all the possible alternatives: HFC-134a, and different hydrocarbons and decided finally to implement hydrocarbons because:

- it does not require important changes in the compressors and oils;
- tests showed similar energy performance to CFC 12;
- refrigerant cost will be far lower with HCs;
- charging conditions are similar to CFCs;
- it is a O GWP alternative, it is a better environmental solution and it will not require further conversion.

During the ECOFRIG tour last September, Argentina and Switzerland discussed a bilateral co-operation project to assist companies in the adoption and implementation of HCs technologies. After this tour, a presentation to the industry was performed by an INFRAS mission. As a consequence:
As a result of this action:

- a third company, discussed with INTI the different possibilities to assist them in the development of hydrocarbon technologies for its production and finally decided to change its original HFC project to hydrocarbons, bearing in mind the assistance through this bilateral co-operation program;
- one of the two largest manufacturers in the sector, a Chilean company which, on a customers' request, had actually introduced the use of HCFC and HFC for a bottle display refrigerator, requested the preparation of a hydrocarbon project.

b) Companies which have chosen HFC as refrigerant:

Medium - large companies

Most of them feel that there are not important technological barriers to adopt hydrocarbons.
International companies are demanding CFC free technologies, so to comply with this demand some of them have introduced at pilot level the use of HFC and HCFC-141b, since it is the easiest, cheapest, quickest to get out of CFCs because, in their opinion, it demands only the change of the compressor and oil.
The higher cost of the appliance could be considered by their customers simply as model upgrading and it is not a determining factor..

Medium small companies

This type of company have in some points different opinions about the barriers they would phase to adopt HCs.

- higher cost of appliance would affect in this case their position in the market. Their customers can not afford this incremental costs. Market for their product may be different from the companies mentioned before;
- they have still some doubts with respect to the technology itself, mainly because of safety reasons. Technology development is based on suppliers recommendations and they can not afford the redesign procedure;
- they would follow the market, if they are provided with technological assistance.

Driving forces to adopt HCs as refrigerants

- definitive solution, only one conversion is needed and this is an advantage if funding and technical support are provided;
- energy performance could compensate the increase of energy consumption introduced by the C5;
- longer useful life of the appliance.
- use of the same oils that are currently used for CFC 12

Major barriers to adopt HCs

The main barriers to the adoption of HCs are:

- development facilities: most of them do not have adequate facilities and enough personnel for research on development for the redesign of models, which is required. That means that the investment for development could be high;
- cost of machinery and related facilities for charging;
- the market does not demand HCs refrigerators. Global warming is associated with combustion and the public does not know the different between HFC and HCs in this respect. (Neither some technicians in these companies);
- there are no restrictions with respect to HFCs at the moment;
- problems related with service are claimed as important but not relevant.
- doubts about sufficient supply of compressors and other raw materials

Support of driving forces

- if the market would demand of HCs refrigerators, they will do immediately.
- general awareness with reference to GWP would help.
- technology support for the redesign;
- availability of funds: They would change, if funding was available for the higher costs of the technology.

Most of the companies have projects already approved for HFC 134 and it would be difficult to resubmit the projects to ask for additional costs under the current cost effectiveness restrictions.

An overview on MF funded projects

The level of funding of re-conversion projects has been decreasing dramatically during the last year. Looking at Argentine projects, the following shows:

- December 1994 - GROUP 1 - All of them with a good funding level of investment, technology transfer, technical assistance and training costs. Production facilities: 50,000 to 70,000 units per year

HFCs	***US$***
• Mac Lean: Project Cost without IOCs: Technology transfer and technical assistance: Training:	1,160,000 75,000 17,000
• Fribe Buenos Aires: Project Cost without IOCs1	1,181,000
Fribe La Rioja: Project Cost without IOCs Technology transfer and technical assistance: for both Fribe projects:	1,063,000 130,490
• Helametal (Two plants BsAs and Catamarca)	
Project Cost without IOCs:	2,559,085
Technology transfer and technical assistance:	73,000
Training	17,000

1 IOCs: incremental operational costs

- July 1994 - GROUP 11 - Prepared and revised under the constrictions of the cost effectiveness thresholds established by the XVI Ex Com Meeting of 13,76 US$/kg ODS, allowing to discount safety costs without any percentage limitation. The level of funding fell down drastically. Production facilities 35,000 to 50,000 unit per year.

HFC	***US$***
• Neba: Project Cost without IOCs:	686,370
Technology transfer and technical assistance:	40,000
Training	4,500
• Briket: Project Cost without IOCs:	726,400
Technology transfer and technical assistance:	40,000
Training HCs	4,500
• Autosal: Project Cost without IOCs:	797,390
Technology transfer and technical assistance:	53,000
Training	9,500

- November 1995 - GROUP III - Prepared and revised under the constrictions of the cost effectiveness thresholds and the additional limitation agreed during the XVII meeting of a maximum level of 35% discount of safety costs. Production facilities 50,000 to 70,000 units per year would receive technical assistance for HC technologies from the bilateral co-operation with the Swiss Government.

HCs	***US$***
• Aurora: Project Cost without IOCs: Technology transfer and technical assistance:	567,590 12,000
• Piragua: Project Cost without IOCs - Two plants	1,040,264
Technology transfer and technical assistance	5,000

HFCs	***US$***
• Adzen Project Cost without IOCs:	356,790
Technology transfer and technical assistance	0

- May 1995 GROUP IV - Project sent and submit to the XIX Ex Com under a third non agreed restriction, that are the "Templates". Production facilities 120,000 units per year.

HCs	***US$***
• Frimetal: Project cost without IOCs:	1,855,000

Conclusions

General barriers have been identified above, they affect in different proportions the adoption of hydrocarbon technologies. Key factors are:

Technology

a) Safety aspects:

- *Safe plant operation:* Uncertainties with respect to safety levels required. Local regulations are not clear and depend on plant locations. There is a need to revise and compile this regulation and to adopt international standard to local conditions and to provide to the industry with one clear and easy to implement recommendation;
- *Safety of the appliance:* Standards needed for model approval are unknown;
- *Safe service:* Standards for servicing have to be developed.

b) *Development of technology*. Appropriate transfer of technology is required:

- *Support:* for redesign of models;
- *Support:* for safe operation of the plant and safety related audits.

c) Development of suppliers:

- *Support of compressors manufacturers:* to assure adequate technical assistance and provision;
- *To explore the possibilities of local supply of HCs* and to assure adequate handling, "in time" delivery.

Market

Undoubtedly, the success of this technology is given by the acceptance and demand of the consumer:

a) *Acceptance* given by the assurance that the appliance is safe.

b) *Demand based on public awareness* with respect to the ozone layer and global warming effects of the alternatives.

c) *Cost of appliance:* mainly for standard models where an increase in price is not acceptable.

d) *Market in the region:* Operations under the Mercosur (Common Market of the South American Region) will influence companies decision. In addition, following questions are the most common:

- i) possibility of energy consumption standards, and uncertainty of pentane foams to comply with them.
- ii) delivery and marketing of this product in the region and coexistence of HFC-134a and HCs technologies.
- iii) the development of a service net.

Policy

a) *Cost effectiveness:* Decisions taken by the Ex Com of the MF affect directly to re-conversion process in article 5 countries. Cost effectiveness threshold and limitation on the percentage discount of safety costs to 35% limited the possibilities of hydrocarbon project. At the same time this discount is not allowed for the commercial sector or for panels, being impossible in such conditions to submit projects with pentane technologies in this sector. The results is that projects with hydrocarbon refrigerant technologies can not compete with HFC-134a projects or even HCFC-141b ones.

b) *Multilateral Fund* does not take into consideration Global Warming effect.

c) *Multinational companies* impose their technologies choices to their associated companies.

The US Domestic Refrigeration Industry

The World Bank

Domestic Refrigeration Production

By the end of 1994, the US domestic refrigeration industry produced 9,760,300 units of all types - representing a net 15% increase during the three years since 1991. The bulk of this total, 88%, were standard US refrigerators, 11% were compact refrigerators, and 1% were compact, built-in, undercounter refrigerators. Five manufacturers (GE, Whirlpool, Electrolux, Maytag and Amana) satisfied 99% of the market for standard refrigerators, with GE and Whirlpool alone manufacturing a total 60% of the market share.

Total production of standard refrigerators increased 18% over the same three year period and compact built-ins increased by 23%, while compact refrigerator production declined by 11%. Sanyo (63%) and U-Line (58%) are the market leaders in the latter two sub-sectors.

All US domestic refrigeration manufacturers have now nearly entirely converted out of CFCs into HFC-134a as refrigerant and HCFC-141b as blowing agent - although there is still some remaining use of HCFC-142b/HCFC-22 as blowing agent. However, the USEPA considers HCFCs as transitional (ozone-depleting) materials which must be replaced by the end of 2002. As a consequence, US manufacturers are presently testing a number of potential replacements, including various HC blowing agents such as cyclopentane.

Technical Barriers

According to the Association of Home Appliance Manufacturers (AHAM), the return/repair rate on HFC-134a refrigerators has fallen below the level of CFC-12 refrigerators during the past 2.5 years. One US manufacturer asserted that the very availability of HFC-134a, a proven non-flammable, non-toxic, alternative, is in itself the greatest practical barrier to HC usage as a refrigerant in the U.S today. Nonetheless, some U.S. manufacturing company engineers also claim they would much prefer using hydrocarbon refrigerants because they would be “easier to work with”.

In light of the obvious capital costs of changing to production with flammables (and before amortisation of recently introduced non-CFC technologies is fully realised), manufacturers feel no particular domestic market pressure to shift their technology choice to hydrocarbons, especially for smaller producers. The lack of established U.S. safety and regulatory standards (for flammability, toxicity, worker exposure) in either production or servicing further inhibits decision-making.

U.S. manufacturers, on the other hand, are not monolithic in their perceptions of the relative energy efficiency or other benefits of isobutane as a refrigerant. Some deny the European claims outright, while others affirm conviction of at least marginal energy savings with isobutane in certain models. The bottom line appears to be that there is not yet a universally accepted technical standard (agreed to by both European and American, let alone Article 5, manufacturers) for comparing alternative refrigerants, insulation and refrigerator models (in terms of energy efficiency, TEWI, testing protocols, etc.) which fact in and of itself may constitute an additional barrier to communication and understanding of the various HC alternatives or their trade-offs.

For example, standard US Department of Energy energy tests of refrigerator/freezers using cyclopentane blown foam result in a 10 % energy penalty when compared to an HCFC-141b baseline - a result which contrasts starkly with the cyclopentane energy saving claims asserted by some HC proponents[2][3]. On the other hand, the countervailing energy efficiency gains of 8.5% for isobutane relative to HFC-134a, also claimed by HC advocates, are similarly denied by their American counterparts[4][5].

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2 G. J. Haworth, Maytag,, Representing the Association of Home Appliance Manufacturers (AHAM) Appliance Research Consortium, “Next Generation Insulation Foam Blowing Agents for Refrigerator/Freezers”, paper presented at the International Appliance Technology Conference, Purdue University, May 1996.

3 Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Hydrocarbon Technology Yearbook 1995, Eschborn, 1995, pp. 84, 120.

4 Personal communication of slide presentation on TEWI comparisons from Mr. Len Swatkowski, Association of Home Appliance Manufacturers, Chicago, Illinois, April 1996.

5 INFRAS & FKW, Natural Fluid Based Refrigeration, presented on November 27, 1995, at the Conference of Parties of the Montreal Protocol, in Vienna, Austria, p. 20.

Market Barriers

The technical barriers issue is more complicated than just product liability in the U.S. Even if there were zero legal liability risk, some manufacturers fear what the media and general public's reaction might be to a serious explosion or other flammability-related accident attributed to HCs. This concern might reflect an underlying US cultural or possibly even parochial bias mitigating against any such risks ever being taken by this industry.

AHAM also claims that US domestic refrigerator manufacturing operating margins are only in the 2-3% range, which allows for very little variation or experimentation and risk taking where technology choices are concerned. There is a perception that some European manufacturers may enjoy operating margins of 30-40% - which has allowed them to produce a more diversified or customised product, with various cultural or other niche markets - in particular "green" or environmentally marketed models - and build very expensive no-frost models which could never sell in a US mass market having relatively little product differentiation. Nonetheless, American manufacturers also see their domestic refrigerator appliances as distinctly different products in character (larger average size, no-frost freezers as standard) than those of their European and Japanese counterparts.

In North America, environmental awareness is primarily driven by top-down environmental authorities, such as the increasingly stringent domestic refrigerator energy efficiency standards set by the U.S. Department of Energy. Europe, on the other hand, has witnessed the emergence of increasing market demand by grass roots "green consumers".

Policy/Economic/Institutional Issues

The flammability barrier to hydrocarbon use as a refrigerant is codified in the U.S. market where various federal, state and municipal codes and standards PROHIBIT the use of flammable refrigerants in domestic refrigerators.

U.S. toxicity and health regulations also require that blowing agents pass strict toxicity tests which have not yet been undertaken for HC blowing agents such as cyclopentane. A direct consequence (barrier) is that U.S. manufacturers are therefore entirely dependent upon the willingness of the chemical industry to make the necessary toxicity testing investments (in terms of cost and time - nor-

mally about $6-8 million and 3 years) before a blowing agent may be vetted for use in a U.S. household appliance.
The US media's potentially highly negative treatment of accidents - which could be related to the use of HC refrigerants in the home - is perceived, in prospect, as a greater threat by the industry than even the legal liability issue. The anticipated litigation risk and how manufacturers address this risk is a substantial issue or barrier to the use of hydrocarbon refrigerants in the U.S.. However, it is not anticipated that hydrocarbon blowing agents such as cyclopentane would contribute materially to the litigation risk, assuming that they were ultimately fully vetted and proven non-toxic.

The bottom line is that most manufacturers are loathe at the present time to consider making any sizeable additional investment allocations necessary for working in the U.S. with flammable HC technologies which appear to promise somewhat questionable TEWI results coupled with unpredictable product liability risks, if not considerable energy penalties.

UK case study

Deloitte & Touche Consulting Group, London, England

Why look at the UK?

By examining the domestic refrigeration market in the UK, we present the case of an Article 2 country that has converted by and large to HFC refrigerants. The UK situation offers a number of insights into the technology choices of manufacturers, consumers issues and the role of the regulatory regime. In gathering data for this case study, we have spoken to domestic and commercial refrigeration manufacturers, civil servants in the departments of trade and industry and environment, non-governmental organisations, retailers, consultants within the refrigeration sector, and to producers/suppliers of hydrocarbons.

At the time of the GreenFreeze Campaign in Germany, Greenpeace launched a similar campaign in the UK. However, whilst the German campaign has evidently been successful and well documented, the results of the UK campaign were very different. The UK campaign lacked a number of ingredients that were key to the success in Germany; Germany had a unique political environment resulting from reunification that was supportive of commercial initiatives in East Germany, the UK campaign, by contrast, was not based on a domestic manufacturer and, furthermore, was not supported to the same extent by a strong and well-informed green consumer movement.

Hydrocarbon technology is, however, gradually gaining ground in the UK as evidenced by number of recent events. In November 1995, the British Standard governing refrigeration was amended to permit the use of HC technology in domestic refrigeration and, in February 1996, a small commercial refrigeration manufacturer converted to HC technology amidst much publicity and government support. Many manufacturers are exploiting the export opportunities for HC refrigerators, particularly to Germany.

Many observers cite the UK as one of the world leaders in the development of HC technology, however, as the following sections show, there is a significant degree of inertia in the UK domestic refrigeration market with respect to technology choices and it would appear that there is potential for change.

The UK Market

The UK market is typical of many Article 2 countries with 99% of all households owning a refrigerator. As with the rest of Western Europe, the market for "white goods" is relatively static (market growth for refrigerators in 1995 was 0.4%) since the majority of purchases are for replacement purposes.
The major UK refrigeration manufacturers are Hotpoint, LEC and Electrolux; there are also a number of smaller manufacturers such as Norfrost, Star Refrigeration and Candy which often produce refrigeration units for the "Own Label" market (i.e. sold under the label of a large retailer). Most manufacturers source their compressors internationally, mainly from Italy.

The main producer/supplier of HC refrigerants in the UK is Calor Gas which is pursuing an active marketing campaign in the UK and overseas for its refrigerant blends and after-sales support, in both the domestic and commercial sectors. Calor Gas has also undertaken some risk assessment for the usage of HC refrigerants in supermarket appliances; a change to HC refrigerants would increase the number of fires from 56 to 57 per million store years.

Total retail sales of refrigerators in 1994 amounted to 2.4 million units, of which over 50% came from 4 producers:

Producer	Market Share
Hotpoint	15%
LEC	12%
"Own Label"	14%
Zanussi	12%

At present, less than 5% of the UK market is given over to using hydrocarbons as the refrigerant, although cyclopentane is used as the blowing agent in 50-60% of all domestic refrigeration appliances. One of the smaller manufacturers does produce HC (refrigerant and foam) refrigerators (some 500,000 units in 1996) solely for export, mainly to Germany.

The HC refrigerator imports are largely targeted at the higher end of the UK market; for example, Bosch has approximately 2.5% of the UK domestic refrigerator market, which actually equates to 5% of the market value. This is further evidenced by looking at the market share by price of model: Bosch holds 25% of the £300+ market.

Despite the very low rate of adoption of HC technology in the refrigeration circuit, manufacturers do acknowledge that the technology would be feasible in the domestic refrigeration market. Manufacturers are aware of the changes to the British Standard 4434 which now permits the production of HC refrigerators for domestic usage and acknowledge that any safety risks in production are largely perceived and can be minimised.

The Barriers to HC Technology

Whilst manufacturers acknowledge that HC technology does have a number of advantages (export opportunities, environmental benefits, lower cost of refrigerant), they have identified some issues that are impeding their adoption of HC technology.

The majority of UK manufacturers have recently converted to HFC-134a from CFCs; they are unwilling to undergo a second conversion so soon whilst they still await the payback on their investment into HFC-134a and before the production line equipment comes to the end of its useful life. One of the larger manufacturers mentioned that its parent company is inclined to take a short term view of the opportunities and technologies available and is therefore reluctant to make any financial sacrifices at this stage.

By contrast, another manufacturer is investing in a new production line which will have the possibility for using HC technology both as refrigerants and foams. The refrigerators produced from this line will mainly be targeted at the export market in continental Europe; there is also a possibility that this technology may be transferred back to the parent company in the Far East.

Safety issues in production are not seen as an issue for manufacturers; they acknowledge that the changes to the British Standard mean that safety issues can be minimised. The lack of experience that manufacturers and retailers have with HC technology, however, is evidenced by some of their fears on safety issues occurring outside the production process; for example, one retailer expressed concern about potential safety hazards and liability risks of warehousing HC refrigerators. The retailer had even gone as far as undertaking risk analysis of the extent and likelihood of any damage arising from a potential accident in a warehouse. Manufacturers also have concerns about consumers tampering with, and damaging, their refrigerators, which with an HC refrigerant could lead to safety risks.

In the servicing of HC refrigerators, manufacturers and retailers again raise cost issues as a barrier; having converted to HFC-134a and invested in new equipment, they are concerned about incurring additional costs for HC refrigerants, both in terms of training service engineers and the equipment they require (vehicles, charging stations etc.). Calor Gas has offered free training to service and maintenance engineers; however, there has been limited take-up of these courses by service engineers on the grounds that there are insufficient domestic HC refrigerators in the UK market at present. Those HC refrigerators that do require repair and maintenance are normally sent back to the manufacturer (usually Germany) under the terms of their guarantee. This situation contrasts with the training offered for servicing commercial refrigerators where there is more demand.

Consumer Issues

Many of the manufacturers cite the lack of demand pull for HC refrigerators in the UK as a reason why they have not seen fit to adopt this technology. This is attributable to many reasons; refrigerators are not marketed on their environmental merits and consumers choose their refrigerator appliance on the basis of price, size, energy efficiency and reliability/warranty. Those HC refrigerators that are purchased in the UK are sold on the basis of their quality, their longer life and their energy efficiency. There is also a general lack of awareness of refrigeration technologies and environmental issues among consumers. The overall lack of awareness is largely due to the technical nature of refrigeration issues which means they are not "media attractive". Manufacturers and retailers also cite the poor and inappropriate labelling of appliances as not assisting consumer choice and awareness.

Policy/Government Issues

The UK government does not provide financial support or grants to assist manufacturers in changing to environmentally friendly production techniques in the refrigeration sector. The general policy is "polluter pays" and the government advises manufacturers to plan their investments ahead of the compliance date for environmental directives. Changes in the production process should be undertaken as part of the natural investment cycle, rather than when companies are forced to. The Department of Trade and Industry publicises the available options and relevant caveats associated with new technologies. The Department of the Environment has sought some voluntary agreements for the phase-out of all HFCs where viable alternatives exist; in the refrigeration sector, this agreement is limited to a declaration of intent.

As energy efficiency standards are tightened, manufacturers have expressed concern that the adoption of HC technology may affect their compliance with EC energy efficiency directives. They cite a lack of clear evidence of the energy savings from HCs, particularly for temperatures below 0°C.

Regulation and Standards Issues

The British Standard that covers refrigeration (BS4434) was modified in November 1995 to permit the use of HC technology in "closed dwelling places". This standard now provides clear safety guidelines for the production of HC refrigerators. The impetus for the change came from the British Standards Institute in recognition of the fact that the previous standard, last modified in 1989, was outdated. It is anticipated that a European standard for HC technology, which will supersede BS4434, will not be in place before 1997. However, the electrical standard (60-3352-2-24) for the design of HC refrigerators is not yet finalised; some manufacturers cite this as a reason not to convert to HC technology.

There is no standard for the servicing of refrigerators (HC or otherwise) although there is a voluntary scheme for the safe handling of refrigerators that covers HC technology. Many manufacturers would like to see a mandatory scheme if only to drive out disreputable service engineers, even though there are concerns about its enforcement and the costs it would impose; such a scheme is being resisted by government on deregulation grounds.

Conclusions

The domestic refrigeration market in the UK can be typified by its ambivalence and inertia towards technology choices for refrigerants. The commercial refrigeration sector, by contrast, particularly for drink chiller cabinets, is more innovative and is seeking to exploit the advantages of new technologies, such as HC technology.

Despite the appropriate regulatory regime and the minimisation of safety hazards, it appears that manufacturers are not yet ready to convert, either partially or completely, to HC technology in the domestic refrigeration sector. However, manufacturers are willing to respond to the market and, if there was sufficient consumer pressure, they claim they would do so. Any transition that occurs is likely to be export-led, rather than consumer driven, and would occur in the medium term. The key barrier, therefore, would appear to be the dearth of appropriate information to enable consumers and manufacturers alike to make informed decisions about their technology choices.

Germany / Case Description

Klaus Meyersen (Advisor to GTZ), Germany

Part One / The People

Hydrocarbon Technology in Germany was PEOPLE! And it was CHANCES! And it was a string of unusual and creative initiatives, based on personal involvement, coming from the inside and the insight. This triggered a before-hand unpredictable change in industry at a breath-taking speed:

Two Researchers at the Dortmund Institute for Hygiene

Preisendanz and Rosin, were curious enough to convert their lab refrigerator to hydrocarbons in their conviction that this is the most ecological CFC-phase-out solution, thus reactivating the pre-CFC-technology in post-modern times.

One Greenpeacer in Hamburg

Lohbeck, heard about this, arrived at the place when this project was already stopped, the model fridge put into the cellar, saw the chance, started the Greenpeace campaign and took Greenpeace money to invest into technical development and found interest in industry.

One East-German Manufacturer in Niederschmiedeberg

Günther of Foron, understood the chance of survival for an East German refrigerator manufacturer to go against the established and fighting back main stream, digging into appropriate refrigerant technology of propane/ butane blends and going into the market with it despite all the risk and uncertainties.

One Mail-Order-House in Frankfurt

Dorlöchter of Neckermann, took the green market chance and ordered the first 20.000 at a stage where there were only prototypes available without the stamped approvals by German safety institution TÜV.

One Entrepreneur in Ochsenhausen

Liebherr of Liebherr, shortly before his death, took the decision to go straight to hydrocarbon, the lasting solution, pioneered in cyclopentane for foaming, avoiding any costly in-betweens by trusting that his boys would not blow up his factory.

One Market Leader in Giengen

Bärmann of Bosch-Siemens, understood the ecology market chance, using his market power to have the compressor manufacturers turning to the hydrocarbon high-tech version of isobutane and gained market shares.

The German Public

was behind it all and all the time, ecology minded supported it all the way through, placing 80.000 blind orders in the Greenpeace Campaign and were really buying these Greenfreezers when they became available.

Part Two / The Facts

Domestic Refrigerator Production

Annual volume (approximate)

4.209.000 units (3.294.000 refrigerators, 915.000 freezers)

Recent trends in production and consumption

- Proportion of production: using HC for refrigerants ca. 95% and 134a ca. 5%; for foams cyclopentane or pentane ca. 95% and 141b ca. 5%. 134a mainly for exports. None of the manufacturer produces still significant amounts of R134a-models.
- No-frost refrigerators are now also available from major manufacturers, share expected to increase slowly from around 10% now.
- Hydrocarbon is done. Main effort of the entire industry today is energy saving. This may eventually mean drastic design changes, e.g. width going from 60 cm German kitchen standard to 65, 66 and 70 cm, to gain more space lost in thicker insulation. Yet in the moment different outside dimensions are

nearly impossible to push into the market although the refrigerator industry is trying to convince the furniture industry. Sales of stand alone units are fairly stable.
Liebherr developed "Zero-energy" prototype using solar cells.

Manufacturers

- Bosch-Siemens (one production, two distribution lines) 30%
- Liebherr 25%
- AEG 15%
- Zanussi 10%
- Whirlpool Varese 10%

Market and Technical Aspects

State of knowledge of hydrocarbon technology

Firmly established technology, there seem to be no more basic development efforts, besides for safety and energy savings.

Safety risks in manufacture and in use

With about 5 mio HC refrigerators produced there are alltogether 5 reported cyclopentane accidents in manufacturing. One recent major accident (3/96, yet without injuries) at a leading manufacturer is being investigated by TÜV. This is puzzling and cautioning the industry - happening at the most safety conscious manufacturer taking all safety precautions, including inertisation with nitrogen - since it may indicate dangerous situations beyond the present stage of knowledge. The risk is always only reduced, and obviously there is not yet the full experience with flammables for foaming.

There are no reported accidents on hydrocarbon refrigerants, neither from manufacturers nor from the service sector nor from normal household use.

Market barriers

None visible, the market runs smoothly. Slightly higher prices in hydrocarbon refrigerator manufacturing (parts like visible evaporators, klixon safety switch overload protection devices are still produced in smaller series by more expensive manufacturers only) may force retailers / wholesalers back to 134a in the increasingly competitive market.

Imports

Europe: mostly from Italy mainly Whirlpool, Zanussi, some imports from Spain yet not significant. - Outside Europe: only low end imports at a minor scale.

Exports

Europe: Isobutane and 134a each estimated at 50% at present, with isobutane increasing due to change in legislations. - Outside Europe: 134a due to legislation of importing countries - most likely no significant amounts of isobutane refrigerators.

What technology is being transferred (134a or HC)

(especially to A5 countries - which German manufacturers have ownership, joint ventures or technical cooperation agreements with which firms in A5 countries?

First rule of policy of mayor manufacturers is "100% CFC-free", that means a minimum conversion to cyclopentane + 134a. Second rule of policy is "most economically friendly", that means cyclopentane + isobutane. This applies to Bosch-Siemens acquisitions, e.g. in Turkey; China yet is not ecology driven only, but by reliability of the system. Ecology pays says Bosch-Siemens and this they want to prove also in article-5-countries, explicitly in China. - This is also the line followed by Liebherr in setting up their technical cooperations; Liebherr is not seeking joint ventures.

Consumer awareness/advertising of refrigerator technology/environmental issues

CFC- plus HFC-free is now common standard, taking for granted by the customer and no longer a big issue in advertising; energy saving is the topic at present with each of manufacturers providing A-models to European standards. The flammability was never in intensive public discussions, even at the early stages when the West-German manufacturers were blackmailing the East-German attack. Greenpeace was pushing the public discussions on risk acessment, thus putting the pressure on industry. TÜV safety standards are taken as a quality guarantee.

Legal / regulatory issues

Under German law there is no additionally manufacturer liability as long as the goods fall in the frame of safety standards set by the official institutions. Existing regulation covers the field of household refrigeration sufficiently. Up-coming overruling European regulation will focus on commercial use and may cause some uncertainty there in future - unlikely to effect the household refrigeration scene.

Policy/Economic/Institutional Issues

- government views:

Due to the Montreal Protocol regulations this is no longer a political issue in Germany.

- support from funding agencies:

Germany has in the past funded the introduction of this technology additionally to the contribution to the Multilateral Fund of the Montreal Protocol, e.g. in India and China, and will continue to do so with the present GTZ / PROKLIMA-Project.

There is at present a consideration by the German government to support ecologically sound German technologies, if this will have a positive effect for the German employment situation as well. It may be that there will be some funds available for Hydrocarbon Technology within this frame.

New Developments

There is not any further mayor technical contribution to the Hydrocarbon Technology to be expected in the sense as CFC substitution. The new efforts are directed towards energy saving. These do make this technology more valuable, but energy considerations are unfortunately outside the narrow scope of the Multilateral Fund.

Conclusions

An established situation which puts Germany in a singled-out position to the rest of world with the exemption of Switzerland and the Northern European countries. Compared to the change-over situation 1992/95, however, the situation 1996 is best described by fading public and political interest which might make it more difficult in future to obtain additional public support on the issue of ozone layer protection.

8 TECHNOLOGY, MARKET, COSTS AND ENVIRONMENT Hydrocarbon Technology in Relation to HFC/HCFC Technology

- September 1996 -

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Editorial

The authors of this report are the Forschungszentrum für Kältetechnik und Wärmepumpen GmbH (FKW; Research Centre for Refrigeration and Heat Pumps Ltd.) in Hannover, Germany, and INFRAS AG in Zurich, Switzerland. The underlying study was led by Stephan Sicars and Thomas Tiedemann, Forschungszentrum für Kältetechnik und Wärmepumpen GmbH, in close collaboration with Dr. Othmar Schwank from INFRAS AG. The authors want to thank all persons and groups who made contributions to the study, in particular (in alphabetical order) Jessica Irvine and Fraser Morrison from Deloitte & Touche Consulting Group; Dr. Michael Arnemann from FKU GmbH; Dr. Klaus Meyersen and Dr. Peter Störmer from GTZ; Dirk Legatis and his colleagues from Heat; Dr. Mike Jeffs from ICI; Bilal Rahill from the World Bank and several refrigerator, component and equipment companies. Their help and contributions as well as those of several others are highly acknowledged.

Executive Summary

When it was discovered that chlorine-containing fluids used as refrigerants and foam blowing agents deplete the ozone layer in the upper atmosphere, their use was regulated in the 1987 Montreal Protocol for the Protection of the Ozone Layer and its subsequent amendments. It took more than a decade from the formulation of the hypothesis that CFCs deplete the ozone layer by Rowland and Molina in 1973 to the enforcement of legally binding control measures. During the 1980s a precautionary principle against the use of chlorine-containing synthetic compounds has been reflected in most environmental legislation of developed countries. This precautionary principle is closely linked to the concept of sustainability supported by most nations at the Rio Conference in 1992.

CFC-12 has been used nearly exclusively as a refrigerant in refrigerators and freezers due to its superior properties. It provides a good energetic behaviour, although its stability and oil behaviour has led to some laxity in handling but this does not have any negative effects on the refrigerator. The main demerit of CFC-12 is the significant contribution to ozone depletion which has resulted in a phase-out of this substance, as well as of the ozone depleting CFC-11. CFC-11 is a very good blowing agent used to form PUR foam providing not only insulation, but also structural stability to refrigerators.

As a result of recent technical developments, a considerable number of European refrigerator manufacturers have demonstrated the technical and economic feasibility of producing and selling competitively priced products using hydrocarbon technology in the refrigeration circuit as well as using it as a blowing agent. Hydrocarbon technology replaces CFC-12 as well as CFC-11 by non-halogenated fluids which have molecules consisting purely of hydrogen and carbon.

However, although hydrocarbon fluids have found widespread use as foam blowing agents globally, the use of hydrocarbon refrigerants has yet to break out from its European origin into the rest of the world, in both developed and developing countries. Even the European market does not present a homogenous picture of refrigeration technologies; to date hydrocarbon refrigerants have only come to dominate the domestic refrigeration market in northern European countries (from Austria/Switzerland to Scandinavia) whilst Anglo-Saxon and Latin cultures continue to use synthetic fluids. Manufacturers do, however, report evidence of increasing acceptance of hydrocarbon refrigerants in the Italian and Spanish markets

This study is meant to inform about advantages and disadvantages of the two different technologies which are used to phase out ozone-depleting substances used in domestic refrigerators. Such technology options are on the one hand the use of cyclopentane as blowing agent for the rigid polyurethane foam of the refrigerator and isobutane or a blend of isobutane and propane as refrigerant. These fluids are flammable. Alternative technical options are the use of HCFC-141b as a blowing agent and HFC-134a as a refrigerant. These two fluids are potent greenhouse gases and HCFCs are still ozone-depleting.

The second option being the technology discussed for phase out of CFC-11 and CFC-12 for a long period, has several merits which have been described and published widely, allowing engineers to gain information mainly about their advantages. The products and information about their use have been available for years because the chemical industry responded fast and with large investments to the political and public request for ozone friendly products. In contrast, hydrocarbons are not only an option which has only been discussed for a short period but also one which is commercially less interesting for suppliers of components, even threatening the return of their investment costs for the HCFC and HFC technology formerly strongly requested by the customer. This situation leads to an imbalance in information on the side of the technology user and political and industrial decision makers who presently need information on hydrocarbon technology as well as comparisons between the two technologies to be able to make a well-considered choice of technology. This study is meant to provide such information, but the comparison of the two options showed that a clear, definite general choice of one technology will not be possible. Instead, every user will have to make his choice, considering the advantages and disadvantages of both options for his situation.

The study consisted of several parts, dealing with technology, market, costs and environment. The important findings as well as remaining uncertainties are stated in brief in the following paragraphs.

The **technology comparison** shows that both technologies proved to be suited for large-scale refrigerator production in article 2 countries. The foam using HCFC-141b as blowing agent has good insulation values, the equipment is easy to convert. Incompatibilites of HCFC-141b and materials in the refrigerator caused problems. The foam using cyclopentane has no incompatibilities with any materials in the refrigerator, but has slightly lower insulation values than the foam blown with 50 % reduced CFC-11. The foaming equipment has to be converted in order to handle the flammability of the blowing agent. Both foam options are similarly flammable when the manufacturing process is finished.

In comparing the alternative **refrigerants**, isobutane shows an energy efficiency at least equal to HFC - 134a, with a slight tendency to an efficiency advantage under moderate climatic conditions and an advantage at high ambient temperatures. Isobutane is compatible with the oils and materials used with CFC-12 in the refrigeration cycle, and the handling of the components and oil is similar to the handling of CFC-12. As isobutane is flammable, factories need to meet safety precautions which involves increased investment, and in some cases, design changes of the refrigerator, consisting usually of a change in location and protection of electric components to ensure that accidents are avoided. A disadvantage of isobutane - its lower volumetric capacity compared with CFC-12 - may lead to larger compressor housings with similar sized motors as for CFC-12. A blend of isobutane and propane can use similar sized compressors, but in most cases this is only suitable for single temperature appliances or for those which have been re-designed for the needs of a blend.

HFC-134a can use the same size compressor as CFC-12 and is not flammable.
However, there is a disadvantage with the ester oil which has to be used with HFC-134a. It is expensive, highly hygroscopic and forms acid with water; its use requires very strict workplace discipline in manufacturing the refrigerator. A refrigeration cycle containing ester oil which has been contaminated with moisture, for example from ambient air, will almost always result in a total compressor breakdown within a few months to up to two years. The combination of HFC-134a and ester oil is a solvent, capable of dissolving leftovers from the manufacturing or service process, in particular those oils used for machining. Usually, these substances are deposited in the capillary tube of the refrigeration cycle, causing anything from a decreasing capacity to a break down of the system. In order to avoid this, a specially adapted production process must be followed with strict workplace discipline for all components which are used in the cycle.
This will narrow down the component availability and market.

There have been indications for quite some time that there are major manufacturing problems of refrigerators and their components with HFC-134a during their mass production phase. In one reported case at one medium-sized manufacturer, close to 10,000 warranty cases had to be taken care of. It is worth mentioning that the liability claims amount to twice the hydrocarbon refrigerant conversion costs for the whole plant. Experts from large compressor manufacturers state that these compressor related problems have now been overcome in developed countries after some five years of extensive research and development. However, there is a concern that developing country manufacturers lacking this expertise may run into the same or similar problems, which are more likely under less stringent quality controls.

It is obvious that in the **service sector** additional training has to take place to enable service technicians to master the additional requirements of the two refrigerant choices. The difference in effort necessary for the training when using either isobutane or HFC-134a is unknown. It is expected that training concerning the handling of hydrocarbons is relatively simple because the service technicians are used to handling hydrocarbons, and it is in their interest to avoid an explosion. On the other hand, the handling of HFC-134a and its oil does not only require a strict working discipline, but also the ability and the will to recognise own mistakes as well as unfavourable circumstances and act accordingly, which usually means disposing of significant quantities of the oil. Depending on the region, the value of the ester oil filling of one HFC-134a refrigerator can very well be above the service technician's salary for two weeks. The customer of the service has no means of verifying the quality of workmanship and oil. In the case of a repair not being carried out properly, the breakdown will follow after several months. Hydrocarbons fit much better into the workculture prevailing in most A5 countries than HFC-134a. However, since refrigerator manufacturers have not used flammable substances for several decades there are severe reservations. Further training will be necessary as the vast majority of technicians do not think of refrigerants and flammable hydrocarbons in the same context, they expect their refrigerants to be non-flammable.

In article 5 countries, there are significant amounts of CFC-12 refrigerators in the market which will continue to be serviced with CFC-12 and mineral oil. While isobutane or a hydrocarbon blend will work with the mineral oil used for CFC-12, this is not true for HFC-134a. If, when servicing, the wrong oil type is supplied to an HFC-134a refrigerator, a breakdown is very likely. In addition, HFC-134a requires different charging equipment that can not be used with CFC-12. CFC-12 and hydrocarbons can be used parallel in a market without major problems.

On the **environmental** side, the blowing agent HCFC-141b is not favourable at all because it contains chlorine, is therefore ozone-depleting and restricted under the Montreal Protocol. In addition, there is also a significant greenhouse effect. But due to the possibility of a relatively easy and cheap conversion of existing CFC-11 foaming equipment, HCFC-141b facilitates a fast tenfold reduction in ODP terms in comparison to CFC-11. New fluids, HFC-245ca and HFC-365mfc, are presently under development but quantities and experiences are not available yet. It is not known if these fluids will actually be produced and supported as a blowing agent.

HFC-134a has no **O**zone **D**epleting **P**otential (ODP), but a relatively high **G**lobal **W**arming **P**otential (GWP), while the hydrocarbons have zero ODP and a negligible GWP.

Information that HFC-134a degredation causes formation of trifluoroacetate (TFA), causing TFA-concentration in rainwater, or that hydrocarbons in refrigerators would contribute to low level smog do presently not seem to be significant enough to be considered as negative for either one of the fluids. If TFA turns out to be an environmental problem, it will be a long-term, global one, which should be avoided from the viewpoint of the precautionary principle and the sustainable development principles set in Rio.

The **T**otal **E**quivalent **W**arming **I**mpact (TEWI) effect, combining energy consumption related emissions of carbon dioxide and their effect on global warming with the direct effect caused by emissions of the fluids used in the refrigerator, is a value for the impact on global warming caused by an appliance over its lifetime. It was investigated if there is hard evidence that for given costs, HFC/HCFC technology could achieve a greater TEWI reduction by improving energy efficiency, thus being more environmentally efficient. Without being able to provide exact numbers, the investigation showed that the direct GWP of the fluids contributes significantly to the TEWI. In addition, from a certain point of energy efficiency onwards, a TEWI reduction is achieved more cost effectively by using hydrocarbons, rather than by further decreasing the energy consumption. In addition, the minimum TEWI can only be achieved using hydrocarbons.

Comparable **cost** information is unavailable for conversion costs for refrigerator and compressor manufacturing plants. Comparable information on estimated costs is available from conversion projects of refrigerator manufacturing plants submitted to the Multilateral Fund. In an evaluation undertaken by the Multilateral Fund, the incremental investment costs for hydrocarbon technology needed for safety precautions are 27% compared with the 35% eligibility threshold for financial assistance. It is often cited that investment costs increase between 10% and 90% for the conversion of a refrigerator factory in comparison with the costs arising when converting to HFC-134a.

The **unit costs** of those refrigerators using hydrocarbons as a refrigerant have been higher in the past because of the small numbers produced, but there is no solid information if the unit costs will change in the future compared with HFC technology. In general, a decrease in the cost of hydrocarbon refrigerant technology has been experienced in the European market and is expected to become more significant if the technology continues to spread. Cyclopentane as a blowing agent turned out to be the most cost effective solution for the phase-out of CFC-11 as a blowing agent.

From a lifetime cost perspective, the use of hydrocarbon technology for the production of refrigerators is very likely to provide higher cost effectiveness than the use of HFC-134a as a refrigerant or HCFC-141b as a foam blowing agent under developing country conditions.

The first non-ODS technology available for refrigerator manufactures was the use of HFC/HCFC. These technologies, which have been used since 1990/1991, have gained a world-wide **market** share of approximately 40% of the total production of refrigerators (early 1996). Around 10% of the refrigerators produced are using hydrocarbons as a refrigerant, roughly 15% as a blowing agent; a market share achieved since 1993. In some areas, cyclopentane foam was combined with HFC-134a as a refrigerant. At present, slightly less than 50% of the world-wide refrigerator production still uses CFCs as refrigerants and blowing agents. In most countries, customers do not seem to have any preference for a specific technology and it is not known if the customer is willing to pay for the benefits associated with a particular technology, and if so how much he is willing to pay. While consumer safety acceptance is not an issue because the consumer (correctly) assumes that the manufacturer will address safety issues, at the same time it is not possible to estimate the value of cheap and reliable service or reliability to the consumer at time of purchase.

The study provides evidence that the use of hydrocarbon technology as a refrigerant and blowing agent offers some advantages over HFC/HCFC alternatives, particularly in meeting the requirements of sustainable development in developing countries:

- HC technology is an old and relatively simple technology which, when the necessary safety precautions are taken, is well suited for production in developed as well as in developing countries. Even through HFC-134a appliances may be produced successfully in the conditions prevailing in developing countries by manufacturers with technology tie-ups to multinational companies, it is doubtful whether the same is feasible for independent manufacturers, which have to rely on the technology transfer facility offered under the procedures of the Multilateral Fund. Furthermore, an appropriate service infrastructure for HFC-134a based appliances has not yet been established, particularly in rural areas in developing countries. On the other hand evidence from countries with an established LPG servicing practice for CFC-12 appliances (e.g. Cuba [Inf96]) suggests that no serious hazards have been reported.

- The choice of hydrocarbons offers the advantage of independence from high-tech manufactured or patented substances such as HFCs, HCFCs and the synthetic oils. These substances would have to be imported from industrialised countries or a production license would have to be purchased while hydrocarbon fluids, sometimes at insufficient purities, can be procured from refineries located in at least major developing countries. HCs are not patented.
- Hydrocarbons are environmentally benign fluids and are degraded within a few days into nature-identical substances whereas HFC-134a and HCFC-141b contribute to global warming although at present there is no scientific consensus about further possible environmental damage caused by their degradation. Restrictions for production and the use of HFCs are discussed and regulations for the reduction of HFC emissions can be expected in some countries. HCFC-141b is already controlled through the Montreal Protocol while limitations in the use of hydrocarbons are not likely to come and only would require the same techniques to avoid emissions already valid for HFC-134a. Those manufacturers converting to hydrocarbons choose a long term alternative to CFCs.

A Short Introduction to Domestic Refrigeration

Recent Technology History

Before the discovery of the CFCs, hydrocarbons were widely used as refrigerants in domestic and commercial refrigeration. They were gradually replaced on account of the advantages of the non-flammable nature of CFCs. The revival of hydrocarbon technology in Europe during the early 1990s is likely to turn out as an interesting piece of technology history. The high global warming potential and the incompatibility with mineral oils of HFC-134a - promoted as the mainstream replacement for CFC-12 in domestic refrigeration - first made researchers, then industrial manufacturers of refrigerant equipment look into the group of so-called natural fluids as refrigerant alternatives to CFC-12. Also hydrocarbon refrigerants, requiring only well known technology with respect to the refrigeration cycle, were reconsidered. For safety reasons design related changes were made using proven technology from petrochemical applications. Different tests with hydrocarbon refrigerants were made in the late 1980s, however, manufacturers were not prepared to announce a hydrocarbon-based domestic refrigerator before 1992.

In 1992 - the year of the Rio Conference - the Copenhagen Amendment advanced the CFC phase out date to January 1, 1996 for Article 2 countries. The European Union, prior to Copenhagen, had already announced a phase out of CFCs by January 1, 1995, while Germany's manufacturers volunteered for an earlier date (mid-1994). Manufacturers were put under pressure to come out with 'green' refrigerators by 1993.

In 1992 Greenpeace - with an effective media campaign and an R&D contribution of DM 30,000.00 - supported the East-German manufacturer Foron with respect to the development of the first modern hydrocarbon refrigerator based on a propane/isobutane blend. The announcement of this technology forced more and larger refrigerator manufacturers to prove their ability to develop similar models.

Together with the media presence and sales success of the Foron refrigerator, backed up by an environment price award and the environment label 'Blue Angel', two other German hydrocarbon pioneers, Liebherr and Bosch-Siemens, developed CFC/HFC-free products and brought them into market in 1993. These two manufacturers launched the first isobutane/cyclopentane refrigerators.

In order to meet the 1994/1995 CFC phase out dates, these companies, as well as the players associated with the Whirlpool Group (Bauknecht) and the Electrolux Group (AEG), had to convert the bulk of their models to HFC-134a, an R&D work that was 50% completed by autumn 1992. By then the landmark decision in favour of hydrocarbons had been taken within Germany’s refrigerator manufacturers association - a decision to which the German Environment Ministry significantly contributed by questioning the rationale behind HFC-134a, the only position so far taken by the manufacturers’ association. Foron was the only manufacturer present on the German market which did not convert first to HFC-134a.

Informally, Liebherr and Bosch-Siemens have confirmed that they have not regretted their landmark decision of autumn 1992 since they will have got rid of the HFC-134a related problems they experienced 1992 and 1994. A number of European refrigerator and compressor manufacturers report liability claims from customers pending in the order of several million US$ due to failures of HFC-134a products /Sch96/.

Liebherr reports that with conversion to HFC-134a, returns from customers have doubled compared with CFC-12, whereas isobutane returns are at the same level as CFC-12 /Mel96/.

By taking the lead in conversion to hydrocarbon refrigerants Foron benefited from the strategic advantage of still producing its own compressors. This put Foron into a position to launch a simple conversion solution. Foron’s conversion criteria were: Safe product and at least CFC-12 equivalent performance at minimal conversion cost for compressor and refrigerator design adjustment. The conversion to a blend of propane and isobutane matched the cooling capacity of CFC-12 with a given compressor displacement almost exactly. Thus, any major conversion of compressor production was avoided.

The hydrocarbon blend as compared with CFC-12 does have - besides flammability - some demerits, such as slightly higher noise level, the problem of temperature glide and the possibility of a differential leakage. Compared with blends, the major merits of isobutane as a single refrigerant are its higher energetic efficiency and lower noise emission levels. The major players on the German market accordingly gave preference to isobutane.

Hydrocarbon blend compressors fulfilling the same requirements of high energetic efficiency and lower noise emission levels could not be developed within the short 6-month time span between the landmark decision in favour of hydrocarbon refrigerant and the market introduction of the Foron refrigerator. The first hydrocarbon compressors freely accessible on the market were isobutane compressors produced by Danfoss. The warranty for this compressor was granted later on only. The extremely fast growing market for isobutane refrigerators took some big players in the compressor business by surprise. They had invested heavily in HFC-134a conversion and were not prepared for an almost simultaneous second conversion to hydrocarbons. So, the limited supply of compressors together with the above mentioned isobutane merits made the preliminary selection of isobutane an acknowledged standard.

By 1994/1995 the European factories of Electrolux - Zanussi, Unidad Hermetica and Verdichter Oe - had joined the production of isobutane compressors on a large scale. The European subsidiary of Embraco, Brazil, which in turn belongs to the Whirlpool group, has been catering to a sizeable portion of the growing Western European isobutane compressor market. Matsushita, after losing some of the previous HFC-134a market share, had introduced its own isobutane line for the European market.

Fundamentals of Refrigerator Technology

Refrigeration technology plays an important role in the safety and health of mankind. The preservation of food is vital to the stability and economic growth throughout the world. Food conservation is achieved by slowing down biochemical processes to reduce the propagation of bacteria. This can easily be done by cooling or freezing, without the addition of preservatives. Refrigeration technology provides the technical aids to cool food throughout the cold chain starting at production, through to transportation, and finally in storage, sale and storage at the consumer’s home in a refrigerator without interruption. In industrialised countries almost every household possesses a refrigerator. Over the last few decades, production has increased dramatically in developing countries from a low level with the goal of providing one refrigerator for each household.

The primary function of a refrigerator or freezer is to provide food storage space at a reduced temperature. For the preservation of fresh food, a general storage temperature of around 4°C is desirable. Freezers and combination refrigerator-freezers that are used for long-term storage are designed to keep temperatures near -18°C.

Due to different demands by the customers all over the world, various climatic and technical requirements, a wide variety of refrigerator and freezer types have been developed and are available in the marketplace (Figure 1).

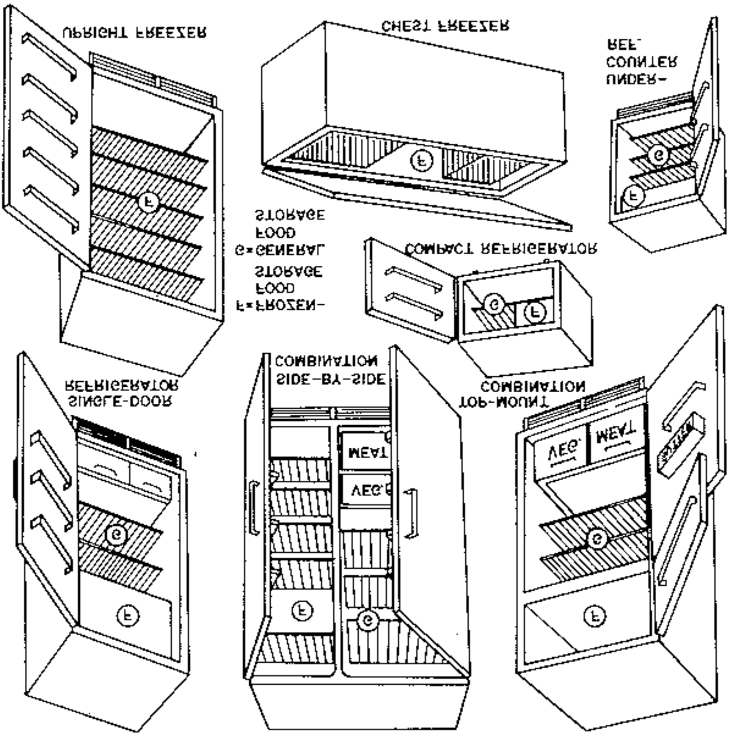


Figure 1: Type of refrigerators and freezers [ASH88]

From a technical view most of these types are very similar. Common special types are combined refrigerator/freezers where two or more different compartment temperatures are desired and the so-called no-frost refrigerators or freezers. These refrigerators are more expensive, with automatic defrost cycle after some cooling periods in the cooling compartment and automatic defrost as required (1 to 7 days) in the freezing compartment. The defrosting is achieved by electrically driven heaters. The cold air inside the compartments is circulated by an electrically driven fan. This type of refrigerators, which is very convenient, is very common in the United States, but it does have an increased energy consumption of 10 to 30% compared with standard models.

When purchasing a refrigerator, customers focus their interest on the following characteristics:

⇒ Maximum inner volume for storage,

⇒ minimum cost, meaning minimum investment costs, and, to a lesser extent, minimum energy consumption,

⇒ optimum comfort (handling, low noise),

⇒ reliability and

⇒ lifetime without extra service.

Refrigerators (henceforth the term ‘refrigerator’ will be used for both, refrigerators and freezers) are the most widespread applications of refrigeration technology in the world. Approximately 64 million refrigerators are manufactured worldwide each year [UNE94]. Hundreds of millions are currently in use. It is expected that the number of refrigerators in developing countries will substantially increase in the near future, in the order of 15% per year [UNE94], because of the growing demand of the population.

However, the large number of refrigerators produced annually and the expected increase in production lead to a significant contribution to several environmental problems. In the context of destruction of the ozone layer and global warming, refrigerators are involved in three ways :

- some types of blowing agent used in insulation contribute significantly to ozone depletion and global warming.
- some types of working fluid used in the refrigeration cycle also cause a depletion of the ozone layer and increase global warming.
- in operation, a refrigerator needs a lot of energy which is mainly produced by combustion of fossil fuels thus increasing the global warming effect. The energy consumption necessary to maintain the desired compartment temperatures in turn depends mainly on the insulation and the refrigeration cycle.

To minimise the effect of refrigerators on ozone depletion and global warming, the insulation and the refrigeration process have to be discussed.

Insulation and Blowing Agents

To reduce the energy consumption of the entire refrigeration system, an efficient insulation of the cooled system is desired to minimise the heat transfer through the system’s border. Various kinds of insulating material have been developed and applied over the course of the history of refrigerators. Prior to the development of rigid polyurethane foams (PUR) glass wool has been, and still is, used mainly for cost reasons by some manufacturers in developing countries. Nowadays, PUR foams are increasingly used because of their advantageous material properties and because they simplify the production process and refrigerator design.

The use of expanded-in-place foam insulation has had an important influence on the cabinet design and assembly procedures. Not only is the wall thickness reduced, but the rigidity and bonding action of the foam usually eliminates the need for structural supports. The foam is normally expanded directly into the insulation space, adhering to the compartment liner and the outer shell. Unfortunately, this does not permit disassembly of the cabinet for servicing or scrapping.

The best type of insulation can be achieved by using vacuum panels. These are presently under development but do not promise to be cost effective in the near future, as a simple production technology has yet to be developed.

It is necessary to modulate the foam blowing agents which simultaneously serve as an insulating gas. The blowing agents have to remain in the bubbles forming the foam to provide constant insulation quality over the lifetime of the foam. In selecting blowing agents for insulation, various thermophysical, chemical, physiological, ecological and economical requirements have to be considered, e.g.

- low heat conductivity,
- compatibility with existing production equipment
- high chemical stability,
- should remain in the cells of the foam
- none or negligible negative chemical reaction with the material and goods to be insulated,
- no toxicity
- high perceptibility
- no flammability
- high availability,
- low costs

environmentally benign behaviour over the short and long term (GWP, ODP).
With the development of PUR foaming trichlorofluoromethane, CFC-11, was introduced as a blowing agent and became the most commonly used since it matched all the requirements with the exception of environmental acceptance. The phase-out of CFC-11 as agreed by Montreal Protocol and subsequent conferences has led to intensive research for substitutes. Four less ozone depleting sub-

stances have been widely considered: HFC-134a, HCFC-141b, a mixture of HCFC-22/HCFC-142b and cyclopentane.

Among the natural fluids, cyclopentane has proved to be the optimal blowing agent. The main drawbacks of cyclopentane are its flammability requiring additional safety installations and in some cases the incompatibility with existing foaming equipment. However, the possible alternatives, HCFC-141b, HFC-134a, or the mixture HCFC-22/HCFC-142b also have different shortcomings, not to mention their high ODP and/or GWP values.

Refrigeration Processes and Refrigerants

Technical Principles of Refrigeration Processes

Refrigeration processes can be divided into open type systems, cycle processes and other processes such as thermomagnetic and thermoelectric refrigeration.
During substance consuming processes e.g. solid CO_2 or liquid water is evaporated absorbing heat from the system to be cooled. It is characteristic for such processes that the working fluid is afterwards in a final state which does not allow its reuse.

From an economic viewpoint, cycle processes are more interesting. Here the working fluid is used cycling continuously in a hermetic circuit. There are three important types of cycle processes:

1. Vapour compression cycles,
2. Vapour absorption cycles and
3. Gas cycles (such as Stirling and air cycles).

The majority of all existing domestic appliances are systems with a hermetically sealed vapour compression cycle where the thermodynamic state of the working fluid is varied during the cycle process. An absorption system or thermoelectric refrigeration are only used for special purposes and small refrigerators. Other technologies like the stirling cycle, air cycles, or thermoacoustic compressors are under development. Presently, the optimum principles are still discussed, and no production know-how and cost indexes are available. As these technologies for which a significant market availability cannot be foreseen, these processes can neither be proposed to be used in developed nor in developing countries in the near future. Therefore only appliances employing the vapour compression cycle are covered in the following.

In a vapour compression cycle a working fluid circulates in a hermetic circuit to generate cold. Figure 2 presents a schematic circuit, which principally consists of a compressor, a condenser, an expansion device and an evaporator connected by piping.

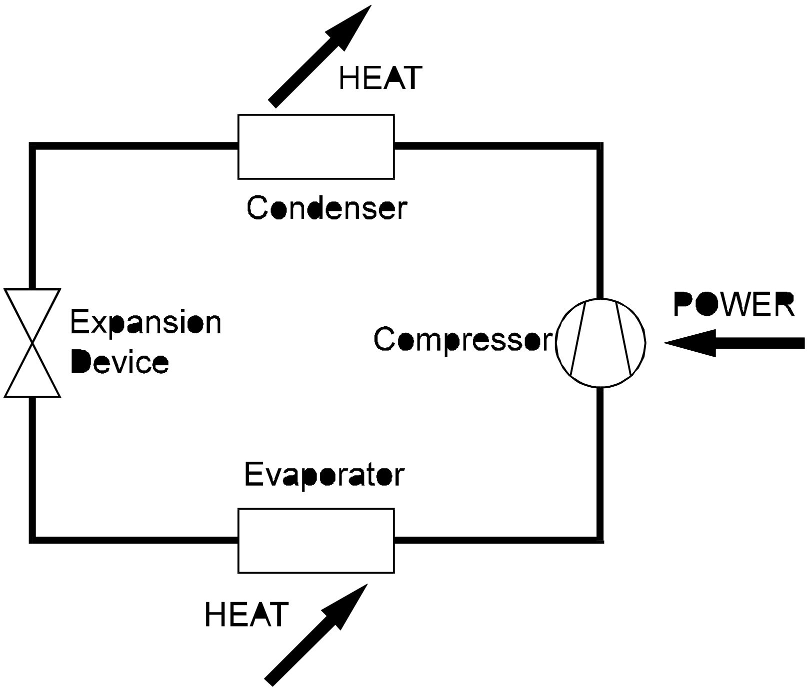


Figure 2: Scheme of vapour compression cycle

Coming from the evaporator at low pressure and low temperature, the refrigerant vapour enters the compressor where it is elevated to the high discharge pressure. It enters the condenser as a superheated gas. From the condenser heat is emitted to the ambient so that the refrigerant gas is first cooled down and then condensed at constant pressure and high temperature. From the condenser the refrigerant passes the capillary tube while it reduces its pressure. Now the refrigerant enters the evaporator at low pressure and low temperature. During heat absorption from its surroundings, the refrigerant evaporates and finally is again withdrawn by the compressor.

A portion of the capillary tube is usually in thermal contact with the suction line for heat exchange thus increasing the system capacity. A dryer is placed ahead of the capillary tube to remove foreign material and moisture. A thermostat cycles the compressor to provide the desired temperature within the refrigerator. Vapour compression refrigerating systems are hermetically sealed and normally require no replenishment of refrigerant or oil during their life.

Refrigerant Options

When selecting working fluids for the vapour compression cycle, thermophysical, chemical, physiological, ecological and economical requirements have to be met: e.g.

- thermodynamic data, in particular temperature-pressure relation, strongly influencing system size, cost and performance,
- transport properties, such as viscosity and high heat conductivity, influencing system performance,
- definite miscibility with oil,
- high chemical stability,
- compatibility with existing materials, lubricants and food,
- no toxicity, high perceptibility, no flammability,
- high energy efficiency, optimum volumetric capacity,
- high availability, low costs,

environmentally benign behaviour in short and long terms (GWP, ODP, TEWI).
The refrigerant used in vapour compression cycles until 1992 was almost exclusively dichlorodifluoromethane, CFC-12. This fluid very well matches all these requirements except the environmental aspects. Due to its contribution to ozone depletion, this refrigerant has to be replaced in A5 countries by 2010, while it has already been phased out completely in A2 countries since January 1, 1996.

In view of this phase out date, intensive investigations have been performed to find a substitute for CFC-12 in domestic appliances. It soon turned out that a halogenated replacement would be from the methane or ethane family. Experimental work in domestic refrigeration first focused on HCFC-22, HFC-134a, and, as the greenhouse warming potential of HFC-134a was considered, HFC-152a.

Due to very similar thermodynamic properties and its inflammability, HFC-134a was propagated as the replacement for CFC-12 by the refrigerant manufacturers of industrialised countries. It was introduced first by the European appliance industry, later on by the manufacturers of all other industrialised countries. At this time, HFC-134a had already come under pressure from environmentalist groups in Central Europe due to its contribution to man-made global warming. Thus, in these countries hydrocarbons were finally considered as environmentally benign refrigerants for domestic appliances. Since there is no pure hydrocarbon with similar thermodynamic properties as CFC-12 and HFC-134a, a mixture of two fluids was used by the hydrocarbon pioneer Foron whereas other manufacturers and later on Foron as well converted to pure isobutane. The use of refrigerant mixtures will be addressed in the next section.

Pure Fluid - Mixture Refrigerant

In all refrigerators presently in production, a pure refrigerant is employed as working fluid. Therefore, the search for a substitute concentrated also on pure substances which preferably should have thermodynamic properties similar to CFC-12. Another possibility for creating a suitable alternative is a mixture of two or more fluids. There are two kinds of mixtures: Azeotropic and zeotropic ones.

Azeotropic mixtures like the long-known R500, R502, and R503 have already been used intensively in other refrigeration applications than domestic. The reason is that azeotropic show the advantageous behaviour of a pure refrigerant since their bubble line and dew line meet at the azeotropic point; this is shown in Figure 3.

Most refrigerant mixtures are zeotropic with a thermophysical behaviour lying between those of the pure fluids. This affects the boiling point, the volumetric capacity, and the flammability which are the main criteria for application in refrigerators. A desired property of a pure fluid to be substituted can be achieved more or less by varying the composition of a zeotropic mixture.

The major differences in the application of pure fluids and azeotropic mixtures on the one hand and zeotropic mixtures on the other hand will be explained using Figure 4 which shows a simplified refrigeration cycle for a zeotropic mixture of the components A and B. The compressor draws cold, low-pressure refrigerant vapour at the circulating composition y_0 and compresses it.

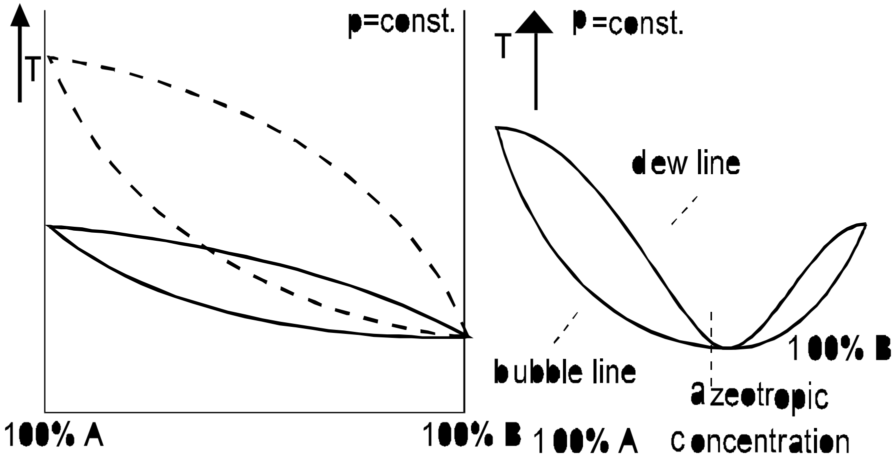
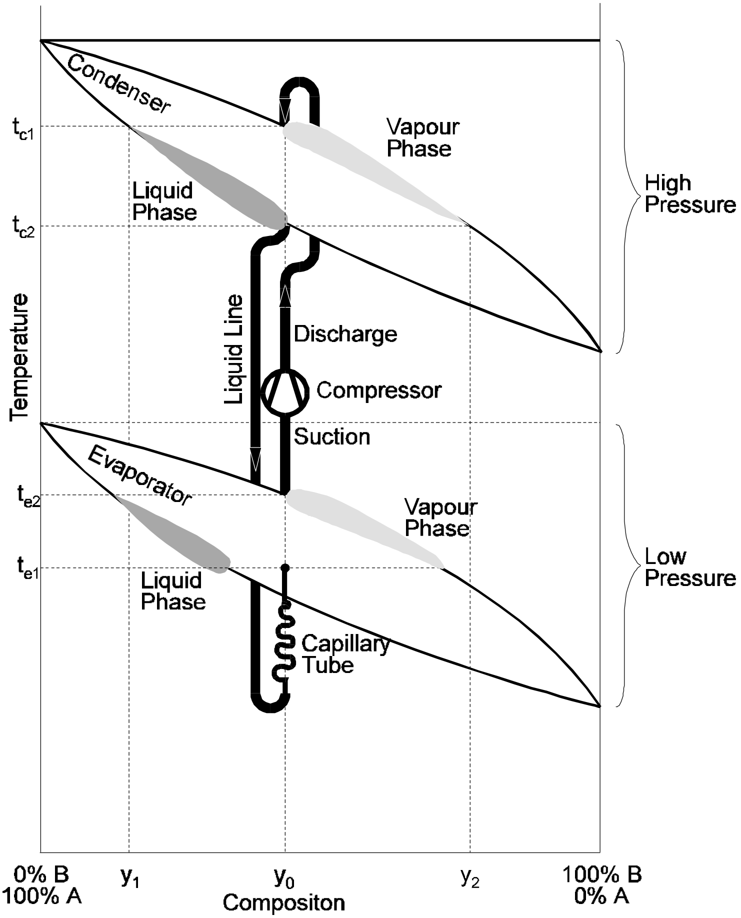


Figure 3: Zeotropic and azeotropic refrigerant mixture

The resulting high-pressure, high-temperature discharge gas then enters the condenser where it first is desuperheated. When the condensation starts, the first liquid drop consists of a composition of y_1. Since the overall composition has to be constant, the composition of the vapour enriches on component B. This process continues while the decreasing amount of vapour is always richer in component B with the result that the vapour as well as the liquid continuously change their composition. The last vapour bubble just before the condensation is complete consists of a composition y_2 while the liquid has reached the original fraction of both components. As shown in Figure 4, the temperature continuously decreases during this condensation process from t_{C1} at the beginning of condensation to t_{C2} at the end of the condensation process. The liquid refrigerant leaving has again the composition of the vapour entering the condenser. It passes through the capillary tube to the evaporator at a reduced pressure and starts evaporation at the lowest temperature t_{E1}. During evaporation the same process than during condensation takes place in the opposite direction: The composition of the decreasing amount of liquid gets poorer in component B while the part of vapour changes from high B-compositions to the composition y_0. Having finished the evaporation at a higher temperature t_{E2}, the gas at the original composition is again withdrawn by the compressor.

Figure 4: Condensation and evaporation of zeotropic refrigerant mixture



In contrast, when using a pure refrigerant or an azeotropic mixture the temperature during evaporation and condensation remains constant and the composition of vapour and liquid phase remains the same and does not change.

Both effects of zeotropic mixtures - the temperature glide and the composition shift during phase change - can be employed advantageously in a refrigeration cycle designed for the use of such a mixture. On the other hand a simple substitution of a pure refrigerant by a zeotropic mixture without proper cycle adaptation or inadequate handling of the mixture may give very favourable results in a refrigerator but it also may result in limited functionality or cause severe damage depending on the design of the application it is used in.

Since there is no suitable pure hydrocarbon with thermodynamic behaviour similar to CFC-12 the German hydrocarbon pioneer Foron started with a mixture of the two fluids which are closest to CFC-12, propane and isobutane. By forming a well-fitting composition, the blend facilitated the further use of the existing CFC-12 compressor with only minor modifications. Later on, Foron converted its compete production to a pure hydrocarbon refrigerant like the other manufacturers had done in the meantime. Foron only utilised a mixture in simple, one-temperature refrigerators. In units with compartments for different temperatures like refrigerator/freezer combinations, a simple replacement by a refrigerant blend may lead to a mismatch of desired temperatures inside the refrigeration cycle during evaporation. This can be overcome either by changing the evaporator design or by using different refrigerant mixture compositions. This would result in various blends of different compositions handled on the market.

In any case, only proper handling during manufacturing and servicing ensures that no demixing occurs when charging the refrigerator. If a significant demixing and thus a composition shift the difference in working fluid behaviour may lead to reduced capacity of the appliance.

All these possible problems related to the use of refrigerant blends may be minor and manageable in A5 as well as in A2 countries. At Foron a mixture was applied for a restricted time in a limited number of high quality units under the conditions of a A2 country. Apart from that, mixtures have not been used in domestic refrigeration. Therefore this matter has never been taken care of and presently still is of no interest in those countries where hydrocarbons are used, which are mainly A2 countries. In the field of small air conditioners which are similar to mass-produced refrigerators in industrial circumstances, the HFC blend R407C has been widely accepted. If as a measure of zeotropic mixture behaviour the temperature difference in the evaporator between the inlet and end of evaporation is used, R407C has for its applications in air conditioning units a temperature glide of 5.3K. For lower temperatures such as refrigerators, this temperature glide would be for R407C 4.9K, for a 50/50 mol% mixture of propane and isobutane 6.3K. Obviously, such a temperature glide can be handled also in refrigeration applications if desired.

Environmental Issues

All man-made activities have some kind of impact on the environment. The history of CFCs shows that even fluids that have been used for several decades may cause severe environmental damage which may remain unnoticed for a long time. This is due to the fact that the chemistry of complex systems like the atmosphere or the stratosphere is still not completely known. In most cases these impacts were only detected when perceptible environmental changes had been noticed.

While this in principle applies for HFCs as well as hydrocarbons when used as refrigerant or blowing agent, it is more likely for HFCs for two reasons: On the one hand, HFCs are like CFCs, artificial substances which do not exist in nature. On the other hand, the amount of hydrocarbons which would be released additionally if hydrocarbons were widely used as refrigerants is still negligible compared with other sources of hydrocarbon releases. But to present knowledge no environmental impact of HFCs apart from global warming has been proven by scientists.

When comparing different refrigerators, their effect on the environment during the production of the appliance and of all its parts, transportation, distribution, use and disposal has to be considered. At present no complete environmental balance exists. In general it is assumed that, apart from energy consumption, production and disposal of blowing agents, refrigerants, and refrigeration oils the environmental effect of refrigerators with vapour compression systems does not vary for different refrigerants. Therefore, only the aspects of the influence of blowing agents and the refrigerants on the environment will be discussed here.

ODP and TEWI of CFC Replacement Fluid Options

Introduction

Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) which are used as refrigerants and foam blowing agents have been the subject of world-wide attention due to their stratospheric ozone depletion. Therefore their use and production was regulated by the 1987 Montreal Protocol for the Protection of the Ozone Layer and the following amendments. In industrialised (Article 2) countries CFCs have already been phased-out while developing (Article 5) countries are allowed to continue the use of CFCs for a 10-year grace period up to 2010. For HCFCs a nearly phase-out deadline has been established for article 2 countries in 2020 with several more stringent national regulations and for article 5 countries in 2040. The phase-out of CFCs and HCFCs as agreed at the Vienna conference in December 1995, the most recent follow-up conference concerning the Montreal Protocol, is presented in Figure 5.

While the production of CFCs has already stopped in industrialised countries, a second environmental effect of refrigerants and refrigeration technology increasingly gains public attention: global warming. Figure 6 illustrates the significant proportional contribution of CFCs to calculated global warming [Fis91]. As shown, the contribution of CFCs to global warming is second only to carbon dioxide (CO_2). CFCs are much more potent on a per molecule basis than CO_2 and some other greenhouse gases, even though the emissions of those gases are larger than CFC emissions by several orders of magnitude. Table 1 provides an overview of the GWPs of selected refrigerants, given for time horizons of 20, 100, and 500 years.

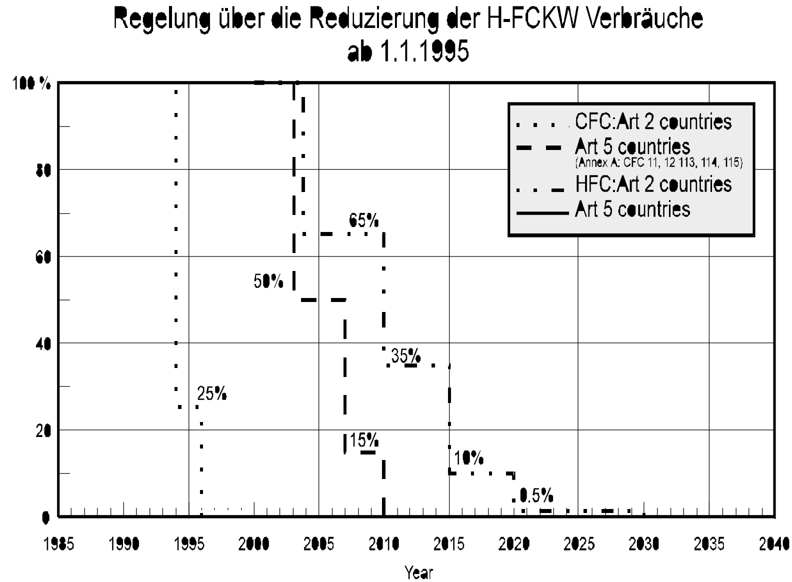


Figure 5: Phase-out scenario for CFCs and HCFCs (Vienna Conference 1995)

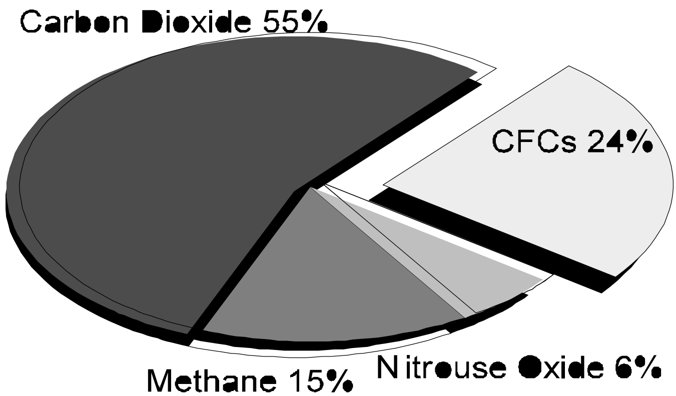


Figure 6: Relative contributions of greenhouse gases [Fis91]

Table 1: ODP and GWP of selected fluids [IPC95]

Fluid	**ODP**	**GWP 20a**	**GWP 100a**	**GWP 500a**
Carbon Dioxide (R744)	0.0	1	1	1
CFC-11	1.0	5000	4000	1400
CFC-12	1.0	7900	8500	4200
HCFC-22	0.055	4300	1700	520
HFC-134a	0.0	3400	1300	420
HCFC-141b	0.11	1800	630	200
HCFC-142b	0.065	4200	2000	630
Ammonia (R717)	0.0	0	0	0
Isobutane (HC-600a)	0.0	3	3	3
Propane (HC-290)	0.0	3	3	3
Cyclopentane	0.0	3	3	3

When looking for an alternative refrigeration technology it must be taken into account that even the artificial, chlorine-free halogenated substitutes for CFCs contribute considerably to the global warming if emitted to the environment. By simply replacing CFCs by HCFCs and hydrofluorocarbons (HFCs), the proportional impact on global warming of these fluids would change as presented in Figure 7 [Fis91].

Refrigerant/ blowing agent	European Model		US Model		Indian Model		Near future Europ. Model	
	indirect	direct	indirect	direct	indirect	direct	indirect	direct
CFC 12/ CFC 11	66%	34%	68,6%	31,4%	61,2%	38,8%	43%	67%
HFC-134a HCFC-141b	92,2%	7,8%	94,2%	5,2%	89,5%	10,5%	91,4%	18,6%
HFC-134a/ cyclopentan	96,0%	4%	98,1%	1,9%	90,5%	9,5%	92,5%	7,5%
isobutane/ cyclopentane	99,98%	0,02%	99,92	0,08%	99,99%	0,01%	99,95%	0,05%

Figure 7: Contribution of HCFCs and HFCs to global warming as replacement of CFCs [Fis91]

The energy consumption of refrigeration systems affects CO_2 emissions because of the link between use of electricity and fossil fuels used to generate it. The direct chemical greenhouse gas emission effect must therefore be seen, not in isolation, but together with the indirect energy-related CO_2 emissions caused by the systems in which they are used. For convenience in combining both effects, the direct (chemical emission) effect is expressed as equivalent carbon dioxide. This equivalent CO_2 direct effect can readily be combined with the indirect (energy related) CO_2 emissions. The combined or total effect is termed **T**otal **E**quivalent **W**arming **I**mpact (TEWI).

In a former study concerning TEWI [Fis91] which focused on Europe, North America and Japan the major findings regarding refrigerators/freezers were that refrigerators/freezers show only 2-3% direct impact with a variety of HFC refrigerants and HCFC foam blowing agents, and that once HCFC/HFCs have replaced CFCs, the only way to effect further significant reductions in TEWI is through energy efficiency improvements.

In another study concerning the global warming impact of refrigerators in Malaysia [Bin93] the authors came nearly to the same conclusion. The impact due to refrigerant and insulation foaming gas was calculated to 21% for CFCs and less than 2% for HFC and HCFC alternatives.

Despite these findings the Western European, especially the German refrigerator industry has performed a second conversion from HFC to hydrocarbons based on global warming concerns of the public and environmental groups. In the competition between the HCFC/HFC technology as applied in North America and Japan on the one hand and hydrocarbon technology as used in Europe on the other hand the effects of global warming and TEWI again have been brought into discussion.

The objective of the study described in this chapter is to develop representative indications of the TEWI of available and proven CFC-replacement options in the area of domestic refrigerators and freezers while not-in-kind technologies will not be considered. Therefore, the focus is on the application of tetrafluoroethane (HFC-134a) and isobutane as refrigerants to replace dichlorodifluoromethane (CFC-12) and dichlorofluoroethane (HCFC-141b) and cyclopentane as foam blowing agents to substitute trichlorofluoromethane (CFC-11). In addition to the study cited above [Fis91] this report will also include refrigerators of developing countries in order to take these rapidly growing markets into account as well as a near future model to evaluate the effect of upcoming energetic improvements on TEWI.

In a second step the potential for further TEWI reduction - the direct as well as the indirect part - is evaluated. A first attempt is made to compare the cost effectiveness in relation to TEWI savings of the indirect part by increasing the energetic efficiency and the direct part by changing the working fluids. Also the limitations concerning further reduction of both parts will be elaborated.

This chapter of the study is, wherever information was available, international in its scope under special consideration of the USA, Western Europe and India (representing developing countries) and takes into account significant differences in present appliance design, climatic conditions, and sources of energy.

TEWI Calculation for Refrigerant/Foam Blowing Options

Basis

The Total Equivalent Warming Impact (TEWI) reflects the lifetime contribution of an appliance to the global warming. It is expressed in terms of an equivalent mass of carbon dioxide released. This contribution of any appliance depends on the direct effects of the chemicals used as refrigerants and blowing agents and also on the energy consumed by the appliance over its useful life, because the generation of electricity by combustion of fossil fuels is connected with the emission of CO_2. Hence, the calculation of TEWI for refrigerators has to take into account the GWP of the chemicals used as refrigerant and foam blowing agent as well as the energy consumption of the appliance and the generation of electricity. As the majority of all existing appliances employs the vapour compression cycle, only these systems were considered here. The TEWI is then calculated by:

$$TEWI\left[kgCO_2\right] = m_{refr} \cdot GWP_{refr} \cdot z + m_{ba} \cdot GWP_{ba} + t \cdot E \cdot f$$

with:	*TEWI :*	Total Equivalent Warming Impact in $kg\ CO_2$
	m_{refr} :	mass of refrigerant in *kg*
	GWP_{refr} :	Global Warming Potential of refrigerant in $kg\ CO_2$
	z:	number of charges of refrigerant during service life
	m_{ba} :	mass of blowing agent in *kg*
	GWP_{ba} :	Global Warming Potential of blowing agent in $kg\ CO_2$
	t:	service life of appliance in *years*
	E:	annual energy consumption of appliance in *kWh/yr.*
	f:	CO_2-factor of energy conversion in $kg\ CO_2/\ kWh_{el}$

Taking only the refrigerator itself into consideration, it can be seen from the formula that the direct part can be reduced to zero by selection of proper working fluids or a different cooling technique while the indirect part only can be reduced to a specific amount due to the minimum energy consumption defined by the Carnot cycle.

Models and Assumptions

Since the average refrigerator used in the different parts of the world varies, depending on climate, lifestyle and national energy policy and also the data for the calculation of the indirect part of TEWI differs, four models have been defined as examples following a study on behalf of the US Department of Energy (DOE) and the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) [Fis91]:

A typical US refrigerator/freezer as defined in [Fis91],
A typical European refrigerator/freezer as defined in [Fis91],
A typical Indian refrigerator of 165 l volume with about 80% market share in India, representing developing countries´ refrigerators,
A near-future European refrigerator/freezer based on the present model which will be produced in a few years to meet the coming energy standards of the European Union. The main difference is a larger foam volume of this appliance resulting in a higher mass of blowing agent and better insulation. Therefore, the energy con-

sumption of this near future appliance will be lower than for the baseline European refrigerator.

Table 2 shows the baseline data for the four refrigerator models defined for the different regions.

Table 2: Baseline data of refrigerators

	North America	**Europe**	**India**	**Future European Model**
Size litre	522.0	230.0	165.0	230.0
Annual energy consumption kWh/yr.	918.0	500.0	438.0	256.0
Charge CFC-12 kg	0.170	0.140	0.140	0.140
HFC-134a (=90%)kg	0.153	0.126	0.126	0.126
hydrocarbon (=40%) kg	0.068	0.056	0.056	0.056
Mass insulating foam kg	6.750	3.360	2.250	6.000
CO_2-factor kg CO_2/kWh_{el}	0.672	0.513	1.650*	0.513
Service lifeyears	15.0	15.0	25.0	15.0
Number of refrigerant charges in life	1.0	1.0	5.0	1.0

* assuming electricity generation in coal fired power plants and transmission losses with overall energy efficiency of 20 %

As shown in Table 2 the average size of a refrigerator varies over a wide range from 165 litre in India to 522 litre in the US. Values were taken from [Fis91] and [INF96a].

The values for energy consumption were taken from [Fis91] and [Ind93]. The energy consumption of the appliances is assumed to be constant using different refrigerants and, in case of a change in foam, was estimated to be proportional to the thermal conductivity of the foam given in Table 3.

Table 3: Foam data [Jef96]

Blowing agent	Weight fraction blowing agent %	Average core density kg/m^3	Thermal conductivity [W/m*K]
CFC-11	13.7	28.5	0.0171
reduced CFC-11	5.9	32.0	0.0190
HCFC-141b	6.9	35.9	0.0192
Cyclopentane	4.5	36.8	0.0196

The masses of refrigerant and blowing agent in the appliance depend on the size of the appliance, the insulation thickness, and on the refrigerants and blowing agents themselves. The charge of an alternative refrigerant relative to the charge CFC-12 in the corresponding baseline unit is assumed to be directly related to the refrigerant's density. The average charge of HFC-134a will be about 90% of the baseline charge of CFC-12 while the charge of a hydrocarbon as an alternative will only be about 40% of the charge of CFC-12.

The average baseline European refrigerator using CFC is insulated with foam containing 5.9 wt% of CFC-11, while the average US and Indian refrigerator uses CFC-11 as sole blowing agent for the foam containing 10.3 wt% of CFC-11. The mass of the foam necessary for the various blowing agents in the appliance has been computed from the mass of CFC-11 foam given in [Fis91] using the density as listed in Table 3 and assuming the volume of insulting foam in the refrigerator to be constant. In this way no design changes are necessary. With this data the mass of the blowing agent itself has been calculated using the weight fraction of blowing agent listed in Table 3.

The CO_2 factors for the different regions account for different electricity generating processes in the regions. Given values are 0.513 $kg\ CO_2/kWh_el$ for Europe and 0.672 $kg\ CO_2/kWh_{el}$ in North America [Fis91]. For India, as a developing country, no values were found. It was assumed that carbon dioxide emission from electric power generation is significantly higher than for the other regions. This accounts for generation by coal-fired power plants and transmission losses with an overall efficiency of about 20%.

The service life of the appliance is about 15 years for Europe and North America. Here, the refrigerators are generally not serviced during their lifetime and one refrigerant charge is emitted. For India the service life using CFC-12 at present is assumed to be 25 years. Due to hard working conditions, high ambient temperaures, and high voltage fluctuations refrigerators in India have to be repaired several times with one charge released to the atmosphere each time since recovery equipment will be to expensive for the unorganised service sector. A period of five years has been assumed for these maintenances which results in five charges during the life time. The same service intervals and the same number of charges are assumed for hydrocarbons as alternative refrigerant. For HFC-134a, current knowledge about existing servicing quality and required servicing level using this refrigerant led to the assumption of shorter maintenance periods. Therefore, until the first repair of the refrigerator after production the same period (5 years) as for the other refrigerants has been assumed while intervals of 3 years were supposed for the following repairs.

While for the refrigerators, the blowing agents, and the refrigerants the same data has been used in the AFEAS report [Fis91] and in this work whenever possible, the major difference between both is the integration time horizon for the calculation of the GWP. In the AFEAS study a 500-year time horizon is preferred, while here the time horizon has been set at 100 years as according to the present state of knowledge this value balances out the effect of these substances compared to CO_2 better and is used also by governmental organisations.

Results

For each model calculations of the TEWI in terms of kg CO_2 were made for different combinations of refrigerant and blowing agent. The results of the calculations carried out are shown in Table 4 for the four main foam blowing/refrigerant options used today: CFC-11/CFC-12, HCFC-141b/HFC-134a, cyclopentane/HFC-134a, and cyclopentane/isobutane. The value of the absolute TEWI in kg CO_2 for each combination is shown first, followed by the direct and indirect part of the TEWI as absolute and relative values. The results are also presented graphically in Figure 8.

The results prove that the direct contribution to TEWI is significantly reduced by the phase-out of the refrigerant CFC-12 and the foam blowing agent CFC-11 as it is stated in the AFEAS report [Fis91]. But when using HFC-134a as refrigerant and HCFC-141b as foam blowing agent the direct part is still in the range of 5-10% and reaches 18.6% in case of the future European model. Even if the HCFC-141b has been replaced by cyclopentane the direct effect caused by the refrigerant HFC-134a reaches values of 9.5% for the Indian model and 7.5% for the future European model while for the present European model it is only 1.9%.

Table 4: TEWI contribution of refrigerator models in kg CO_2

Refrigerant Foam	**CFC-12 CFC-11**		**HFC-134a HCFC-141b**		**HFC-134a cyclopentane**		**Isobutane cyclopentane**	
Model	direct	total indirect	direct	total indirect	direct	total indirect	direct	total indirect
US		13484		10956		10806		10607
	4231	9253	566	10390	200	10606	1	10606
	31.4%	68.6%	5.2%	94.8%	1.9%	98.1%	0.0%	100.0%
European		5828		4215		4133		3970
	1981	3848	327	3888	164	3969	1	3969
	34.0%	66.0%	7.8%	92.2%	4.0%	96.0%	0.0%	100.0%
Indian		17719		13605		13736		12427
	6879	10841	1433	121	1311	12425	1	12425
	38.8%	61.2%	10.5%	89.5%	9.5%	90.5%	0.0%	100.0%
Near future European		4568		2441		2193		2029
	2602	1966	455	1987	165	2028	1	2028
	57.0%	43.0%	18.6%	81.4%	7.5%	92.5%	0.1%	99.9%

Besides the relative contribution of the direct parts the absolute numbers should be looked at. Also if already HFC-134a is used as refrigerant the contribution of the Indian model exceeds the US and European models by a factor of 4-6. In the same way the TEWI effect of the US model is significantly larger than of the European model while the relative values are smaller due to the high energy consumption of this model. The only way to achieve a negligible direct global warming effect for all models is the application of hydrocarbons as refrigerant and blowing agent.

Therefore the conclusion of [Fis91] cited above that energy efficiency improvements are the only way to effect significant reductions in TEWI has been disproved for all models except the European one when using cyclopentane as foam blowing agent. Another interesting fact already stated by Jürgensen [Jue95] is the growing relative contribution of the direct effect due to stronger energy regulations to be expected in the USA and Europe.

Cost Aspects

Introduction

The reduction of the contribution of refrigerators to global warming should aim at reducing the direct as well as the indirect part. A reduction of the direct part means the substitution of the fluids used as refrigerants and foam blowing agents while a decrease of the indirect part has to be achieved by reducing the energy consumption of the refrigerator. Often it is stated that a reduction of the indirect part by a decrease of the energy consumption is more cost effective in terms of TEWI reduced per US$ than of the direct part substituting HCFCs and HFCs by hydrocarbons. For further investigation of this statement one should look at two separated aspects: Foam and refrigerant.

On the foam side there are currently only two mature replacement options for CFC-11 as blowing agent: HCFC-141b and cyclopentane. Since HCFC-141b contains chlorine it contributes to ozone depletion and therefore is only an interim solution. Cyclopentane at present is the only long-lasting and proven substitute for foam blowing. Other, also non-flammable blowing agents are under development but information, especially on the costs regarding these options in industrial use, is not available. Therefore the foam will not be discussed further in this chapter.

For the refrigerant the options HFC-134a and isobutane are discussed. Since only very limited information regarding the costs is available for the refrigerant side, the following comparison will focus mainly on general aspects in the comparison of HFC-134a-isobutane related to the costs of reducing TEWI in refrigerators. Only for the compressor as the most important part of the refrigeration cycle a few numbers regarding the costs and energy efficiency were available and will be presented in the next section.

Principle of Costs vs. TEWI-Reduction

The principle relationship between energy efficiency and costs is shown in Figure 9 where the abscissa showing the energy efficiency is also representing the TEWI reduction of the indirect part. Starting from a very low efficiency basis, an improvement can be achieved by very simple and cheap measures. The next step to get the same amount of improvement will cause more effort and costs while the third step again causes even more costs.

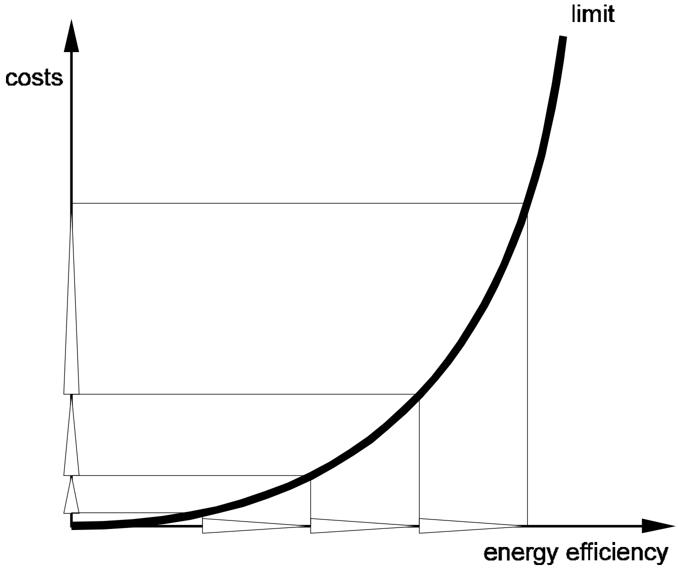


Figure 9: Principle relationship between energy efficiency and costs

As an example for this cost raise some available data for compressors is presented in Table 5. To reduce the energy consumption of a refrigerator by about 10% in a first step by the change from a standard to a medium efficiency compressor, additional compressor costs of 10 - 14% are necessary. A second improvement of 10 % would require a newly developed high efficiency compressor with again additional costs of 20 - 24% over the medium efficiency compressor.

Table 5: Compressor data of types with various efficiencies

compressor type	**relative price**	**standard efficiency**	**rel. energy savings in refrigerator**
standard efficiency	100	0.98	0%
medium efficiency	110 - 114	1.06 - 1.10	10%
high efficiency	130 - 138	1.25	17 - 22 %

The limit for energetic improvements is given by the Carnot cycle, a reduction to zero TEWI therefore cannot be achieved for the indirect part (for a constant CO_2-factor of electricity generation).

Depending on the situation in the various countries the present position on this curve differs. Caused by quite stringent energy regulations, the US seems to be positioned in an already steep part where a further increase in energy efficiency requires a significant effort. Radermacher [Rad96] expects that the upcoming tightening of the US energy regulation will be the last one which can be mastered in the conventional way, e.g. by improving the compressor or increasing the heat exchanger area. In most developing countries the energy consumption of refrigerators is at present not of importance, therefore they are positioned in the flat part of the curve.

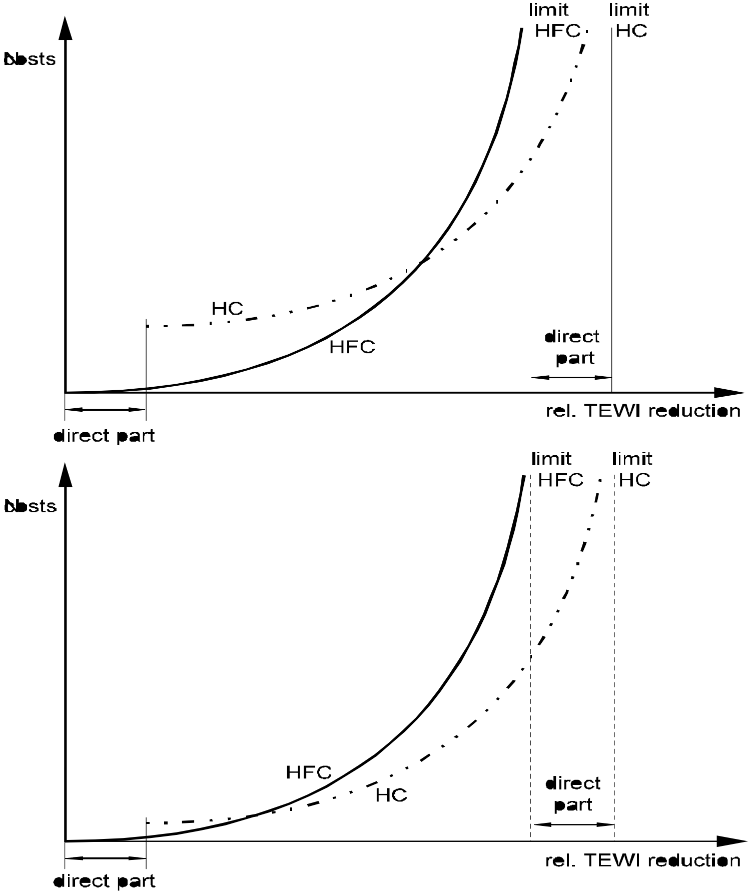


Figure 10: Cost comparison HFCs - hydrocarbons versus energy efficiency

The principle course of this curve is valid for HFC-134a as well as isobutane as refrigerants although it is specific for each refrigerator model. Only the starting point of the curve for isobutane differs from HFC-134a due to the cost difference and the direct part of TEWI already eliminated by the use of the hydrocarbon. There are two views about the starting point. Both opinions are expressed in Figure 10. Some manufacturers claim that there are significantly higher costs for hydrocarbon refrigerators (Figure 10 top) while other manufacturers report no or only marginal additional costs (Figure 10 bottom). On the left side from the point of intersection it is economically advantageous to reduce the TEWI contribution by improving the energy efficiency of the refrigerator while on the right side the conversion to hydrocarbons is more cost effective to achieve the same reduction in terms of TEWI.

Interpretation and Outlook

Depending on the present position on the curve as explained before, the most economic way to reduce TEWI can be found. It is assumed that the US and the most efficient European models are at least near the intersection point where a reduction of TEWI by the conversion from HFCs to hydrocarbons is more cost effective than further improvements in energy efficiency. Table 4 shows a direct part of 18.6% for the future European model. In order to achieve a reduction of the indirect part of the same amount, the energy consumption has to be decreased by additional 23% which will be very costly or impossible on this already optimised refrigerator models.

Another aspect which should be taken into consideration is the expected tightening of energy regulations in the USA and the EU. This will lead to the development of refrigerator models of improved efficiency while the direct part of TEWI for these models increases. In case the energy efficiency is already close to the optimum, a further significant reduction of the TEWI contribution can only be achieved by the use of hydrocarbons, thus decreasing the direct part of TEWI.

For developing countries positioned in the flat range of the curve it seems to be advantageous to use HFCs but two aspects have to be noticed:
For this evaluation only the direct costs related to the production and the TEWI have been considered, other merits and demerits of both technologies (servicing, availability, etc.) are not addressed in this chapter.

The course of the curve depends on many influencing factors and varies at least for each manufacturer. The absolute amount of the additional costs for one technology compared to the other can be significant or marginal.

Therefore, especially in developing countries, the aspect of cost efficiency vs. TEWI cannot be separated from other important factors for coming to a decision about the technology to choose.

Other Environmental Aspects of CFC Replacement Fluids

Two other possible environmental effects of CFC replacement options besides ozone depletion and global warming are currently under evaluation and will be discussed hereafter: The formation of trifluoroacetate (TFA formation) and the ozone creation potential.

TFA-Formation

The atmospheric degradation of the fluids HFC-134a, HCFC-123 and HCFC-124 is expected to produce trifluoroacetate (TFA), which is removed from the atmosphere mainly by rain. The hydrolysis of these acetyl halides in cloud water is expected to form trifluoroacetic acid. The global average TFA concentration in rain water for the year 2010 is estimated to be well below the concentrations thought to inhibit plant growth. But a modelling analyse indicates that in conditions of high evapotranspiration, TFA could attain appreciable concentrations in the local surface waters of seasonal wetlands within a few decades, if removal by degradation and seepage is limited [Tro95].

The database available to calculate the possible concentration of trifluoroacetic acid in the surface water as well as to estimate the effect on nature is presently not sufficient. Even in a study [Tro95] about the potential accumulation of this acid in certain areas the scientists had to presuppose several disadvantageous conditions to reach an effective concentration. A recent paper has shown that TFA is already present in the environment at levels considerably exceeding those that could be achieved from current HFC-134a emissions. Therefore a disapproval of the three effective fluids (HFC-134a, HCFC-123and HCFC-124) cannot be based on present knowledge about the TFA formulation.

Photochemical Ozone Creation Potential

In recent months the creation of ground-level ozone caused by **V**olatile **O**rganic **C**ompounds (VOC) and oxides of nitrogen in the presence of sunlight has been put in relation to hydrocarbons used as refrigerants. This tropospheric ozone is a primary constituent of urban smogThe primary sources of VOCs and oxides of nitrogen are automobile and industrial emissions. Other sources of VOCs include dry cleaners, bakeries, and consumer products such as paints, insecticides, and household cleaners. Of the hundreds of different VOC compounds emitted, each has a different impact on ozone levels.

In order to compare the effect of different VOCs on ozone different ozone reactivity scales were defined. These calculation methods depend very much on presupposed assumptions since a common agreement about the approach to be used for calculation does not exist. An interesting approach is called the Incremental Reactivity describing the change in ozone formed caused by adding a VOC to the initial scenario. Some values of hydrocarbons are listed in Table 6. For further information see [Car94, UN91].

Table 6: Photochemical Ozone Creation Potential [Car94]

Fluid	MIR	Ozone Yield			Integrated Ozone			Int’d Ozone >90 ppb		
		MIR	MOR	EBIR	MIR	MOR	EBIR	MIR	MOR	EBIR
methane	0.015	0.005	0.008	0	0.004 0.006	0.005		0.004	0.006	0.008
ethane	0.25	0.079 0.18	0.140		0.061 0.088	0.078		0.069	0.091	0.109
propane	0.48	0.16 0.33	0.27		0.128	0.17	0.1	0.139	0.19	0.23
n-butane	1.02	0.33 0.70	0.57		0.26	0.33	0.3	0.29	0.38	0.44
i-butane	1.21	0.39 0.80	0.63		0.33	0.43	0.5	0.36	0.48	0.60
n-pentane	1.04	0.33 0.71	0.58		0.29	0.37	0.4	0.31	0.41	0.48
i-pentane	1.38	0.44 0.93	0.74		0.38	0.48	0.5	0.41	0.54	0.63
c-pentane	2.4	0.76 1.46	1.19		0.67	0.80	0.8	0.71	0.89	1.01

MIR: Maximum Incremental Reactivity.
MOR: Maximum Ozone Reactivity.
EBIR: Equal Benefit Incremental Reactivity.

In the USA, the Environmental Protection Agency (USEPA) has published a list to control the emissions of VOCs in an approach to reduce photochemical (O_3) and other oxidants (O_x) in the ambient air based on unilateral control of one of its precursors. For purposes of determining compliance with emission limits a standard test method has been defined. The EPA divided VOCs into three classes based on three criteria: Photochemical reactivity, role in stratospheric ozone depletion, and direct health effects. The first class includes those VOCs which by virtue of their negligible reactivity could be exempt from regulation. The second class includes those VOCs which have low photochemical reactivity but their control has lower priority than that of the more reactive compounds (Table 7).

The third class, encompassing all VOCs other than those in the first and second class includes those VOCs the control of which has relatively high priority [EPA92].

Table 7: Classification of VOCs [EPA92, extract]

Class I **VOCs of Negligible Photo-chemical Reactivity**	**Class II** **VOCs of 'Low' Photo-chemical Reactivity**	**Class III** **VOCs of 'High' Photochemical Re-activity**
Methane, Ethane CFC-11, CFC-12, CFC-13, CFC-22, CFC-113, CFC-114, CFC-115 HCFC-123, HCFC-141b, HCFC-142b, HFC-134a, HFC-23	Propane Acetone Methanol Acetylene	All VOCs other than those in Class I and Class II

While the hydrocarbons methane, ethane, and propane are listed in the classes I and II, the emission of butanes and pentanes is restricted. Due to this classification, the use of these substances as propellant is restricted, while the use of these fluids as blowing agent is currently under investigation and the use as refrigerant is not discussed presently due to the small amounts emitted by refrigeration systems.

If the emission of hydrocarbons used as blowing agent or refrigerant will be restricted in the future, the avoidance of emissions from the refrigeration sector will only cause the same procedures of refrigerant reclaim already requested for CFCs, HCFCs and HFCs today.

Conclusions

The TEWI effect, combining energy consumption related emissions of carbon dioxide and their effect on global warming with the direct effect caused by emissions of the fluids used in the refrigerator, is a value for the greenhouse warming caused by an appliance over its lifetime. It was investigated if there is hard evidence that for given costs, HFC/HCFC technology could achieve a higher TEWI reduction by improving energy efficiency, thus being more environmentally efficient. Without being able to provide exact numbers, the investigation showed that the direct GWP of the fluids contributes significantly to the TEWI. In addition, the TEWI reduction is from a certain energy efficiency of the refrigerator onwards more cost effective to achieve using hydrocarbons than improving the energy efficiency. Finally, the minimum TEWI can only be achieved using hydrocarbons.

From the environmental side, the blowing agent HCFC-141b is not favourable at all because it contains chlorine, is therefore ozone depleting and restricted under the Montreal Protocol. In addition, there is also a significant greenhouse warming effect. New fluids, HFC-245ca and HFC-365mfc, are presently under development, but quantities and experience are not available yet. It is not known if these fluids will be actually produced and supported as a blowing agent.

HFC-134a has no ODP, but a relatively high GWP, while the hydrocarbons have zero ODP and a negligible GWP. Information that HFC-134a causes TFA or hydrocarbons in refrigerators would contribute to low level smog do presently not seem to be balanced and unbiased enough to be considered as negative for one of the fluids.

If TFA turns out to be an environmental problem, it will be a long-term, global one, which should be avoided from the viewpoint of the precautionary principle and the sustainable development principles set in Rio.

Foam Blowing Agents

This chapter as well as chapter 10.3 is consisting of material from the presentation „Properties of Cyclopentane Blown Foam“, presented at the ECO-REFRIGERATION Conference on Hydrocarbon Fluids in Domestic and Commercial Refrigeration Appliances“ by Dr. Mike Jeffs, ICI Belgium /Jef96/. Review comments received concerning this text were kindly evaluated by Dr. Jeffs and changes were made based on his suggestions.

Polyurethane rigid foam has achieved almost 100% share of the market for insulation materials in household refrigerators and freezers since its introduction in Europe in the late 1950s to replace other insulators, mostly fibreglass. This has been achieved because of the very significant advantages which it offers in the manufacturing process and end product properties.

The composition of the foam has changed during this period. MDI is now the dominant isocyanate and many types of polyols have and are being used. However, for more than thirty years the universal blowing agent was CFC-11. It gave unrivalled insulation properties and had no apparent negative features until its role, with other CFCs, in ozone depletion was realised and its phase-out proscribed by the Montreal Protocol and other, national, controls.

There has been a five year period of uncertainty during which many replacement blowing agent options have been evaluated. Several HCFCs have been extensively evaluated and some, notably HCFC-141b, are in use. However, cyclopentane was introduced in German refrigerator factories in 1993 and has since become the dominant blowing agent in Europe and its use in spreading rapidly to both A2 and A5 countries world-wide. This acceptance is based on its environmental properties of zero ODP and very low GWP which offer the manufacturers of appliances a period of stability. The technology offers a one step change to a durable solution and where A5 country enterprises can learn from the experience of those in A2 countries.

In the following section the properties of cyclopentane based foams in comparison with CFC-11 and with the other options are described. It is indicated that precautions must be taken because of the flammability of cyclopentane. These precautions are described in detail in another source [Gar96].

It will also be made clear that the technology is still evolving and there will be improvements in the properties of cyclopentane based as well as alternative options based foams and refinements in the composition of the blowing agent itself. The application of vacuum panels and the potential use of liquid HFCs will also be discussed.

Technical Requirements of Polyurethane Rigid Foams and Blowing Agents

Modern refrigerators and freezer designs rely heavily on the properties of the insulating foam which is, in turn, dependent on the characteristics of the blowing agent.

The prime requirement is to provide **long term insulation** to reduce the energy consumption of the appliance whilst maintaining the contents at the required temperature and to prevent moisture condensing on its outside surfaces. The foam also provides **strength** and **dimensional stability** to the structure allowing the use of thinner gauge steel and plastic (liners) with considerable cost and weight savings. These properties must be long lasting so that the appliance has a useful life of 20 years or more.

The processing properties of the foam are critical in the cabinet manufacturing stage. The reacting foam has to flow throughout the cabinet in a minimum time so that product quality and production rates are maintained.

This short statement indicates the critical technical aspects for the evaluation of any new foam technology such as one based on a different blowing agent. These are complementary to requirements of safe operation in the factory and meeting contemporary environmental standards.

Blowing Agent Options

This section covers the blowing agent options which have been considered during the CFC replacement programme by appliance manufacturers and their suppliers. The principal characteristics of these are shown in Table 8.

Table 8: Blowing Agents - Characteristics

	CFC-11	**HCFC-22/ HCFC-142b**	**HCFC-141b**	**HFC-134a**	**Cyclo-pentane**
Chemical formula	$CFCl_3$	$CHClF_2$/ CH_3CClF_2	CH_3CCl_2F	CH_2CFCF_3	$(CH_2)_5$
Molecular weight	137	86/100	117	102	70
Boiling point (°C)	24	-41/-10	32	-27	50
Gas conductivity (mW/mK at 10°C)	7.4	9.9/8.4	8.8	12.4	11.0
Flammable limits in air (vol. %)	None	None/ 6.7-14.9	7.3-16.0	None	1.4-8.0
TLV or OEL (ppm)	1000	1000/1000	500	1000	600
ODP	1.0	0.055/0.065	0.11	0	0
GWP (100 yr. ITH)	3400	1700/2000	630	1300	3

In traditional technologies CFC-11 has been used at concentrations of between 12 and 17% by weight of the polyurethane foam chemicals. Technologies in Europe and those based on European technologies used concentrations in the range of 12-14% by weight. In North America and Japan concentrations in the range 15-17% have been the norm in order to optimise insulation values. Most developing country technologies are of European origin, hence using CFC concentrations at the lower end of the range.

The reduced CFC technology option is normally based on a CFC-11 concentration of 6-7% by weight. The common definition of <2.5 g/l equates to 7 to 7.5% by weight CFC-11. Reduced CFC technology is based on increasing the amount of CO_2 co-blowing by increasing water level in the formulation. This gives increased CO_2 generation through the water isocyanate reaction. This technology has been a useful interim measure but is now outdated because of the availability of cyclopentane and other technologies.

The mixed HCFC-22 / HCFC-142b option has been developed to counteract the comparatively rapid foam thermal conductivity ageing characteristics of HCFC-22, if used alone, and is normally used at a 40/60 molar ratio. This ratio negates the flammable nature of HCFC-142b. This option is used by very few manufacturers and some in Europe which used it as an interim step have now fully converted to cyclopentane.

HCFC-141b has been a leading contender and is widely used in North America. Its comparatively high ODP of 0.11 has resulted in its replacement in other areas by cyclopentane. This is despite its good initial thermal conductivity.
HFC-134a was used for a short time in Europe before being replaced by cyclopentane.

The use of CO_2 alone is not viable for domestic refrigerators and freezers because of a comparatively high initial foam thermal conductivity which itself would require unit redesign and, more importantly, the rapid ageing of the foam, even with the protection of plastic liners, to wholly unacceptable values.

Cyclopentane Foam Properties

Since their introduction in 1993 polyurethane rigid foam systems designed for use with cyclopentane are now available from several suppliers although, arguably, the most highly developed are available from the main European suppliers who have been operating in this highly competitive market.

Hydrocarbon foam technology is comparatively young and is still evolving. The main development areas are

- Reduction of foam density the first cyclopentane foams to be commercialised had to have a foam density up to 15% higher than had been used with CFC-11 based foams. This has imposed a considerable cost penalty and has been due to the solubility of the cyclopentane in the foam matrix causing a loss of mechanical strength. This had to be compensated by increasing the foam density to ensure freedom from foam shrinkage. The development routes include optimisation of the foam strength through choice of polyol structure and the modification of the blowing agent to include n- or iso-pentane in a blend or, more radically, replacement of cyclopentane by a n/iso pentane blend. This latter solution has a negative effect on thermal conductivity, at least, at temperatures of 10°C or higher.
- Reduction of thermal conductivity - Table 8 indicates that the vapour thermal conductivity of cyclopentane is higher than for CFC-11. In fact, all the alternatives are inferior to CFC-11 in this respect. This effect is transposed through to the thermal conductivities of the respective foams. Various routes exist to

ameliorating this effect. These include the optimisation of cell structures to obtain smaller cells and hence reduce the transfer of heat by radiation.

- The related phenomenon of the condensation of cyclopentane at low temperatures can affect the thermal conductivity of the foam at lower, for example, freezer operating temperatures. This, in turn, can be ameliorated by using blends with iso- or n-pentane which can increase the vapour pressure in the cells.

A range of foam systems are available to meet the needs of manufacturers of domestic appliances. Table 9 lists the formulation and the key parameters of three cyclopentane based systems in comparison with controls based on CFC-11, reduced CFC-11 and HCFC-141b. Table 10 lists the foam properties of the same systems.

All the data displayed are for commercially used formulations. The three cyclopentane based systems are optimised for:
- thermal conductivity - Formulation 4
- demould time - Formulation 5
- low density and low viscosity - Formulation 6

Table 9: Foam Systems Formulation and Processing Parameters

Formulation No. Blowing Agent	**Units**	**1 CFC-11**	**2 Reduced CFC-11**	**3 HCFC -141b**	**4 Cyclopentane**	**5 Cyclopentane**	**6 Cyclopentane**
Polyol	Pbw	100	100	100	100	100	100
Blowing agent	Pbw	36	15	18.7	11	12	13
Isocyanate	Pbw	126	140	154	135	161	138
Reaction tmes							
cream	s	7	5	9	5	5	5
string	s	53	45	65	43	45	40
tack free	s	75	70	105	68	70	58
Free rise density	kg/m3	20.6	22.0	22.4	25.0	25.0	22.6
Brett							
200’20’5cm	kg/m3	29.6	31.0	34.2	35.0	35.5	33.5
- minimum fill	mm	50.9	50.8	50.9	50.8	50.5	50.7
- JDT 10% OP, 4 min	from 50						

Table 10: Foam Systems Typical Foam Properties

Formulation No. Blowing Agent	Units	1 CFC-11	2 Reduced CFC-11	3 HCFC -141b	4 Cyclo-pentane	5 Cyclo-pentane	6 Cyclo-pentane
Average core density	kg/m^3	28.5	32.0	35.9	36.8	37.0	35.1
Thermal conductivity at 10°C	mW/m K	17.1	19.0	19.2	19.6	20.0	20.2
Compressive strength at 10%	kPa	150	149	180	234	241	185
Dimensional stability	% vol. change						
-25°C		< 1	< 1	< 1	< 1	< 1	< 1
+100°C		< 1	< 1	< 1	< 1	< 1	< 1
Closed cell content	%	95	94	95	96	96	95
Cell size	µm	250	238	180	170	182	180

These effects are evident in the properties displayed in Tables 9 and 10. Formulation 4 has a foam initial thermal conductivity only 3% above that of Formulation 2 reduced CFC-11 which it is designed to replace. Formulation 5 shows, through the Brett mould data, curing or jig dwell time performance equal or superior to those of CFC-11 based formulations. Formulation 6 shows a step in the reduction of the foam density with a density increase of just under 10% relative to that of the reduced CFC-11 formulation compared to a density increase of 15% for Formulations 4 and 5.

The HCFC-141b based formulation shows the low foam initial thermal conductivity in keeping with its vapour phase conductivity being closest to that of CFC-11.

The above properties were obtained with ’’pure’’ grade cyclopentane (> 95% cyclopentane). Experience has shown that the difference in overall performance with technical grade cyclopentane (about 70% cyclopentane) is very small. The change in thermal conductivity is typically less than 0.5 mW/mK.

Ageing Phenomena

Domestic refrigerators and freezers should have a service life of 20 years or more. Unit failure caused by foam defects could arise from either loss of insulation value or shrinkage / dimensional instability. These faults could take 10 or more years to manifest themselves - a far longer time scale than can be afforded when meeting an environmental challenge such as CFC-11 replacement.

Rapid diffusion of the blowing agent can cause these failures. Some alternatives, notably CO_2 plus HCFC-22, are known to diffuse rapidly out of the foam and also, possibly, through the ABS or PS inner liner. For the other blowing agents it is not easy to differentiate. Accelerated ageing studies [Baz96] of uncovered cyclopentane based foams show that the ageing phenomenon is of the same time scale as CFC-11 and, although the initial thermal conductivity is typically up to 1 mW/mK higher than a reduced CFC-11 foam, this difference has disappeared after 4 to 5 weeks ageing at 70°C. In turn CFC-11 based foams have been proven over many years of practical service.

There is also discussion over the amount of ageing over the lifetime of a practical appliance in service. One study [Wor94] indicated that the upward drift for CFC-11-based foams in appliances does not exceed 4 mW/mK. Another study [Jef83] of foams extracted from appliances after use for up to 9 years gave thermal conductivities in the range 16.8 to 18.1 mW/mK (measured at 0°C) for CFC-11-based foams. These are effectively initial thermal conductivities.
Based on this analysis and by comparison, cyclopentane based foams are extremely durable.

Plastic Liner Interactions

The strong solvent effect of HCFC-141b on HIPS (high impact polystyrene) or ABS (acrylonitrile butadiene styrene) liner plastics was effective in prolonging the development time before implementation of the systems in North America. The solutions, whilst varying with appliance design, have necessitated modifications in the base plastics or the use of barrier layers incorporated into composites. These result in significant additional costs which will be displayed later.

In contrast, all experience with cyclopentane based foams has shown that the standard plastics developed for use with CFC-11 are suitable for use with the hydrocarbon solution.

Energy Consumption and Safety Measures

Whilst laboratory measured thermal conductivities give an indication of relative energy consumption, reliable data can only be obtained from in use tests of assembled cabinets. An average increase in energy consumption of up to 3.5% has been quoted in one study [Wor94].

A recently published paper [Lee95] has indicated the following comparison, relative to reduced CFC-11, shown in Table 11 between cyclopentane based and other systems.

Table 11: Thermal Conductivity and Energy Consumption

	Reduced CFC-11	HCFC-141b	Cyclopentane
Thermal conductivity	100	98.6	107.6
Energy consumption	100	98	102

This confirms that the thermal conductivity of the foam can only be used as a guide and that the energy consumption of cyclopentane based foam insulated appliances are only slightly above that for reduced CFC-11 based units.

This small change in energy consumption has been compensated for by, at the most, modest changes in unit design.

Equipment - Changes and Safety Measures

This is an important topic which requires detailed analysis and only an outline will be provided here. Because of the generally inferior thermal insulation properties of all the CFC-11 alternatives, the use of high pressure (hp) polyurethane processing equipment is preferred as it contributes to improving the foam structure.

The main changes necessary with the principal alternatives are listed in Table 12. With HCFC-141b based technology there is the necessity to consider the liner processing step.

For cyclopentane based technology there has to be a professionally conducted audit of the safety precautions for both the trial and production stages. The necessary changes are now well established and expert guidance is available from many sources. In addition to converting the processing equipment and the door and cabinet moulds and jigs there are two other aspects which it is important to highlight.

Table 12: Equipment Changes

Alternative	Polyurethane Processing	Refrigerator Jigs/Moulds	Sheet Extrusion	Liner Vacuum Forming
Reduced CFC 11	None	None	None	None
HCFC 22/ HCFC 142b	hp equipment plus pressurised blowing agent equipment	New jigs for thicker walls may be necessary	None	None
HCFC 141b	Leak-proof blowing agent blending	None should be necessary	Depending on grade of HIPS or ABS technology new equipment may be necessary	None
HFC-134a	As for HCFC 22/ HCFC 142b	As for HCFC 22/ HCFC 142b	None	None
Cyclopentane	Precautions to avoid explosive atmospheres	Precautions to avoid explosive atmospheres	None	None

There should be a safe delivery and storage facility for the bulk cyclopentane. The use of drums with the necessary frequent handling should be avoided. Ideally there should be bulk tanker deliveries to an underground storage facility which is located outside the factory wall.

There must be an emphasis on training of all personnel involved with the process so that agreed procedures are understood and followed. The factory management should arrange for periodic audits of the operating procedures.

The flammability issue relates to the handling of the bulk hydrocarbon and the polyol blend containing it. There is no relevant effect on the foam or the appliance itself.

Future Developments

It would be naive to expect insulation technology development to plateau out in the next decade. In addition to the programmes to refine the hydrocarbon including cyclopentane technology described in section 4 there are other relevant developments in progress.

Driven by the need to reduce energy consumption and increase effective internal volumes the use of vacuum insulation panels are being actively considered and are in production in some cases. Most of these technologies replace part of the normal polyurethane rigid foam with panel whose thermal conductivity is up to four times less than that of the foam. The energy consumption of the cabinet may then be reduced by, typically, 20%. There are several contending technologies based on silica particles, glass fibres or microcell (open celled) polyurethane foam. Specially developed encapsulating foams based on cyclopentane are available to use with these products. They are optimised to flow well in the cavities within the refrigerator walls which are constricted by the inclusion of the vacuum panels.

A second development is that of liquid HFC blowing agents. These are being evaluated with a view to possible commercial availability about the year 2000. The main characteristics of these blowing agents and the results of early evaluation in US refrigerator systems are shown in Table 13 in comparison to HCFC-141b.

Table 13: Liquid HFC Blowing Agents

	Units	HCFC-141b	HFC-35 mfc	HFC-245fa
MW		117	134	166
Boiling Point	°C	15.3	25	32
GWP	100 yr.	950	1160	630
Flammability limits in air	%	None	7.3-9.6	7.4-15.5
Foam thermal conductivity at 10°C	mW/m K	17.3	17.7	17.7
DoE Energy Consumption		100.9	103.7	100

There are many aspects including these costs and toxicology to be evaluated as well as their effective contribution to climate change which is being studied by application of TEWI (Total Equivalent Warming Impact) analysis.

Conclusion

Rigid polyurethane foam technology based on cyclopentane is now well proven and in wide scale use. It provides an environmentally acceptable solution whilst fulfilling all the complex technical demands for an insulating foam in a stringent application.

Non ODS-Refrigerants

Natural and Synthetic Refrigerant Fluid Options

A variety of fluids were investigated as potential working fluids for the vapour compression cycle in refrigerators. Only a few turned out to be generally suitable by satisfying the thermophysical, chemical, ecological and economical requirements. Hydrocarbons and their halogenated derivatives, such as CFCs and HFCs, were found to have excellent thermodynamic properties which are advantageous in vapour compression cycles. The refrigerants CFC-12, HFC-134a, and isobutane have turned out to be especially suited for domestic refrigeration applications due to their thermodynamic characteristics, especially their high coefficient of performance (COP) and their refrigeration capacity per compressor swept volume. Using these refrigerants leads to economically sized high performance compressors and refrigerators.

The pure fluid isobutane has a vapour pressure curve significantly different from that of CFC-12, therefore requiring a compressor with a new combination of the actual compression part and the electrical motor. If the costs for such a conversion do not seem to be suitable, it is also possible to use a mixture of propane and isobutane as replacement. The specific advantage of a propane/isobutane mixture is that its vapour pressure curve can be adapted to the needs of the application, i.e. matching the vapour pressure curve of CFC-12. Thus, it is possible to use such a mixture in a CFC-12 cycle without modification of the swept volume of the compressor. This will simplify the task of converting the world-wide production of approximately 80 million compressors for household appliances to a new refrigerant. The pioneer of modern household refrigeration systems with hydrocarbons as refrigerant, the German manufacturer FORON, first converted the production towards a mixture before later switching to pure isobutane.

In this chapter, a comparison of several aspects of these working fluid options is shown.

Energy Efficiency

A theoretic comparison of the refrigerants CFC-12, HCFC-22, HFC-134a, isobutane, propane and of a mixture of propane and isobutane was carried out. As mixture composition, a ratio of 43% isobutane and 57% propane (50/50 mol%) was selected due to the commercial availability of such a mixture. The comparison was carried out for an evaporation temperature of -30°C, a compressor suction temperature of +25°C and a condensation temperature of +40°C. An internal heat exchanger as well as a constant isentropic efficiency was assumed. These are common refrigerator design values. Figure 11 shows the necessary change in swept volume of the refrigerator's compressor in comparison to CFC-12, while Figure 12 shows the change in calculated COP compared to CFC-12.

Experiments were performed to verify the theoretically predicted efficiency advantages of isobutane. It turned out that the very first measurements carried out with isobutane showed poor performance results, while later measurements delivered better results. This is due to the optimisation process mainly of the compressor, while the other parts basically remained unchanged compared to CFC-12. A very similar effect was also observed some years earlier introducing HFC-134a, before the optimisation for this refrigerant was performed.

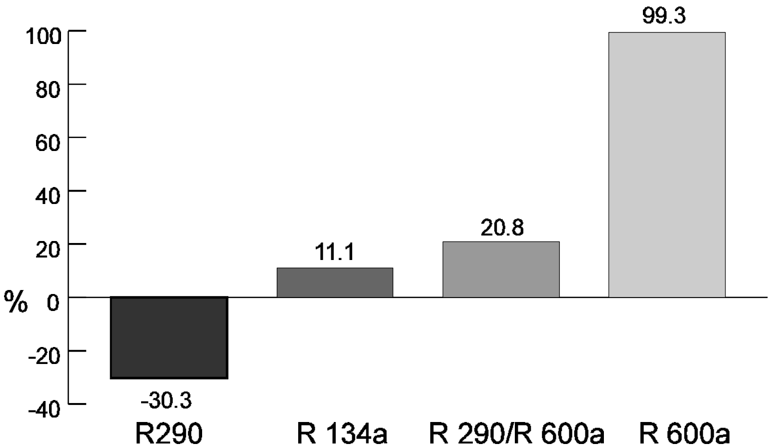


Figure 11: Change in necessary compressor swept volume for different refrig erants compared to CFC-12 (calculated)

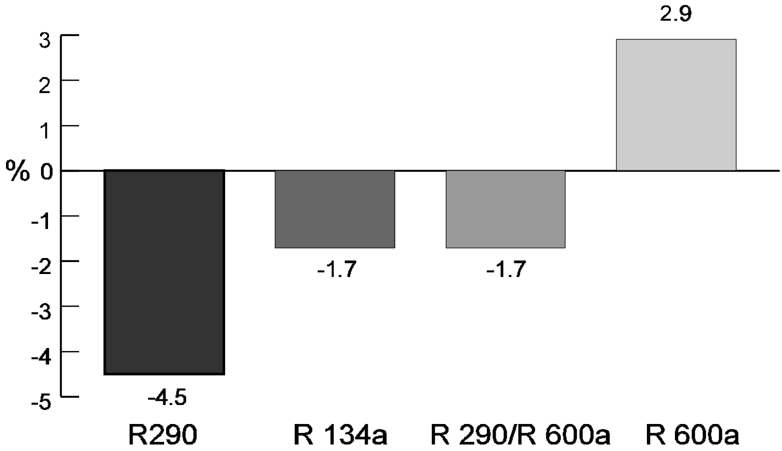


Figure 12: Change in COP for different refrigerants compared to CFC-12 (calculated)

The latest test results show a better performance for isobutane compared to CFC-12 and CFC-134a, as shown in Figure 13. These results were achieved with refrigerators adapted in 12 month to the refrigerant isobutane, while the comparison results with CFC-12 were achieved after decades of optimisation [Wie94].

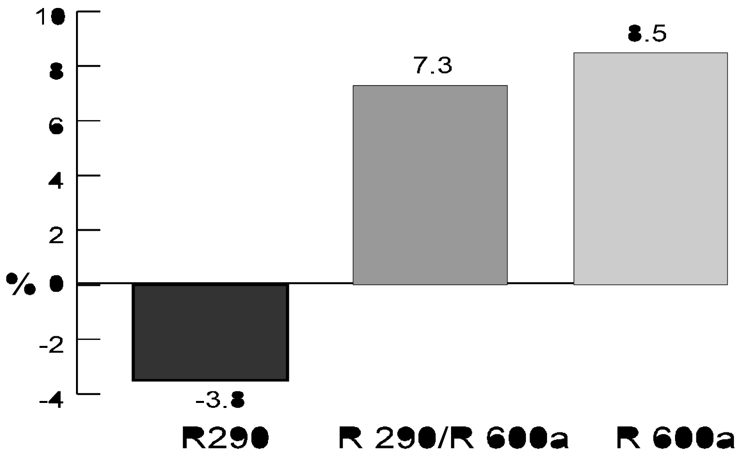


Figure 13: Measured COP relative to CFC-12 for different refrigerants [Wie94]

Also due to positive performance test results, different refrigerator manufacturers independently decided to produce refrigerators, refrigerator/freezers and no-frost appliances using isobutane as refrigerant. Among those are the leading manufacturers in Europe, who converted at least part of their production to the new technology.

Lubricants

The basic role of the lubricant in a refrigeration system is to lubricate the sliding parts of the compressor. Inside the refrigeration cycle the effect of the oil is most unfavourable regarding heat transfer. Due to design necessities of the compressor some lubricant enters the refrigeration circuit. In order to minimise the negative effects on heat transfer and to ensure the oil return to the compressor the oil should be sufficiently miscible with the refrigerant.

State of the art is the use of fully miscible mineral oils with CFC-12. In contrast HFC-134a is not miscible with these mineral oils. Therefore synthetic ester-based oils and polyalkyleneglycol-based oils were developed. In domestic refrigeration systems mainly ester-based oils are used with HFC-134a, which are approximately 3 to 5 times more expensive than mineral oils while being very sensitive to humidity. From the vapour phase water content of the ambient air the oil extracts water if not stored properly. Oil and water may form acids in the refrigeration cycle, which can cause insufficient lubrication and thus damage the compressor. In those cases, the exchange of the compressor, the most expensive part of the refrigerator system, is necessary. This problem gains importance in hot and humid climates.

If the ester-based oil is exposed to the atmosphere for more than very few minutes, the humidity content might already be higher than the widely acknowledged limit of 200 ppm. Therefore, this problem requires a reorganisation of the production to ensure that the compressors containing the oil as well as all other parts are highly dried after manufacturing and sealed air tight, to be opened only directly before assembly. The fulfilment of most of these requirements can not be monitored by some kind of test equipment, but depends highly on the responsible acting of each worker in the assembly line over the whole production time. If a minor mistake has been made and, in the worst case, has been repeated, it is not noticed before the customers lay claim to the warranty a few month later. In addition, a high vacuum should be applied to the cycle before the refrigerant is charged to remove humidity still resident in the cycle

What sounds like a very simple engineering problem is a disadvantage which causes tremendous difficulties, especially in hot and/or humid climates. The refrigeration oil is delivered with a humidity content of approximately 50 ppm, significant negative effects to the cycle can be observed from 200 ppm onwards. Some fast calculations show how small this amount actually is: The remaining 150 ppm are, for an average refrigerator with an oil content of 300g, 45 mg of water. This amount can be extracted from less than 3 litres of air at 25°C; at higher temperatures, this value decreases to less than 1 litre of air.
On the other hand, the hydrocarbons isobutane, propane and their mixtures are miscible with the same type of oil used with CFC-12, even if often a higher viscosity of the oil should be used. Further suitable lubricants with hydrocarbons are polyolester oils and poly-α-olefin oils. Also ester oils can be used for hydrocarbons.

Material Compatibility

In refrigeration circuits a variety of different materials is used like metals (e.g. steel, brass, copper), sealing material and desiccants. Table 14 gives an overview about the compatibility of several materials with CFC-12, HFC-134a and hydrocarbons. In general it can be stated that all the material in use with CFC-12 can be used also with hydrocarbons and mainly also with HFC-134a. Nevertheless, this does not account for any residuals on the prefabricated parts which are left over from the production process.

HFC-134a is very sensitive to contamination by several chemicals. During the introduction of HFC-134a in the European as well as the American refrigeration industry several related problems were mentioned in personal communications, but were never published. In most cases the problems were caused by remaining chemicals from the production process of the various system components, e.g. remaining paraffin oils were dissolved by HFC-134a and deposited in the capillary tube. The results are inefficient working conditions of the system or a total breakdown.

There have been indications for quite some time that there are major manufacturing problems of refrigerators and their components with HFC-134a during their mass production phase. In one reported case at one medium sized manufacturer close to 100,000 warranty cases had to be taken care of. It is worth to mention that the liability claims amount to twice the hydrocarbon refrigerant conversion costs for the whole plant. Experts from large Article 2 compressor

Table 14: Material compatibility

defined Nomenclature acc. to ISO1629	Use	Propane	Isobutane	CFC-12	HFC-134a
Steel	construction, piping	++	++	++	++
Brass	construction, piping	++	++	++	++
Copper	construction, piping	++	++	++	++
Aluminium	construction, piping	++	++	++	++
Molecular Sieve	desiccant	++	++	++	++
Silicagel	desiccant	++	++	++	++
CR	elastomer	+	+	0	0
FPM	elastomer	+	+	0	-
PTFE	elastomer	+	+	+	+
Polyamide	elastomer	+	+		+
NBR	elastomer	++	++	+	+

manufacturers stated that the compressor related problems have been overcome after five years of extensive research and development

To avoid problems caused by contamination, a careful examination of the entire production process is necessary. The conversion to HFC-134a requires many changes in the manufacturing process of the refrigerator and its components and special knowledge in servicing.

Some metals, especially alloys with zinc or solders with zinc show increased corrosion with ester based oils and HFC-134a. No problems of this kind are known for the use of hydrocarbons as refrigerant. Here, the same standard of production precision and cleanliness as achieved with CFC-12 seems to be sufficient.

As a result of the fact that isobutane and propane are fully compatible with all materials traditionally used in refrigerator/freezers, unmodified CFC-12 refrigerators can be used with a mixture of propane and isobutane, achieving the same cooling capacity.

Quantity of Charge

The quantity of charge is of interest for safety, costs and influence on the environment.

The amount of refrigerant in a refrigeration system depends on size, technology and type of refrigerant. Due to the low density of hydrocarbons, being only around 40% of CFCs' density, the charge with isobutane, propane or mixtures of both will be about 60% less compared to CFC-12, while HC-134a would be about 10% less than CFC-12. An overview about typical charges is given in Table 15.

Table 15: 1991 Estimates of average size of refrigerator and average charge [UNE91]

Area/Country	Average Size / Litres	Average Charge CFC-12 /g
Western Europe	200	140
Eastern Europe	180	200
North America	440	180
Japan	300	160
India	165	140
Brazil	175	180

Servicing

The production standards of refrigerators are high, causing an average lifetime of a refrigerator or freezer of 15 years in industrialised countries, normally without any servicing. In Europe, North America and Japan a refrigerator is simply scrapped if it is not working properly. Only in some cases a new appliance is repaired by well-trained technicians, educated by the refrigerator manufacturer and equipped with the appropriate tools.

In developing countries refrigerators are repaired several times over their lifetime for cost reasons. High voltage fluctuations, high load conditions due to high ambient temperatures and frequent door openings, a less sophisticated quality control in production and an often not quality oriented service are reasons for the frequent failures.

Repairs are mainly carried out unorganised or informal sector which is characterised by small enterprises that are independent from the refrigerator industry. Servicing is done on a very cost effective basis, while at the same time the customer has no real means of quality control. The cost effectiveness also causes a limited time spent for training and knowledge gathering and little inclination to purchase appropriate tools for specialised repairs if the tools already possessed still seem to work properly.

The refrigerator industry will have to convert to a new working fluid. If the manufacturers decide to convert to HFC-134a, it has to be seen that it will be virtually impossible to train the whole unorganised sector in the handling of sensitive refrigerants, lubricants and equipment with respect to cleanliness, humidity, etc., as well as convince them to purchase new vacuum pumps, handle the oil properly and so on. This difficulty is increased because of the fact that the negative effects of improper handling are only evident after months.

On the other hand, the service technicians are already trained in the use of flammable gases due to the use of their soldering torches and mistakes they make will affect them directly, causing appropriate handling of hydrocarbon refrigerants.

Since HFC-134a is much more sensitive to improper handling than the hydrocarbons, and according to the hazard humidity constitutes for the lubricants required for HFC-134a, isobutane or mixtures of propane and isobutane are likely to be the better choice for refrigerators in developing countries.

Drop-In and Retrofitting

The availability of CFC-12 for repairs of appliances using this refrigerant will decrease in the near future, causing the need for another refrigerant to be charged.

In general, a refrigeration system is designed for a specific refrigerant. This relates to the dimensions of compressor and heat exchangers as well as the used materials and the lubricant. If the original refrigerant is exchanged and replaced by another one, it can be distinguished between drop-in and retrofit. Drop-in means the exchange of the refrigerant without any and retrofitting with some system modifications.

HFC-134a cannot be used for drop in or for retrofitting of CFC-12 refrigerators because of the immiscibility with the lubricant, sensibility to contaminants, missing material compatibility, etc. Charging with HFC-134a is very likely to result in severe damage of the refrigerator, unless an extensive flushing procedure including removal and opening of the compressor has been carried out.

The use of pure isobutane for retrofitting or as drop-in, which is in general possible, causes a decrease of refrigeration capacity of around 50% due to the low volumetric capacity. In most cases, this cannot be accepted. Propane as a drop-in would lead top high load on the built-in electric motor, causing its malfunction.

In contrast, the hydrocarbon mixture of propane and isobutane can be used as a drop-in replacement for CFC-12 at least in one-temperature and several two-temperature appliances. Such a mixture can have nearly the same refrigerating capacity as CFC-12 if the mixture is appropriate. Thus, a similar refrigerating capacity with a slightly lower efficiency due to less favourable heat transfer values can be achieved.

Nevertheless, in the case of hydrocarbons used as a drop-in refrigerant for CFC-12, the safety requirements of the refrigerator have to be considered. Most likely, some components have to be replaced or cut off to ensure that no ignition sources are present in the refrigerator compartment. In several cases, the use of hydrocarbons as drop-in replacements in old refrigerators will not be appropriate due to safety considerations.

Recovery

At the end of a refrigerator lifetime or in case of servicing the working fluids refrigerant and oil should be recovered from the appliance, if the emission to the environment would have negative influences.

Recovery and reclamation of CFC-12 and HFC-134a are expensive since special equipment is necessary. Due to high contamination of these fluids the process of reclamation is too complicated and expensive for the unorganised service sector in A5 countries so that the working fluids often will be destroyed or, even worse, emitted to the atmosphere.

Hydrocarbons can in principle be emitted to the environment or, better, be burned together with the mineral oil without any environmental effect.

Safety

The main objection to the use of hydrocarbons as refrigerants is the flammability of these fluids, whereas the alternative HFC-134a is non-flammable. Therefore, the safety aspects of applications with hydrocarbons have to be considered carefully. Nevertheless, HFC-134a can also form explosive mixtures with air if the system pressure is higher than approximately 2 bar (abs).

Safety concerning flammability aspects must be considered for the hydrocarbons isobutane, propane, and their mixtures - as well as for cyclopentane for insulation - during production, distribution, use, recovery and recycling.

The safety principle for the use of hydrocarbons is very simple if one reflects the basic idea: The awareness of the necessary conditions for an accident:

- a flammable mixture of air and working fluid and
- an ignition source
- have to be avoided.

Safety in Production

Flammable fluids are handled in many production processes all over the world. Since the refrigerator industry has not been using flammable fluids up to now, there are objections. But for production it is, undertaking a reasonable effort, possible to fit the appropriate safety installations, to adopt the manufacturing process and to train the staff.

Safety measures in production are of high relevance. Due to the high amounts of fluid, the large number of appliances and the actual handling of flammables the absolute risk of an accident in production is much higher than that for a single consumer.

Of special importance for the safety are measures which prevent leakages of hydrocarbons and as a result the formation of explosive mixtures. If leakages can not be excluded, the forming of an explosive atmosphere has to be prevented, e.g. by adequate ventilation. Additional measures have to be performed to reduce ignition sources, e.g. measures to avoid static electricity. Also pits and drains without lid or open connections to cellar rooms must not be located in the storage areas.

Also every refrigerator has to be tested for leak tightness before and after charging hydrocarbons. The first test, e.g. carried out by maintaining a constant pressure over a certain time in the cycle, with a helium leak test or with other methods, shows that the cycle is generally leak tight. The second test is applied only to those locations at the cycle where any changes (bending, soldering, filling) have taken place since the first test. The second test can be carried out with standard leak detecting devices. The combination of both tests is the best way to be sure

that the refrigeration cycle is hermetically closed. The filling apparatus is designed and controlled in a way that emissions are prevented. The control ensures that the filling process is only initiated if the vacuum in the cycle is constant over a certain time. The filling head of the filling station can only be taken away from the refrigerator after shutting the refrigerator's service line.
Furthermore, it is recommended that the following requirements are met when handling flammable gases:

1. Definition of appropriate safety areas. These have to be checked in accordance with the actual safety regulations by local authorities.

2. In the safety area with the highest safety level the following conditions should be maintained:
    - venting of the air, monitoring of hydrocarbon content
    - elimination of possible ignition sources
    - only use of components approved for explosion proof safety areas
    - training of the staff in handling of flammable gases

3. The gas indication system should indicate a possible leakage in two steps:• indication at 15% of lower explosion level (warning)
   • fault indication at 35% of lower explosion level (danger)

4. Installation of a ventilation in the charging area underneath the conveyor belt, since hydrocarbons are heavier than air. This ventilation system should also contain hydrocarbon content monitoring devices.

Safety in Product Design

There is no official standard for safety testing of appliances containing flammable refrigerants. A draft of the European standard "EN 60335-2-24 : Safety of household appliances, particular requirements" is likely to be accepted in general with some modifications. The most important conditions of this standard are:

1. Maximum mass of the refrigerant: 150g

2. Marking: Symbol "Caution risk of fire"

3. Warning: Information for handling, cleaning, etc.

4. High pressure test (isobutane):

- times saturation vapour pressure at 70°C, high side compressor (31.8 bar)
- times saturation vapour pressure at 20°C, low side compressor (15.1 bar)

5. Maximum temperatures on surfaces which might be exposed to leakages: Ignition temperature minus 100K

6. Protection against corrosion

To avoid the coincidence of an explosive mixture and an ignition source the following measures are effective:

1. A hidden evaporator should be implemented so that the forming of an explosive atmosphere inside the refrigerator cabinet is prevented and the switching elements are allowed in the food compartment.

2. If the evaporator is visible the electrical switching elements have to be placed outside the food compartment or IP54 sealed electrical devices have to be implemented (cased lamp). Additionally a label has to give warning information that the evaporator must not be damaged in any way. A smooth surface can give some protection against damage.

3. For no-frost appliances explosion proof electrical devices are recommended.

To avoid leakages the components of the product have to be designed, arranged and fastened in a way that there is maximum protection against leakages due to mechanical (or chemical) damages:

1. The condenser should be protected against damage e.g. by a casing which does not hinder the convection of air.

2. Use of brazed joints instead of flares

3. Use of suitable flexible hose instead of copper tubes for pressure switch connection

4. Ensuring vibration transmission from the compressor is as low as possible by flexible mounting of the compressor and by using flexible pipework connections where appropriate

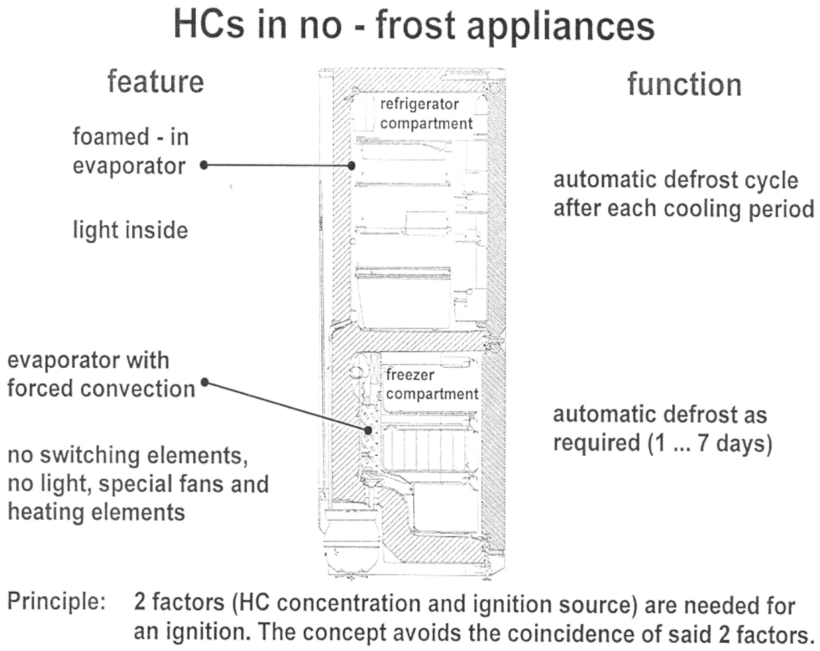
5. Use of good quality valves and always fitting valve caps

6. Packing of the refrigerator should be good enough to prevent damage

7. The charge of refrigerant has to be minimised. In case of a leakage a very low charge can hardly form an explosive mixture, and if it does nevertheless, the consequences of such an event are also minimised.

Those requirements can be met without an economical cost increase. Presently, several refrigeration manufacturers even marketing no-frost appliances which are most difficult concerning inherent product safety. A drawing of such an appliance is shown in Figure 14.

Figure 14: No-frost refrigerator/freezer using refrigerant isobutane with incor porated safety measures[Wen95]



To generate a flammable mixture in a room with 8 cubic meters (2 x 2 x 2 m) 340g isobutane or propane are necessary assuming even dispersion. Typically a 165 litre domestic refrigerator would contain about 30g, with some 10g remaining in the oil in case of a major rupture. The typical leak rate of a household refrigerator is between 0.5g/year and 1g/year.

During a fire e.g. in the kitchen, the refrigerant circuit is closed with no oxygen inside. Therefore, even at higher temperatures there will not be an explosion inside the refrigerant circuit. If the temperatures outside increase to a very high level, the soldered connection will leak so that the refrigerant is going to blow out due to its vapour pressure. The hydrocarbons and the mineral oil will burn to natural CO_2 without causing an additional hazard while HFC-134a will form toxic substances.

Additionally, it must be taken into account that refrigerators are often repaired in developing countries, either in contract workshops or in free workshops. To avoid the risk of explosions during faulty repair or resulting from faulty repair, two measures are proposed:
Reducing the delicacy for faults,
leak testing as part of routine maintenance,
training programs for technicians of factory workshops and those of the unorganised sector.

Refrigerators with hydrocarbons have been produced, sold, and used in Europe since 1993. Up to now, more than 8 million units are produced without any reported accident. Furthermore, a risk assessment showed that the explosion pressure would be low and of short duration, therefore no immediate harm to people and no ignition of furniture or curtains is expected.

Noise

An additional criterion for comfort is a low noise level of the refrigerator. In comparison to CFC-12, HFC-134a and the mixture of propane/isobutane a significant noise reduction is observed when using isobutane as refrigerant due to the lower load of the compressor.

Conclusions

In Table 16 the essential results of the preceding chapters regarding the comparison of natural and synthetic refrigerant options are summarised.

Hydrocarbon technology helps to develop markets: For example, the European Union, forming a free trade union with more than 300 million customers with a high demand for refrigeration technology, is completely accessible, while at the same time in several parts of Europe a boycott of HFC-technology is held by the customers. In addition, the technology is commercially competitive, reliable and easily accessible (non-patented). Finally the use of isobutane reduces the noise level of the product and improves the energy efficiency as compared to CFC-12 or HFC-134a as working fluid. Hydrocarbons are a commercially competitive replacement for CFCs today.

The World Bank has reassessed its stand on hydrocarbons within 12 months time. Conversions to hydrocarbons are supported by the Multilateral Fund by granting a 35% safety cost discount while calculating the cost effectiveness on a conversion project basis. This 35% investment cost bonus for safety does, however, as compared to a conversion to synthetic fluids, in most cases not compensate for the additional incremental investment costs a manufacturer incurs when converting its production lines and product designs to hydrocarbons. Increasingly this conversion benefits from the expertise already gained. The manufacturers converting to hydrocarbons choose a long lasting alternative to CFCs, being independent of high-tech manufactured or patented substances, such as HFCs and the synthetic oils. These fluids will have to be purchased in industrialised countries while hydrocarbons can be gained from refineries located on all continents.

Concerning customer safety, one has to consider that with the present use of significant amounts of different fuels in the average kitchen, an additional 30g to 60g of hydrocarbons, being less than the hydrocarbons contained in the average cigarette lighter refill cartridge, do not increase the safety hazards significantly. In addition, a refrigerator has a very high inherent safety, being leak tight and pressure proof, at the same time containing no ignition sources if adapted to hydrocarbons.

Table 16: Summary of working fluids in refrigerators

Refrigerant	**HFC-134a**	**HC-290**	**HC-600a**	**HC-290/ HC-600a**
Environmental aspects				
• ODP	+	+	+	+
• GWP	-	+	+	+
• COP	-	o	+	o
• Recovery	-	+	+	+
Compatibility with existing				
• Lubricant	-	+[1)]	+[1)]	+[1)]
• Material	o	+	+	+
Availability for developing countries				
• Refrigerant	-	+	+	+
• Lubricant	-	+	+	+
• Compressor	-	-	-	+
• Components	-	+	+	+
Servicing	-	+	+	+
CFC-12 retrofitting :				
• without compressor change	-	-	-	+[2)]
• with compressor change	+[3)]	+[2)]	+[2)]	+[2)]
Costs				
• Production	o	-	-	-
• Product	o	-	-	+
Safety installation				
• Production	+	-	-	-
• Product	+	-	-	-
Noise	o	-	+	-

1) Use of a high viscosity ester oil is most likely necessary. Nevertheless, compatibility with CFC-12 oil is given.

2) It has to be ensured that safe operation is possible by shielding, changing, or removal of electrical components. In several cases, a retrofit will not be possible due to safety reasons, even if the refrigerator would provide cold.

3) Needs additional flushing procedure with ester oil and HFC-134a. The ester oil and HFC-134a has to be disposed of afterwards.

World-wide Refrigerator Production

Present Market Situation

To describe the present market situation, data from different public sources was collected and combined. No uniform market information was available.
The purpose of the data collection was to gain information on production, not sales. Nevertheless, for several regions no production data was available. In these cases, the available data concerning shipments is given. In cases where a source gave numbers for entire regions, these were ignored if the total of the countries' values of this region exceeded the amount given in the "region" source.

The main findings of the data search, including the sources used, are given in the Tables 17 and 18. Table 17 gives information concerning the absolute values of refrigerator/freezer production world-wide, while Table 18 lists the conversion projects which have been approved by the MF.

Table 17: Refrigerator/freezer production world-wide

Region	No. of Refrigerators	[Year]	Source	Region	No. of Refrigerators	[Year]	Source
North America	**11,300,600**	[1994]	[App95a]	**Africa**	**≥1,800,000**		[Imp96]
Latin America	**5,970,000**	[1992]	[UNE94]	Algeria	≥ 566,500	*	[Kud95]
Mexico	1,074,500	*	[HEA96]	Cameroon	≥ 82,500	*	[Kud95]
Argentina	257,500	[1992]	[Kud95]	Nigeria	200,000		[Imp96]
Brazil	1,910,000	[1994]	[UNIa]	Egypt	564,000	[1992]	[Kud95]
Colombia	≥ 322,500	*	[HEA96]	Swaziland	200,000		[Imp96]
Costa Rica	≥ 36,000	*	[HEA96]	Mauritius	≥ 5,000	*	[HEA96]
Chile	310,500	shipm. [1993]	[DEG]	Tunesia	≥ 80,000	*	[HEA96]
Ecuador	≥ 68,000	*	[HEA96]	Tanzania, Mozambique, Simbabwe	≥ 30,000		[Imp96]
Peru	≥ 182,500	*	[Kud95]	**Asia (w/o SE Asia)**	**≥16,782,50(**	[Σ]	
Venezuela	≥ 277,500	*	[HEA96]	India	1,460,000	[1993]	[GTZ94]

Western Europe	**16,250,000**	[1992]	[UNE94]	Iran	1,000,000	[1992]	[UNIb]
Germany	4,209,000	[1994]	[App95b]	Jordan	62,500	[1993]	[Kud95]
Sweden	484,000	[1994]	[App95b]	Pakistan	400,000	[1996]	[Gro96]
Italy	7,155,000	[1994]	[App95b]	Syrian Arab. Republic	≥ 397,500	*	[Kud95]
Great Britain	1,396,000	[1994]	[App95b]	Turkey	1,264,000	[1994]	[App95b]
Switzerland	200,000	[1995]	[For96]	China	12,598,500	[1995]	[SIN]
France	580,000	[1994]	[App95b]	**South East Asia**	**≥8,790,000**	[Σ]	
Spain	1,219,000	[1994]	[App95b]	Indonesia	620,500	shipm. [1993]	[DEG]
Austria	475,000	[1994]	[App95b]	South Korea	1,000,000		[Imp96]
CEIT	**6,400,000**	[Σ]		Japan	5,126,000	[1994]	[App96]
Russia	3,800,000	[1994]	[App96]	Malaysia	395,500	shipm. [1993]	[DEG]
Hungary	800,000		[Imp96]	Philippines	274,500	shipm. [1993]	[DEG]
Slowakia	300,000		[Imp96]	Singapore	274,500	shipm. [1993]	[DEG]
Romania	470,000	[1995]	[Gro96]	Sri Lanka	≥ 27,000	*	[HEA96]
Macedonia	160,000		[Imp96]	Thailand	≥ 1,072,000	*	[Kud95]
Slowenia	900,000		[Imp96]	**Australia + New Zealand**	**680,000**	[1992]	[UNE94]
Bulgeria	160,000		[Imp96]				
Moldavia	140,000	[1993]	[UNE95]				
				World-wide	**68,000,000**	**[1995]**	[MPH]

* sum of factory production numbers calculated based on investment projects supported by MF on assumption 0.75 kg ODS per refrigerator,

Table 18: Conversion projects approved for funding by the Multilateral Fund

Region	No. of Units Produced/Yr.	[Year]	Annual Capacity Converted in MF- Project*	Source
Latin America			**3,09,500**	Σ
Argentina	458,500	**	458,500	[Kud95], [HEA96]
Brazil	1,910,000	[1994]	649,500	[Kud95]
Colombia	-		324,000	[Kud95], [HEA96]
Costa Rica	-		36,000	[HEA96]
Ecuador	-		68,000	[HEA96]
Mexico	1,074,500	**	1,074,500	[HEA96]
Peru	-		182,500	[Kud95]
Uruguay	-		24,000	[Kud95]
Venezuela	-		277,500	[HEA96]
CEIT			**274,000**	Σ
Romania	274,000	**	274,000	[HEA96]
Africa			**1,298,000**	Σ
Algeria	-		566,500	[Kud95]
Cameroon	-		82,500	[Kud95]
Egypt	564,000	**	564,000	[Kud95]
Mauritius	-		5,000	[Kud95], [HEA96]
Kenya	-		N/A	
Tunisia	-		80,000	[HEA96]
Asia			**2,815,000**	Σ
Iran	1,000,000	[1992]	785,500	[Kud95]
Jordan	62,500	**	62,500	[Kud95]
Syrian Arab Rep.	-		397,500	[Kud95]
Turkey	1,569,500	**	1,569,500	[Kud95], [HEA96]
South East Asia			**7,367,000**	Σ

China	12,598,500	[1995]	5,357,500	[Kud95]
Indonesia	-		610,500	[Kud95],[HEA96]
Malaysia	-		237,500	[Kud95],[HEA96]
Philippines	-		62,500	[HEA96]
Sri Lanka	-		27,000	[Kud95]
Thailand	-		1,072,000	[Kud95]
World-wide			**14,574,500**	**Σ**

* calculated on assumption 0.75 kg ODS per refrigerator, precise data not available

** capacity of conversion was larger than available production data, therefore total annual production was assumed to be capacity of conversion

Future Developments

The present market for refrigerators will not remain stable, but is likely to increase at different rates in the various regions. For these regions, an attempt was made to estimate the future growth rates. This attempt is based on data concerning past developments, on the case studies, on information publicly available, e.g. announcements of large multinational appliance manufacturers, and on personal communications. Within the limitations of this study, it was not possible to actually model these markets in any sophisticated way. Nevertheless, the authors feel confident that the general trends are described accurately.

The quantitative information given permits an estimation of the additional production capacities to be installed in the near future. As with the situation for the production capacities not converted so far, the technology for these production capacities can chosen freely.

In general, the large appliance companies ("multinationals") are presently expanding their activities especially into China and India. In these countries, strategic joint ventures are being established. In every case known, there are plans to increase production capacity significantly or to build new plants. In addition, Embraco, one of the largest compressor manufacturers for domestic refrigerators and a Whirlpool subsidiary, is planning to set up a compressor manufacturing plant in China. Other compressor manufacturers are working along similar lines.

Western Europe:

Market status:	Nearly saturated, additional sales volume expected only in Southern Europe.
Previous years:	+/- 0.8 m. units on a level of 16 m., no definite trend. 16.25 m. in 1994.
Other information:	Decrease in France and Germany during last year.
Prediction:	Growth of 1% p.a. until 2000.

North America (without Mexico):

Market status:	Nearly saturated.
Previous years:	Relatively stable increase of (average) 0.5 m/year, 11.7 m. in 1994.
Prediction:	Growth of 3% p.a. until 2000.

Latin America:

Market status:	Not saturated. Mexico fairly stable. Middle America highly unstable, therefore no increase expected. South America relatively stable, moderate market increase is expected.
Previous years:	Only for Brazil, the largest market in South America, sufficient data is available. After a remarkable drop from 1.8 m. units in ‘91 to 1.3 m. units in ‘92, the production increased again to 1.9 m. in ‘94. Total volume in Latin America 5.97 m./year. (‘92). No definite trend.
Prediction:	Growth of 5% p.a. until 2000.

Africa:

Market status:	Not saturated. North and Middle Africa unstable. No data about production facilities in South Africa has been found.
Previous years:	Not sufficient data for trend. Total production at least 1.3 m/year (Data from MF-proposals).
Other information:	From 1.3 m/year total production found, 0.57 m are located in Algeria, also 0.57 m in Egypt. Decrease in Algeria likely.
Prediction:	Growth of -3% p.a. until 2000.

CEIT:

Market status:	Not saturated. Infrastructure, especially material supply, transportation and legislation very unclear.

Previous years: Not sufficient data for trend. Total production 6 m/year (1994).

Other information: No major investments from large appliance manufacturers reported.

Prediction: Growth of 0% p.a. until 2000.

South East Asia:

Market status: Not saturated. Fairly stable. Large growth rates in public income.

Previous years: Only data about production in Japan available in sufficient detail. From 5.4 m in 1991, production decreased to 4.6 m. in 1992, reaching 5.1 m in 1994. Total shipped/produced in that area is expected to be 7.8 m. This number is a sum of production (1994) and shipment values (1993) as well as numbers given in proposals to the MF.

Other information: Japanese manufacturers tend to transfer production into surrounding countries. For those countries only shipments but no actual production numbers are known.

Prediction: Growth of 5% p.a. until 2000.

India:

Market status: Not saturated, only 10% of households equipped with refrigerator. Fairly stable. Large growth rates in public income.

Previous years: According to case study, there was an average increase of 20% in sales during recent years, reaching 2 m in '95. Production numbers are said to be 1.46 m. units in 1993, in the meantime, a similar increase in sales numbers seems likely, therefore a production number of 2.1 m units/year can be assumed for 1995.

Other information: Joint ventures and directly owned facilities of Whirlpool, Electrolux, Sanyo, and Goldstar are in place or in the process of being set up. Fastest growing market segment over the last years were no-frost appliances, reaching a market share of 15-18%. According to case study manufacturers are highly interested in that growing market segment.

Prediction:	Growth of 15-20% p.a. until 2000. Presently, very far from saturation compared e.g. with production and population numbers in China.

China:

Market status:	Not saturated. Fairly stable. Large growth rates in public income.
Previous years:	From 1993 to 1994 and from 1994 to 1995, an increase in production of more than 20% each year is reported, reaching 12,6 m. units/year in 1995.
Other information:	Growth rate in 1996 is expected to be lower than in previous years. Joint ventures of Whirlpool, Electrolux, Bosch-Siemens, and technology collaborations of Liebherr and Japanese manufacturers have been established. Market is expected to concentrate on relatively small appliances (200 litres) over the next years. Production capacity per capita already on high level.
Prediction:	Growth of 10% p.a. until 2000.

Others in Asia:

Market status:	Not saturated. Market for production facilities in Iran (1 m units/year) expected to be unstable, same for Syrian Arab. (0.4 m units/year). Turkey (1.57 m) fairly stable.
Previous years:	Not sufficient data available. Status based on numbers between 1992 and 1994 is a production of 2.7 m units/year.
Other information:	Large multinationals tend to invest in Turkey in refrigerator and compressor production.
Prediction:	Growth of 5% p.a. until 2000 for Turkey, 0% p.a. for the rest.

Australia and New Zealand:

Market status:	Fairly saturated. Stable.
Previous years:	Not sufficient data available. Status 0.68 m units/year in ‘92.
Other information:	General tendency to connect closer with South East Asian markets.
Prediction:	Growth of 2% p.a. until 2000.

Based on the assumptions given above, the following Table 19 was generated. In addition to the present and future production numbers, the absolute increase, especially in those regions where a high increase is expected, gives an indication about additional production capacity to be installed.

Table 19: Refrigerator world production development in million units/yr.

Region	Latest Production Numbers	Production in 2000	Absolute Increase
Western Europe	16.25	17.08	0.83
North America	11.70	13.56	1.86
Latin America	5.97	8.40	2.43
Africa	1.30	1.08	-0.22
CEIT	4.00	4.00	0.00
south- east Asia	7.80	9.95	2.15
India	2.00	4.15	2.15
China	12.60	18.45	5.85
Turkey	1.57	2.00	0.43
Other Asia	1.40	1.40	0.00
Australia, New Zealand	0.68	0.78	0.10
Total	65.27	80.86	15.59

It is assumed that manufacturing plants which have been converted from the use of CFCs to one or another option are not likely to be converted a second time without an unexpected market pull happening. For the remaining production facilities, the choice of technology option is still in process. Table 20 provides an overview of the production facilities which may be converted to or designed for a specific refrigerant or foam option. Until better data are available, it is assumed that the manufacturing sites which actually have been converted and which have been in the process of conversion with funding of the MF up to early 1996 have a capacity of 1 m units. All complying Article 2 country productions are being counted as converted.

Table 20: Refrigerator production capacity overview: Converted capacities, future conversions, future capacities

Production already converted	Proposals to MF (not yet converted)	Production without known conversion plans	Future capacities	Total capacity of conversions / new facilities with technology choice
34.76	13.46	17.04	15.59	46.0[illegible]

Partnerships, Associations and International Ownership

For a manufacturer of refrigerators, an important factor in taking the decision which technology is to be used are links with suppliers. Through these links the important details of how to use new technologies reach the manufacturer. Besides these independent manufacturers, there are also a lot of dependent manufacturers, who belong partially or totally to other, larger groups - the multinationals. These manufacturers will get significant technological information from their parent (multinational) companies.

Several dependent manufacturers will be forced by their parent companies to select a certain technology. In the other cases, the flow of technology information will strongly influence the manufacturers' decision to select a certain technology. In this chapter it is tried to show at least some of those links to give an idea how these links might influence technology selection. In order to do so, the general nature of those links will be described for two groups: Links between compressor manufacturer and refrigerator manufacturer, and links between refrigerator manufacturers.

Links Between Compressor and Refrigerator Manufacturer

The compressor and the refrigeration oil which is delivered with the compressor are the two key components not only for energetic performance, but also for reliability of the refrigeration circuit. In addition, the compressor is the most expensive and most complex part of the cycle. The complexity leads to a very extensive design and testing procedure, which in turn is the reason for only a very few compressor designs existing world-wide. Nearly all small manufacturers are licensees of some large companies. Even among larger companies, especially older compressor designs are often shared on the basis of license agreements.

If a refrigerator fails, and the reasons are not leakage or capillary tube blocking, the compressor is damaged. Independent of the reason for the failure - this might be in the refrigeration cycle or the compressor - the fact that the compressor is damaged involves its manufacturer in the search for the reason of the failure. This leads to a significant amount of specific know-how at the compressor manufacturer, which especially smaller manufacturers use intensively, saving their own resources. At the same time, this limits the refrigerator manufacturer’s ability to chose a technical option where he gets no or limited know-how transfer from the compressor manufacturer.

In case of difficult technical questions which a refrigerator company might face during system design or production, the compressor manufacturer provides help, further backed up by his licenser. For conversion projects to another refrigerant, the support of the licenser is very important.

For three countries - Germany, Argentina and India - the compressor imports and exports were investigated. Flow diagrams with approximated numbers of compressors, given in Figure 15, show the results of the investigation. In all three cases, a strong influence of imported technology is present. The German conversion to the use of isobutane in the refrigeration circuit was only possible because of the relatively large compressor manufacturer Danfoss in Germany, which primarily produces for the European market. The use of isobutane made Danfoss the only source of supply for compressors for a certain while and strengthened their market position. Without the technology supplied by this manufacturer, the change to isobutane in Germany would not have taken place.

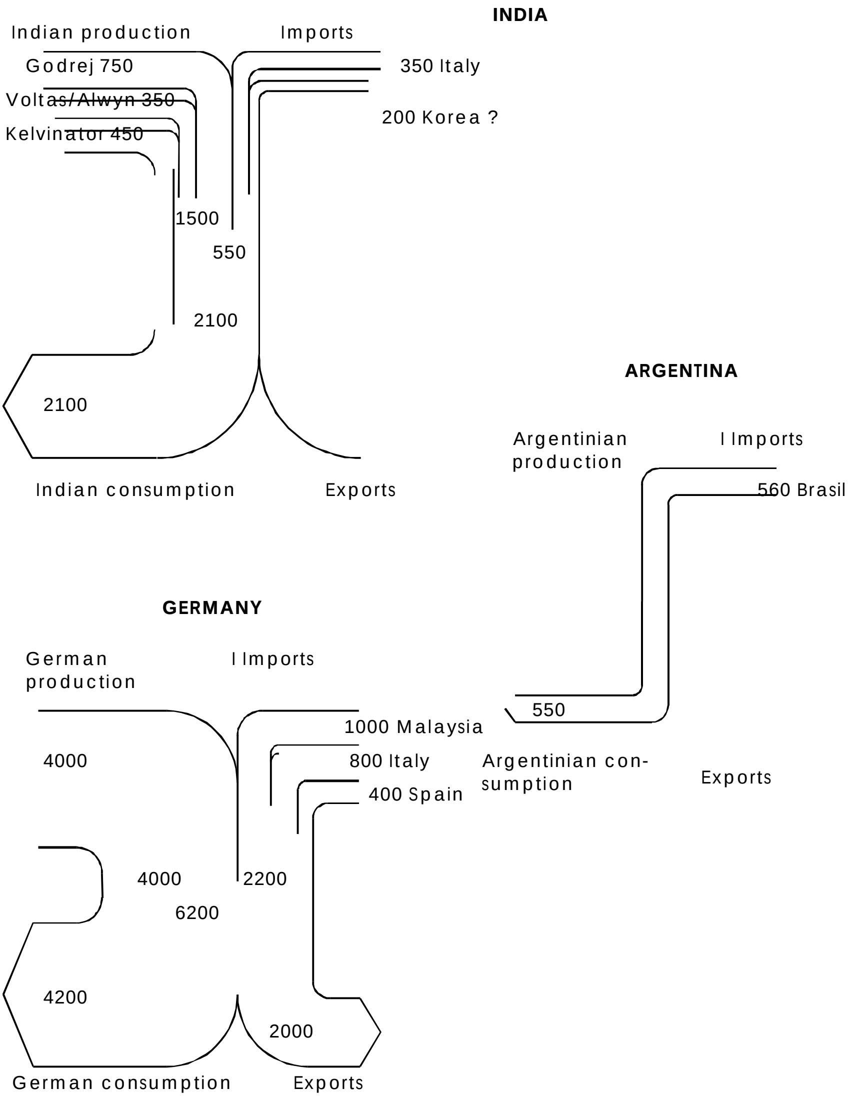


Figure 15: Compressor Exports and Imports in India, Argentina, and Germany

Links Between Refrigerator Manufacturers

Manufacturers, particularly those in Article 5 countries, can save nearly their whole development department by purchasing a license on refrigerator design and production from another - usually larger - refrigerator manufacturer. After purchasing this design, production can be set up according to the specifications supplied. Any refrigerator design changes and changes in production process, such as different refrigerants or - to a lower extent - different blowing agents require the support of the licenser.

For manufacturers without license, general information supply concerning production and purchasing is important. Part of this know-how is delivered by those companies equipping the factory with charging equipment, vacuum equipment, foaming equipment etc., but there is still a lot of additional know-how needed - e.g. for equipment selection. This know-how is often supplied by the parent company if the refrigerator manufacturer belongs partially or totally to another appliance producer.

Argentina and India are used as examples for technology collaboration between manufacturers from Article 2 and Article 5 countries. Both examples reflect the situation in countries with a closed economy. In other Article 5 countries, e.g. in South- East Asia, in Brazil and in Mexico the share of foreign ownership is higher. Table 21 gives the shares for different kinds of co-operation in these two countries.

Country	1995 Domestic Refrigerators [Units/a]	No. of Manufacturers > 20,000 Units/a	In % of Market Share in 1995			
			Foreign Ownership (A2)[1]	Production Under License [2]	Independent Manufacturer [3]	Manufacturer Producing Own Co-mpressors
India	**2,000,000**	**6**	**25 %**	**30 %**	**45 %**	**74 %[4]**
Argentina	**500,000**	**13**	**25 %**	**10 %**	**65 %**	**0 %[5]**

Table 21: Technology collaboration between refrigerator manufacturers in Article 2 and Article 5 countries

1) A2: Ownership of an Article 2 country based manufacturer

2) Or equivalent technology collaboration for refrigerator design

3) Expired license agreements

4) Compressor manufacturing most likely based on licenses (possibly expired)

5) Close to all compressors purchased at Embraco, subsidiary of Whirlpool, and the second largest compressor manufacturer world-wide

Refrigerator production world-wide is lead by very few companies, such as Whirlpool, Electrolux, Bosch-Siemens, and some South- East Asian manufacturers. While there is only limited information available concerning the South- East Asian manufacturers, the other companies are more open. According to their material, one can see some focus areas of interest. These are India, China and Brazil. Table 22 provides an overview about engagements of large refrigerator manufacturers in these countries. This table includes only subsidiaries, joint ventures, etc., but no license agreements.

Table 22: Engagements of large refrigerator manufacturers (examples)

	Whirlpool	**Electrolux**	**Bosch-Siemens**	**Others**
Brazil	Multibras (refrigerators) [1]; Embraco (compressors) [1]	Refripar (refrigerators) [5]	Metalfrio (refrigerators) [1]	
China	Beijing Whirlpool Snowflake (refrigerators) [3]; Beijing Embraco Snowflake Compressors (compressors) [3]	Changsha Zhongyi Corporation (refrigerators) [3], ZEL Tianjin Compressor Comp. (compressors)	Wuxi (refrigerators) [3]	Haier (refrigerators) [6], Liebherr
India	New factory (refrigerators) [4]; Kelvinator (refrigerators)[5]	Maharaja International Ltd. (refrigerators) [5]		BPL (refrigerators) [6], Sanyo

1 Affiliate
2 Division
3 Joint venture
4 Belongs to Whirlpool Asia
5 Majority
6 Technology collaboration agreement

Hydrocarbon Market Development

Development of Refrigerator Market Shares in Western Europe

The introduction of hydrocarbon refrigerators has largely been consumer driven in Western Europe where a hydrocarbon refrigerator is a “CFC, HCFC and HFC-free” refrigerator using hydrocarbons as refrigerant and as blowing agent. Big warehouse groups have taken the lead in that process in the German market. Since Germany - in particular after reunification - is the most important market in Western Europe, other European suppliers have chosen to launch hydrocarbon refrigerator production as well. Due to the short supply of hydrocarbon compressors, more advanced CFC phase out dates (January 1, 1994) in some countries, such as Sweden and Switzerland and restricted national safety regulations in the United Kingdom and the Netherlands for instance, most Western European countries converted to HFC-134a first. Outside Germany sales of hydrocarbon refrigerators started to pick up sizeable amounts in the course of 1995 only. Therefore the present market share of hydrocarbon refrigerators in Western Europe is approximately 25% (Figure 16).

Refrigerator demand on the German market reached a peak in 1990/1992 after the reunification. During 1995 safety regulations were gradually standardised within the European Union (British Standard 4434, German DIN 7003, etc.) and were being formalised into an international standard as well. The national standards mentioned will be valid only until the European Standard EN 378 has come into force. These standards have become the guideline for manufacturers who had not yet converted to hydrocarbon. These standards and an increasing demand for safety components have lead to a reduction in the production cost of hydrocarbon refrigerators compared with the pioneer conversions of 1993.

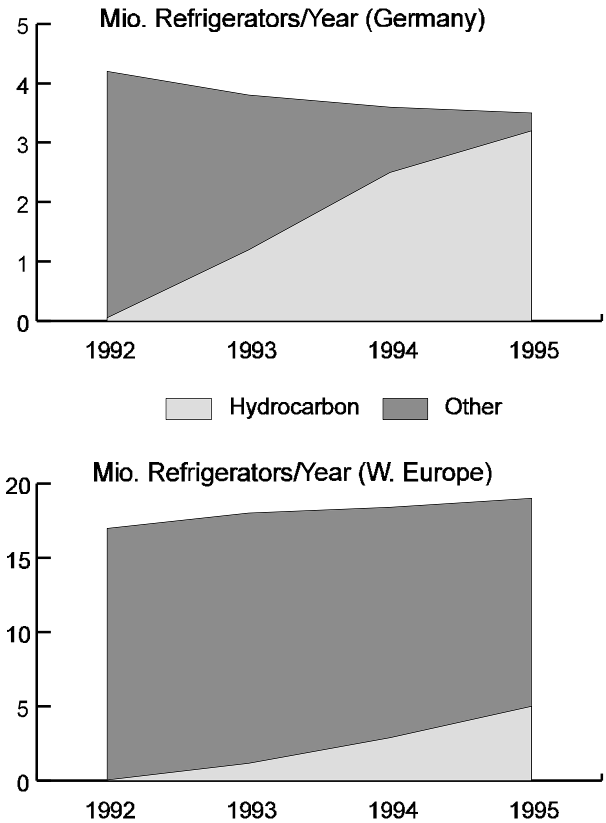


Figure 16: Refrigerator market and market share of hydrocarbon refrigerators in Germany and Western Europe between 1992 and 1995 (estimate, source INF96a)

Future Trends Western Europe

The sales trends for hydrocarbon refrigerators beyond 1995 will be set by comparative performance, service network and marketing strategies adopted on the markets in European countries other than Germany. Preliminary observations made during 1995 indicate that the demand for hydrocarbon refrigerators does pick up faster in the European countries north of the border separating the Romance and Germanic language groups (Table 23). This observation is related to a cultural difference which also is reflected e.g. in different approaches to product liability legislation or a higher willingness among the population of Northern Europe to pay for conservation of natural resources. It is related to the different valuations given to common property within the historical Germanic and Roman legal systems.

Table 23: Domestic refrigerator sales trends in Western Europe by refrigerant (CFC-12, HFC-134a, isobutane), estimate INFRAS based on personal communication with marketing departments of refrigerator manufacturers.

Region	Refrigerant	1993	1995	1997(Forecast)
Northern West Europe	CFC-12	40%	10%	0%
(Ir, GB, NL, L, G, S,	HFC-134a	40%	50%	20%
N, DK, CH, A)	HC-600a	20%	40%	80%
Total no. of units		9 m	9 m	9 m
Southern West Europe	CFC-12	70%	20%	0%
(B, F, I, E, P, H)	HFC-134a	30%	75%	70-80%
	HC-600a	0%	5%	20-30%
Total no. of units		7 m	8 m	9 m

Developments in Using Cyclopentane as Blowing Agent

The most accurate information presently available about developments in the use of cyclopentane as a blowing agent has been derived from a list of approved investment projects of the MF. This list includes information about the blowing agent used as replacement for CFC-11 in refrigerator production [Kud95]. Table 24 shows the blowing agent chosen in the different projects sorted by regions.
From this list it is obvious that cyclopentane is the preferred option in the conversions of refrigerator manufacturing sites supported by the MF.
Customer safety concerning the use of cyclopentane as a blowing agent turned out to be not a problem. Underwriter's Laboratory, which is the safety authority for the US, tested refrigerators using CFC-11 and cyclopentane as blowing agent. In a burning test it turned out that no difference between a CFC-11 foamed refrigerator and one foamed with cyclopentane could be found. Underwriter accepts the use of cyclopentane as a completely safe technology. Similar statements come from European safety authorities.

Table 24: Blowing agents used in MF approved conversion projects for domestic refrigeration applications

Region	No. of Refrigerators		
	C-Pentane	HCFC-141b	All
South America	**556,000**	**858,933**	**1,414,933**
Argentina	257,333		257,333
Brazil	274,667	374,933	649,600
Colombia		301,333	301,333
Peru		182,667	182,667
Uruguay	24,000		24,000
Africa	**1,213,333**	**3,333**	**1,216,667**
Algeria	566,667		566,667
Cameroon	82,667		82,667
Egypt	564,000		564,000
Mauritius		3,333	3,333
Kenya			N/A
Asia	**3,789,333**	**145,333**	**3,934,667**
China	2,253,333		2,253,333
Iran	785,333		785,333
Jordan	62,667		62,667
Syrian Arab Republic	252,000	145,333	397,333
Turkey	436,000		436,000
South East Asia	**325,733**	**1,178,800**	**1,504,533**
Indonesia	230,667	88,000	318,667
Malaysia	86,667		86,667
Sri Lanka	8,400	18,800	27,200
Thailand		1,072,000	1,072,000
World-wide	**5,884,400**	**2,186,400**	**8,070,800**

Principal Production Costs of Refrigerators

The values given in this chapter which are not identified as published material [source] are estimates by the authors. These estimates are based on discussions with several manufacturers and other experts.

The production of a refrigerator is strongly influenced by its poor value to volume ratio. The fact that the inside of a refrigerator is just air - storage volume - means that transport costs are expensive. The principle of production is to purchase small component parts with a good value to volume ratio, while the large parts are produced where the refrigerator is assembled, at the refrigerator production. The production plant and the consumer are usually in the same region. Therefore all housing parts are manufactured at the refrigerator company, while the components for the refrigeration cycle are small and can be transported easily. These components are usually manufactured by other producers.

Table 25: Estimated values for component costs in relation to other production costs for a small European refrigerator

	Costs (US$)	**% of total costs**
Compressor (w/o oil)	44.00	29.3
Oil	1.00	0.7
Condenser	3.00	2.0
Evaporator	7.00	4.7
Capillary tube	0.25	0.2
Refrigerant	0.40	0.3
Thermostat	2.50	1.6
Lamp assembly	1.50	1.0
Production process[1]	90.35	60.2
Total	**150.00**	

[1] Production process includes all costs which are not component costs, e.g. costs for raw material (foaming, sheet metal, ...), overhead, write-off, after sales service, personnel, ...

To give an idea of how components and production process contribute to the total production costs of a refrigerator, we have used a typical small simple European model as an example. The costs given are hypothetical and are only meant to give a first impression about the costs involved in producing a refrigerator for those who are not familiar with it. Table 25 shows the values for the component costs and the production process costs.

To estimate the total production costsof a refrigerator, US$100 can be subtracted from the sales price as the dealer margin and the remainder can be divided by 2; this is approximately what the manufacturer will get, which is - because of the relatively small profit margins - the approximate production cost.

Component Market

The component with the highest share on production cost of a refrigerator is the compressor. The component with the highest indirect influence on production costs is the refrigerant. With CFC technology presently used in Article 5 countries, often both compressor and refrigerants are manufactured locally. In the future, this might change.

The refrigerant HFC-134a will most likely be produced only in the production facilities already in operation, none of them located in an Article 5 country. The HFC-134a market is smaller than expected, the rate of capacity utilisation is presently only 50%. Small increases are expected in the near future, but medium term developments in substitutes of important application areas may constitute a hazard to the stability of the HFC-134a market. The refrigerant isobutane can be derived from LPG or can be produced in petrochemical plants. The amount of isobutane available is magnitudes higher than the amount of HFC-134a, and it is used in such a variety of applications that the market is likely to remain stable.
Based on technical and non-technical reasons (skills, quality management), a number of production facility existing in Article 5 countries are at least very difficult to be converted to HFC-134a. On the other hand it is unlikely that such facilities supplying in total million of compressors to Article 5 markets (e.g. India, China) will be closed. The engagement of multinational companies in the article 5 countries' compressor markets is therefore due to increase.

Refrigerant

HFC-134a and HCFC-141b Production

HFC-134a was originally designed as the CFC-12 replacement in all uses: Refrigeration, foam blowing, cleaning, propellant etc. Presently, a small fraction of the production is used in domestic refrigerators. Other uses in refrigeration are automotive air conditioners, large turbomachinery water chilling units for building air conditioning and for commercial applications, as a refrigerant for dairy product display cases as well as in blends for freezing cabinets. In addition, HFC-134a is used as blowing agent, as medical aerosol and as propellant for spray cans.

There are several different processes for manufacturing HFC-134a (1,1,1,2-tetrafluoroethane). The basic components for all processes are CCl_2=CCl_2 (PCE), CCl_2=CHCl (TCE), CH_2=CCl_2 (1130) and $CHCl_2CHCl_2$ [Wei92]. All producers hold at least one world-wide patent for such a process. The dates of issue for the patents are shown below in Table 26. According to several personal communications with HFC manufacturers, these patents cover all production processes which are economically feasible. Most processes require the use of a catalyst. Producers also hold patents for the purification of HFC-134a.

Table 26: Patents for HFC-134a production and purification

Company	Date of Issue
DuPont	3/92, 4/95
Elf Atochem	7/95 (pur)
Allied Signal	4/93
ICI	6/93, 11/94, 1/95, 3/95, 9/95
ASAHI-Glass	6/95
Daikin	6/93, 12/94, 3/95, 12/95
Schowa Denko	1/95 (pur)
Ausimont	10/95
Solvay	1/95
Hoechst	(date unknown)

Table 27 shows the annual production capacities of HFC-134a manufacturers world-wide. The three largest producers are ICI, DuPont and Elf Atochem with annual world-wide production capacities of around 30.000 tons per year. The major production sites of these companies are located in the US. All other HFC-134a manufacturers have only one production facility located in their country of origin.

There are only three regions where HFC-134a is produced. These are the US, Japan and Western Europe. The country with the largest capacities are the US. In Japan there are several smaller production sites. Combining these, Japan has the second largest production capacities for HFC-134a. Combining the facilities in Great Britain, Italy, France, and Germany, Western Europe has production capacities in the same range as Japan.

Market sources say that the annual production of HFCs is significantly smaller than expected, reaching only 50% of the world-wide production capacities. Several of the production sites planned have not been erected. In the future, it is expected that several HFC-134a markets will come under severe pressure: The automotive industry, having large emission rates of HFC-134a, is presently developing alternatives with negligible GWP, scheduled to be launched beginning of next century. The use as aerosol and in spray cans will most likely decrease in all markets outside the US because of the emission of greenhouse gases and because of the availability of cheaper alternatives. In the commercial refrigeration sector, the trend will either go to natural refrigerants or to the HFC-blend R-410A for most applications, a blend which does not contain HFC-134a.

Table 27: Production facilities for HFC-134a [oko96]

Country	Company	Producer Capacity [t/a]	Total
USA			67,000
	DuPont	23,000	
	Elf Atochem	18,000	
	Allied Signal	16,000	
	ICI	10,000	
Japan			30,000
	DuPont	9,000	
	ICI	6,000	
	ASAHI-Glass	5,000	
	Daikin	5,000	
	Schowa Denko	5,000	
Europe			34,000
England	ICI	10,000	
France	Elf Atochem	9,000	
Italy	Ausimont	10,000	
Germany	Hoechst	5,000	
Total		(Σ)	131,000

Some data concerning the present production capacities of plants producing HCFC-141b and HCFC-142b is given in Table 28. Separate data for HCFC-141b could not be found. The Article 2 countries will phase out HCFCs effectively by 2020. It is more likely that use and production will significantly decrease some years before.

Table 28: Production facilities for HCFC-141b/142b [Gre96]

Country	Company	Producer Capacity [t/a]	Total
USA	Elf Atochem	>50.000	>137,000
	Laroche	>30,000	
	Ausimont	30,000	
	Allied Signal	27.000	
	DuPont	unknown	
France	Elf Atochem	40,000	80,000
	Solvay	40,000	
Japan	ASAHI-Glass	17,000	32.000
	Daikin	15,000	
Taiwan	Formosa Plastics	unknown	
Russia		unknown	
China		unknown	
Total			**131.000**

Isobutane and Cyclopentane Production

This chapter is mainly using material from the OORG Report No. 12, being prepared under the overall direction of Dr. Michael Harris, of ICI Klea, Runcorn, U.K. The study was led by Mr. Brian Joyner in collaboration with Mr. Gregory Collins. The title of the report is "The Availability of Hydrocarbons for ODS Phase Out in Developing Countries". For more information than given in this chapter, please refer to the given source [Wor95].

Propane, butane, isobutane, and cyclopentane, as well as other pentanes, belong to the C_3, C_4, and C_5 hydrocarbons, respectively. The total global consumption of these hydrocarbons averages 221 m te/yr, which is less than 1/3 of the total amount of all hydrocarbons consumed in a single day, i.e. 737 m te/day. Furthermore, the LPG portion of this consumption is overwhelmingly used as fuel (99%), while only 1% is consumed in aerosols and a scant 0.01% is used in refrigeration. Indeed, if all of the world's refrigeration were converted to hydrocarbons today, that portion of total LPG consumption would still only constitute around 0.1% of the total.

Clearly, then, market conditions world-wide are such that whatever the usage, hydrocarbon prices in both the aerosol and refrigeration sectors are received prices in the first instance and consumption volumes are too low to use economies of scale in production comparable to other commonly used hydrocarbons. Non the less, hydrocarbons are certainly available in the developing country world -- in bulk and at a price. Price may vary greatly, however, as a function of transportation logistics, packaging, storage, and safety, and these are different for each subfactor. In the case of pentane used for foams, shipment in bulk tanks is feasible either to a central point or direct to major users. Refrigerant supplies, however, will almost certainly require local packaging into small cylinders.

Refrigerant grade hydrocarbon supply at the national level depends upon the local availability and quality. Local purification, if necessary, is only viable in a few of the largest developing countries. The various pentanes may be available from local refinery streams, but will depend upon wellhead quality and/or the availability of ethylene cracker/isomerization units, as also upon the size of the market. However, the technology is well known and established and subject only to relevant commercial agreements and meeting safety standard.

There is some evidence that hydrocarbon suppliers are positioning themselves to handle an anticipated demand for hydrocarbons around the world. One producer, known to be operational on a world basis, declined to participate in the study laying the basis for the OORG Report No. 12 "for commercial reasons". The C_3, C_4, and C_5 hydrocarbons are in ample supply in Europe and the U.S.A., but availability elsewhere is believed to be problematic. There is a perceived potential shortage of isobutane at the distributor level. Producers state that this is really a price/purity situation, with ample isobutane "in the pipeline".

Purification technology is available as a package, coupled if necessary with storage, handling, and packaging expertise. Given agreed financial arrangements, this could be made available to any country where suitable "raw" hydrocarbon streams are available.

Some indicators of costs for hydrocarbons are given in Table 29. It is very likely that hydrocarbons will be used on a large scale as aerosols. Due to the odour, the required purity for aerosols is 95%. If the capacity for aerosols is built, the refrigeration market can most likely relatively easy be supplied with refrigeration grade C_3 and C_4 products.

Table 29: Costs for hydrocarbons [Wor95].

Substance	Size/Amount	Source	Costs	Delivery
C3				
99.5% Propane	small cylinders	Germany	$10/kg	German market
98.0 % Propane (refrigeration grade)	10 tonne bulk tank	US	$4/kg	FOB
C4				
95% isobutane	bulk	US	$0.45 /kg	ex works
	125 gall		$3.10/kg	delivered US
	50 gall		$5.85/kg	
	5 gall		$12.00/kg	
Blends				
Propane/isobutane (refrigeration grade)	bulk tank 10 to	UK	$15/kg	FOB UK
	bulk shipment of cylinders		$20/kg	
	single cylinder 6 kg		$30/kg	UK market
C5				
n/iso pentane	bulk	US	$465/te	FOB
		Europe	$1300/te	delivered in Europe
Cyclopentane	bulk	US	$1,177/te	FOB
		Europe	$1755/te	
			$3200/te	C&F Asia/South America
	drums (FCL)		$2,400/te	FOB

Other manufacturers have production numbers below 7 m/year.

Compressor

Compressors are a highly sophisticated mass product (see 5.2). The approximately 65 million compressors produced annually for domestic appliances are mainly manufactured in large plants. Very large manufactures production numbers in the region of and above 15 m/a are

- Matsushita (production mainly in Malaysia),
- Electrolux (Italy, Austria, Spain, US, China, Egypt, India),
- Embraco (Brasil, Italy, China),
- Tecumseh (US, Brasil, India).

By 1994/1995 the European factories of Electrolux, Zanussi, Unidad Hermetica and Verdichter Oe, had entered in the production of isobutane compressors on a large scale. The European subsidiary of Embraco Brazil, which in turn belongs to the Whirlpool group, has been catering a sizeable portion of the growing Western European isobutane compressor market. Matsushita, after loosing some of the previous HFC-134a market share, had introduced an own isobutane line for the European market.

Americold, a subsidiary of the Electrolux group, is the only North American compressor manufacturer known to have launched at least a isobutane prototype production. Independent Western European compressor manufacturers are Danfoss in Denmark, Necchi in Italy, and Foron, all of them manufacturing large amounts of hydrocarbon compressors. Danfoss is estimated to be the leading manufacturer with approximately 2.5 m. compressors sold in 1995. The total market volume of isobutane compressors in Western Europe is estimated at 4 to 5 m. units for 1995. The share of isobutane compressors within the domestic refrigerator market is rapidly increasing. The market of small plug-in commercial appliances started to grow for isobutane compressors recently. The global market share of isobutane compressors may in 1995 have reached some 10% of a total volume of estimated 65 m. compressors produced for domestic refrigeration purposes (as compared to some 40 to 45% of HFC-134a compressors) (Table 30).

The experiences gained from the European market, where manufacturers had the chance to test both the technical options HFC-134a and hydrocarbons on a large scale, suggests that hydrocarbons would be a preferable option to convert the remaining half of CFC-12 compressor production. Technical, economic and ecological evidence does support this conclusion [Inf96].

Since the purchasing power of the global markets to be converted yet from CFC-12 to a non ODS is lower and so are the cleanliness of the industrial manufacturing as well as servicing conditions, the considerations which made Foron choose hydrocarbon blends initially may have to be re-evaluated. Foron had also operated within lower purchasing power segments of the German market. Taking into consideration the experiences from the Italian market, Necchi has developed a parallel line of hydrocarbon blend compressors showing good results [Bis96].

Table 30: Overview of regional distribution of compressor production capacity (in thousand units), share of hydrocarbon compressors

Type	Western Europe	North America	Latin America	Eastern Europe (f. USSR)	Japan Asia	Mid East/ Other	Total Compr. for Domestic
Electrolux	13,000	4,100	450	-	1,650	1,300	17,700
Embraco	5,000	-	9,200	-	1,000	-	15,200
Matsushita	-	5,000	-	-	8,000	-	13,000
Tecumseh[1)]							
Danfoss	7,000	-	-	-	-	-	7,000
Daewoo	-	-	-	-	2,500	-	2,500
Sanyo	-	1,800	-	-	2,500	-	4,300
Türk Elektrik	-	-	-	-	-	1,500	1,500
Hitachi	-	-	-	-	1,000	-	1,000
Necchi	4,000	-	-	-	-	-	4,000
Total	25,000	15,000	10,000	5,000	20,000	5,000	80,300
HC [2)]	4,500	0	100 - 500	100	1,000	100	5,000

1) No numbers concerning production or capacity published.

2) Isobutane > 95%

Cost Differences Between Hydrocarbon and HCFC/HFC Technology

Influencing Factors

It is not possible to make a general statement about the production costsof hydrocarbon or HCFC/HFC technology. Instead, the following cases have to be distinguished:

- The selection of **foam technology** has to be **separated from** the selection of **refrigerant technology**. Besides HFC-134a/HCFC-141b and isobutane/cyclopentane, the combination of HFC-134a/cyclopentane is also common.
- The design characteristics of the refrigerator model strongly influence its cost.

The production costs for **converted CFC-models** may vary from the production costs of **models specially designed** for the use of a specific alternative refrigerant. For different blowing agents the costs between converted and newly designed models do not differ significantly.

The **type of refrigerator -** one temperature, two temperature, no-frost **-** as well as its **size** strongly influence the production costs

- Production costs are dependent on the adaptation of the production process to the needs of the manufactured product. The desired level of adaptation is determined by each production facility, with various levels of investment, production costsand other criteria (e.g. flexibility). This will lead to a difference in production costs between **new production sites** and **converted ones**.
- The **component costs** differ depending on various issues. They have to be looked at separately (see 10.2).
- Depending on the technology choice for the refrigeration circuit, the costs for aftersales service (warranty) will be a significant portion of the total production costs, much higher than with CFC technology. The **organisation of after sales service** currently available will strongly influences the future costs for after sales service (see 10.5)

The distinctions mentioned above will influence the production costs for refrigerators with HFC/HCFC or hydrocarbon technologies in a different ways. One technology will benefit from certain circumstances, while another technology from others. In the following paragraphs, more detailed information about the influence of the different factors is given:**New Refrigerator**

Models/Converted Refrigerator Models
The cost effectiveness of the conversion to cyclopentane foam versus HCFC-141b of an existing refrigerator has not been established yet and depends mainly on the necessity on a change of the material for the liner. The conversion of an existing refrigerator to HFC-134a is for some models more cost effective than the conversion to isobutane because of the additional safety features which should be incorporated in a hydrocarbon design, which is a more complex task in case of a conversion.

Type of Refrigerator
A one-temperature appliance can be converted to a mixture of isobutane and propane, with the same compressors used as with CFC-12. For two-temperature appliances, there are no specific advantages for either refrigerant option. No-frost appliances are equipped with more electrical equipment than other models, which leads to an advantage for HFC-134a as refrigerant because of the higher component costs for spark-free, low temperature intrinsically safe electrical equipment needed for hydrocarbons.

Size of Refrigerator
Small appliances (smaller than 300 litres inner volume) usually benefit from the use of hydrocarbon technology because the energy efficiency of very small swept volume compressors is low, a problem already known from CFC-12 appliances. For an isobutane compressor with a larger swept volume, a high energy efficiency can be achieved with low costs compared to HFC-134a. For these small refrigerators, no significant increase in compressor shell size is expected, a decrease in compressor costs for isobutane compared to HFC-134a seems possible.

For appliances between 300 litres and 500 litres inner volume, no size-related cost difference between hydrocarbon and HFC technology is expected.

Large appliances (larger than 500 litres inner volume): The compressor shell size for isobutane is likely to increase compared withCFC-12 or HFC-134a. In some cases, the conversion of an existing refrigerator design, this may lead to investment in a new form for the inner liner. Investment costs may be at least US$50,000. Technically, it is possible to use propane, as refrigerant for these cycles, and this will lead to an even smaller compressor size than with CFC-12. Due to the market situation in the countries where hydrocarbon-technology is used - i.e. low market share for large appliances - this approach has never been investigated.

New and Converted Production Sites

The conversion of existing production sites in Article 5 countries to hydrocarbons may be easier to achieve than a conversion to HFCs. For hydrocarbons - blowing agent as well as refrigerant - additional safety equipment has to be installed. Often, the necessary standards and the experience is available because gas is the primary source of heating energy and also for production processes - contrary to Article 2 countries, where heating processes in production nearly always use electricity as energy source. If cyclopentane is already used as the blowing agent, the educational and organisational difficulties concerning the use of flammable substances in the factory have already been solved, such simplifying the introduction of isobutane into the production process. Conversion to HFC-134a production requires air conditioning (humidity content reduction) plus production reorganisation, which in turn causes the need for additional space and for time - both usually in short supply if production has to run continuously. In every case of conversion, personnel have to be educated.

New production sites allow more cost effective implementation of the features necessary for HFCs as well as for hydrocarbons. There might be a slight cost advantage for HFC/HCFC technology due to the necessary installation of safety equipment.

Components

In general, the costs for the components are influenced by a lot of different factors. As an example, some of the factors influencing the costs for a compressor are given below. The influence of the different factors on costs have been roughly estimated; the results of this estimation is given in brackets as cost increase on top of the lowest compressor costs concerning the factor. As an example, a compressor with a high cooling demand can cost 100% more than a compressor with a low cooling demand.

Costs influenced by consumer market demand and technical reasons

- Cooling demand (100%), depending in turn on
    - size of refrigerator
    - insulation
    - one- or two-temperature model
    - climatic region

The type of refrigerator to be produced determines the cooling demand. This value can only be changed slightly without changing the product characteristic totally.

- desired energy efficiency (15%)
- refrigeration oil (hydrocarbon: 0%; HFC: 7%)

Costs influenced by component market

- amount of this type compressor manufactured (>100%)
- total amount of compressors purchased by this customer (>10%)
- location and policy of compressor manufacturer (10%)
- renown of manufacturer (15%)
- warranty (10%)
- commercial availability (20%)

In the opinion of the authors, a cost comparison of components should be made on the basis of similar conditions at the component market.

A list of the components is given below. For the case of conversion from CFCs to alternatives, changes in components as well as in production are necessary. In the list, components which have to be changed at least in some respect are followed by the substance causing the change, given in *italics*.

- Refrigeration circuit:
    - Compressor with refrigeration oil *(HFC, isobutane)*
    - Evaporator (Roll bond *(isobutane: Either evaporator or electrical devices to be changed*), no-frost or foamed in)
    - Condenser
    - Capillary Tube *(HFC, isobutane)*
    - Refrigerant *(HFC, isobutane)*
- Housing:
    - Thermostat *(isobutane)*
    - Lamp and lamp switch *(isobutane)*
    - Heater for defrosting (only no-frost) *(isobutane*)
    - Evaporator fan (only no-frost) *(isobutane)*
    - Drawers etc.

Obviously, the amount of changes in components is higher converting to isobutane as refrigerant compared to changing to HFC-134a. The type of the blowing agent does not affect the components.

Table 31 shows a cost comparison for components of the refrigeration circuit for different refrigerants.

Table 31: New refrigerants. Cost indexes (CFC-12 = 100)[SCH95]

	CFC-12	HFC-134a	HC-600a	HC-290/HC-600a
Refrigerant	100	600	70	70
Standard compressor	100	110	108-115	102-104
Refrigeration system	100	102	100	100
High efficiency compressor	100	110	100	100

The additional component costs for conversion were estimated by a refrigerator manufacturer. This manufacturer gave the span of cost increase for the components in case of a conversion from HFC-134a to isobutane. The values are summarised in Table 32.

Table 32: Isobutane dependent possible extra cost per appliance changing from HFC-134a to isobutane [Jue95]

Object	Change	Est. cost in US$
Compressor	Necessary changes (total)	0 - 8
	- stand. to high efficiency.	3 - 5
Electrical parts	total	0 - 20
Evaporator	Necessary changes (total)	< 1 - 8
	- added layer	1 - 2
	- extd. suction line	< 1 - 2
	- safety evaporator	3 - 8

For the components with the highest share on production costs, compressor and evaporator, a more detailed breakdown of costs was performed to show the reasons for cost differences between CFC, HFC and hydrocarbon technology. Finally, some information concerning the costs of refrigeration oil and refrigerant is given.

Compressor

- Similar electrical capacity - similar electrical motor
- Displacement isobutane approximately 2 times larger than CFC, HFC
    - Similar manufacturing procedure
    - More steel required
- Cylinder head, valves, ...: Similar technology
- Compressor shell: For high capacities larger shell required for hydrocarbons
- Oil (200 to 300 ml): Mineral oil for hydrocarbons, ester oil for HFC: Cost advantage for hydrocarbons

- Quality assurance and control: Higher effort for HFC-134a: Cost advantage for hydrocarbons

- Summary: Slightly higher machining time and more steel for isobutane, more expensive oil for HFC: No cost difference between hydrocarbons and HFC expected if identical situation at component market.

Evaporator:

- Foamed in evaporator:
    - No major differences
    - Some manufacturers increased internal channel diameter for hydrocarbons: Higher work quality required. Presently no indications for positive influence on refrigeration cycle.
    - Summary: No cost difference between hydrocarbons and HFC expected if identical situation at component market.

- Roll bond evaporator:
    - Alternative 1: Double aluminium liner for hydrocarbons - no changes in electrical equipment in compartment necessary
        - Slightly higher weight for hydrocarbons - added thickness of both layers only slightly higher than previously one layer.
        - Slight difference in manufacturing procedure compared to CFC, HFC
        - Costs mainly proportional to weight
        - Hydrocarbon evaporator expected to be 5% more expensive than HFC model if identical situation at component market.

    - Alternative 2: Standard evaporator for hydrocarbon - changes in electrical equipment in compartment required: For evaporator, no cost difference between hydrocarbons and HFC
    - Some manufacturers increased internal channel diameter for hydrocarbon: Higher work quality required. Presently no indications for positive influence on refrigeration cycle.

- No-frost evaporator: Changes in electrical equipment in compartment required for hydrocarbons

Lubricant and Refrigerant

The costs of the different refrigerants differ per refrigerator only slightly because of the low total filling mass of refrigerant. The refrigeration oil to be used with the refrigerant has a higher influence on refrigerator costs, the difference between the alternatives are nearly one percent of the total refrigerator production costsfor a simple model. The values for refrigerant and refrigeration oil [Kui94] are shown in Table 33:

Table 33: Costs of lubricant and refrigerant per refrigerator [Kui94]

Refrigerant	Lubricant US$	Refrigerant US$
CFC-12	0.5	0.2
HFC-134a	1.5	0.6
HC-600a	0.5	0.2

Foam

In comparing the costs of implementing the technologies to replace CFC-11 in foams the two main factors are the capital costs to convert the manufacturing plant to operate safely with flammable cyclopentane on one hand and the increased costs of more sophisticated plastic liners necessary for use with HCFC-141b on the other.

A study in Korea [Lee95] has given the following costs which include those associated with the foam, the plastic liner and the capital investment. These are illustrated in Table 34 relative to reduced CFC-11 technology.

Table 34: Total Cost Comparison [Lee95]

Reduced CFC-11	HCFC-141b	Cyclopentane
100	120.8	110.1

In the context of the conversion of refrigerator and freezer factories in developing countries and the financing of these conversions by the Montreal Protocol Multilateral Fund a study [Wor94, Wor93] was undertaken of the relative costs of implementing the various options in a factory producing 200,000 units per annum. The results are expressed in terms of a unit abatement cost (UAC) which is the cost to replace a unit of ODS (ozone depleting substance). The results are shown in Table 35.

Table 35: Cost Comparison, CFC Replacement [Jef96]

$/(kg/Year)	Reduced CFC-11	HCFC-141b	Cyclopentane
UAC	0.87	5.45-15.56	2.62

The range of UACs for HCFC-141b projects reflects the various plastic liner technology options. These studies are in agreement that cyclopentane provides the most cost effective CFC-free overall option. Furthermore, the conversion to HCFC-141b technology may result in additional costs to subsequently replace it by a zero ODP technology.
Whilst cyclopentane is typically 50 - 70% of the price of HCFC-141b (per kg) and less is used in a formulation, the potential saving can be negated by the greater use of other components. Foam cost contributions are strongly influenced by the density changes discussed in section 4.3.

Production Process

In the following section the **production process** of a refrigerator is described. There is a slight difference in production between use of open roll bond evaporators, which are often used in older designs, or the foamed-in and no-frost evaporators. Differences between hydrocarbon and HFC technology production are marked in a way that CFC production is used as a baseline, and derivations from it are marked in italics. The production steps are

- Production of external housing/door outside
- Production of door inside *(HCFC: Liner material)*
- Production of inner liner *(HCFC: liner material; isobutane: design change if compressor too large)*
- Assembly of inner liner, evaporator (only for foamed-in evaporators)
- Assembly of external housing
- Foaming *(Cyclopentane: Safety equipment to be installed)*
- Mounting of evaporator (only for roll bond evaporators)
- Mounting of light, thermostat *(isobutane: Design change for gas tight housing in case of no-frost or unchanged roll-bond evaporator)*
- Mounting of compressor, condenser, capillary tube
- Assembly of refrigeration circuit *(HFC: Removing of joint protection and connection of parts directly afterwards; Isobutane: Improved leak test)*
- Charging *(HFC, Isobutane: Better vacuum equipment)*

- Assembly of electrical equipment *(Isobutane: Connections designed in a way that disconnection and sparks can be excluded)*
- Mounting of door
- Testing
- Mounting of the interior
- Packaging

In total, an increase in production costs compared with CFC is likely for each alternative. There seems to be no difference in production costs between hydrocarbons and HFC if the write-off for investments is excluded. The investment costs for cyclopentane are more than compensated by the costs for substituting the inner liner material to be able to use HCFC-141b. The estimated cost increase for handling of a isobutane refrigerator compared to a CFC refrigerator is 1 to 2 US per appliance [Jue95].
If a conversion of the foam blowing agent to cyclopentane is planned, the additional safety costs to be able to use isobutane as refrigerant are relatively small.

After Sales Costs

After sales costs are those costs which arise when the refrigerator is already sold to the consumer. These costs cover mainly warranty claims. There are two reasons for a manufacturer to keep the number of warranty cases low: The increase in production costs due to after sales service and the damage to the brand name which might be caused by malfunctioning equipment. After sales service can in general be performed at the manufacturers place, or decentralised at or near by the consumer.

For medium and large production facilities of refrigerators, an after-sales service at the production site is not feasible. For the consumer, the effort to transport the appliance to the manufacturer is not reasonable. Both hydrocarbon as well as HFC refrigerants require changes in the after sales service. In case of hydrocarbons, the technicians have to be trained for their own good to avoid accidents. HFC-134a requires training and strong work discipline.

In cases where after sales service is performed by private enterprises, e.g. the informal sector in A5 countries, it does not seem to be feasible to train service engineers to use HFC technology in a proper way, because certain needs of HFC technology are contrary to their interests. For example, oil is usually significantly cheaper if sold in quantities of 1 litre or more compared to 300ml-containments. The cost difference amounts in the case of ester oil in India to around one week of income per litre of oil, while at the same time open oil cartridges have to be disposed of once the original seal is broken and some oil is removed. Because the consumer has no means to control the oil, it is likely that humidity-contaminated oil will be used. The training of the informal sector hydrocarbon-technology seems possible because the interest of service personnel and technical needs are similar.

If there is already a service capability, the conversion to hydrocarbon technology seems to be more cost effective than to HFC technology because of the reasons mentioned above.

Both technologies require new equipment, particularly new vacuum pumps for servicing. While the new pumps for isobutane can also be used to service CFC-12 refrigerators, there are often compatibility problems with vacuum pumps and other equipment (filling hoses etc.) for HFC-134a if they are used with CFCs or hydrocarbons. The extra logistics necessary again mean that HFC-134a is the higher cost option.

Factors Influencing Consumer Market

Refrigerators and freezers are consumer products. The task of the refrigerator manufacturer is not only to produce systems providing a cool space for storage of food but to provide consumers with certain expected features to convince them to buy that very product. As such, the features of household appliances in general and refrigerators and freezers in particular are highly dependent on the local markets. These markets differ world-wide in preferences for the refrigerator size, the presence and size of a freezer compartment in a refrigerator, no-frost features, energy consumption, certain electronic controls and price level of the appliance accepted by the market.

Because of the necessary variety in refrigerator models and because of the relatively high transportation costs, refrigerators are built locally and sold locally. In contrast, the main component compressor, having a much higher ratio of value per transport volume, is a world market product.

In many countries consumers' decisions are mainly based on the initial price of the appliance /Gomez/. So far, the safety acceptance of the consumers has not been an issue in general. In those regions where hydrocarbon refrigerators are used, the customer concern of a flammable refrigerant within the refrigerator is very low. According to one refrigerator manufacturer, the consumer safety acceptance is not an issue, because the consumer (correctly) assumes that the manufacturer will address the safety issues /Whirlpool/.

The expected - or required - energy efficiency of the systems is another important feature of refrigerators. In Article 2 countries, labelling schemes support customers in evaluating the annual power consumption. Customers do assess overall lifetime costs of refrigerators, including the expected energy costs. In addition, in some countries, e.g. in the US, government regulations enforce standards with respect to the acceptable energy consumption of appliances. According to local experts /Rademacher/, the required minimum energy efficiency for models sold from 1993 onwards in the US has already been quite difficult to achieve. Therefore, an increased energy consumption - either caused by a less efficient refrigeration cycle or higher heat input due to the refrigerator's insulation - is a significant barrier for any new technology. An increase in insulation thickness is only possible if the inner compartment of the refrigerator is sized down due to the fact that in the main refrigerator markets (US, Japan, Germany) the outside dimensions are either defined by standards or self-defined by the market; in both cases, changes of outside dimensions of the refrigerator will most likely not be accepted in the market /Rademacher/. A few years ago, such an attempt failed completely in Germany /BSHG/.

The introduction of hydrocarbon refrigerators has been consumer-driven. Big mail order companies took the lead in that process in the German market. Since Germany - in particular after the reunification - is the most important market in Western Europe, other European suppliers had to launch hydrocarbon refrigerator production as well. Due to the above mentioned short supply of hydrocarbon compressors, much advanced CFC phase-out dates (1.1.1994) in some countries such as Sweden and Switzerland, and restricted national safety regulations in the United Kingdom and the Netherlands, for instance, most Western European countries converted to HFC-134a first. Outside Germany sales of hydrocarbon refrigerators started to pick up sizeable dimensions in the course of 1995 only.

In the southern European countries, no comparable environmental movements in favour of CFC/HFC-free technology has been observed. Nevertheless, it is expected that the consumer will not hesitate to choose the hydrocarbon refrigerator for environmental reasons if it has equal performance, meets the customer requirements similarly and has the same price as the HFC competition /BSHG/. So far, only one manufacturer produces hydrocarbon refrigerators on a large scale in Southern Europe for the Southern European markets. It is possible that if such a product is marketed increasingly in Southern Europe, that market could also be converted to hydrocarbons /BSHG/.

In the United States, there is an overwhelming consumer preference for frost-free refrigerators (>95% market share[ASH88]). Presently, the US refrigerator manufacturers have converted to HFC-134a/HCFC-141b completely. There are severe liability concerns against the use of hydrocarbon technology, in particular using hydrocarbons as a working fluid. These concerns are raised because of the US liability laws and jurisdiction.

In Japan, mainly no-frost appliances are requested by the customers /INFRAS/. There seems to be no market pressure towards hydrocarbons out of environmental or other reasons. increasingly, the use of isobutane is promoted in Australia and New Zealand, and there does not seem to be a problem with the market acceptance of flammable refrigerants /Roke/.

In the majority of Article 5 countries, refrigerators are - besides TV - one of the first „luxury“ goods purchased by those who reach middle class incomes. Since the price of a refrigerator is equivalent to 2-3 monthly salaries of a middle class family, a significant saving time is necessary to be able to purchase a refrigerator. Therefore, in Article 5 countries the cost and servicing issues are much more important than they are in Article 2 countries. Higher purchasing costs mean a significant delay in purchasing the (first) refrigerator. If significant energy savings are achieved compared to the presently sold models, it might be possible to convince some customers to purchase the energy saving model for cost and environment reasons in the top model class /Electrolux India/. In regions with poor quality of power supply improved insulation would enlarge the time span for which a refrigerator maintains food preserving temperatures during power cuts.

Conclusions

CFC-12 has been used almost exclusively as a refrigerant in refrigerators and freezers due to its superior properties. It provides a good energetic performance, although its stability and oil behaviour has led to some laxity in handling but this does not have any negative effects on the refrigerator. The only demerit of CFC-12 is the significant contribution to ozone depletion which has resulted in a phase-out of this substance. As a substitute two fluids are at present used in developed countries and are under consideration in those countries which will phase-out within the next years: HFC-134a and hydrocarbons. Both of these alternatives have zero ODPs but each has other disadvantages. Thus, if the ozone depletion caused by CFC-12 has to be eliminated the merits and demerits of both substitutes have to be compared and evaluated for the specific situation of a manufacturer.

The disadvantage of HFC-134a compared with CFC-12 and hydrocarbons is its incompatibility with several materials and lubricants currently used with CFC-12. This requires significant changes in the production process and for the service sector to ensure a proper operation over its lifetime. On the other hand the important demerit of hydrocarbons in comparison to CFC-12 and HFC-134a is their flammability which has to be handled in production and servicing at the customer's home.

The problem of flammability can be dealt with as seen in many other industries where inflammable substances are in use and safety installations and safety procedures for handling have been developed. Dealing with fire and flammable substances is part of life in all societies throughout the world. Each mechanic knows about the possible danger and how to prevent dangerous situations and will follow instructions if only to protect himself. However, since refrigerator manufacturers have not used flammable substances for several decades there are reservations on grounds of product liability concerns. Further training will be necessary as the vast majority of technicians do not think of refrigerants and flammable hydrocarbons in the same context, they expect their burning torches to ignite and their refrigerants to be non-flammable.

While the current quality standards in production and servicing used with CFC-12 are also sufficient for hydrocarbons, HFC-134a does require a higher quality standard. In contrast to the handling of flammables, ensuring a high work standard in the assembly of HFC 134a units is exceptionally demanding.

In the selection of a foam-blowing replacement for CFC-11 the situation seems to be the same as that of the refrigerants: on the one hand there is HCFC-141b, which enables the use of existing machinery with only minor modifications and offers low conductivity foams, and on the other hand the flammable but natural hydrocarbon cyclopentane. But when used as a blowing agent, the position of the hydrocarbon compared with halogenated fluids is even stronger than as a refrigerant since HCFC-141b still contains chlorine and therefore has to be phased out. In addition the flammability of cyclopentane can be handled easier as only the production process is affected whereby a few workers can be trained in the handling of this flammable fluid. The consumer and the servicing sector are not affected by the blowing agent used, a study of Underwriters Laboratory proves that the safety level here is identical if CFC-11, HCFC-141b, or cyclopentane is used for blowing.

Besides these significant differences the hydrocarbon technology appears to be in line with the requirements of sustainable development in developing countries for the following main reasons:

- Hydrocarbons are an old and relatively simple technology, suited for production in A2 as well as in A5 countries. In contrast, even if HFC-134a can be produced under conditions prevailing in A5 countries, it is very doubtful if this is possible for the present refrigerator manufacturers in those countries who are independent of multinationals, and there is no service concept at all to ensure long-term operation in the field.
- The choice of hydrocarbons as alternative offers the advantage of independence from high-tech-manufactured or patented substances such as HFCs, HCFCs and the synthetic oils. These substances would have to be imported from industrialised countries or a production license would have to be purchased while hydrocarbon fluids can be gained from local refineries and purified at new local facilities at least in major A5 countries. Hydrocarbons are not patentable.

Applications on the basis of hydrocarbon refrigerants are based on safety know-how plus an old and relatively simple technology, suited for production in A2 as well as in A5 countries. Even if HFC-134a appliances can be successfully produced under conditions prevailing in Article 5 countries by manufacturers with technology tie-ups to multinational companies, it is very doubtful whether the same is feasible for independent manufacturers, which have to rely on the technology transfer facility offered under the procedures of the Multilateral Fund. Further on, no service concept for HFC-134a-based appliances has been established so far to ensure long-term operation under conditions of Article 5 countries.

On the other hand, experiences from countries with established LPG servicing practice of CFC-12 appliances such as Cuba /INF96b/ show that no serious hazards may be expected.

In Europe about 8 million units have been produced and are in operation without any safety incident related to hydrocarbons at the household level. This indicates that hydrocarbons as refrigerant and blowing agent can be handled in a safe way.
The new technology seemed to incorporate a greater risk for the manufacturer and the user than the CFC technology. The comparative evaluation of the hydrocarbon refrigeration technology and of other technologies using hydrocarbons have supported the assumption that the safe use of hydrocarbons in refrigeration applications has become an established and well-accepted technology. This conclusion is also based on the fact that refrigeration applications are technically tight, whereas several other systems of widely accepted applications of flammable substances are not.

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9 THE WORKSHOP PAPER

- September 1996 -

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Context

This paper is part of a series of four papers which give an overview of the conclusions and findings of a study programme initiated by the World Bank and sponsored by Germany's GTZ and the Swiss Agency for Development and Co-operation, under the title "Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market". The study programme has had a number of components:

- a review of the technology, market, costs and environment issues of hydrocarbon technology in comparison with HFC and HCFC technologies (*Technology, Market, Costs and Environment Study: Hydrocarbon Technology in Relation to HFC/HCFC Technology)*
- a study of the non-technical barriers affecting the rate of adoption of hydrocarbon technology (*The Barriers Paper)* together with a number of country case studies
- a workshop, which provided an opportunity for the findings of the study to be presented and discussed, for the validity of the barriers to be examined and, for possible actions to be explored (*The Workshop Paper)*
- an integration of the findings from the Workshop with the Barriers Paper (*Technology Transfer Issues Paper).*

1. The Workshop

1.1. Introduction

An important part of this initiative was the convening of a Workshop with the participation of many of the key stakeholders in the refrigeration sector. The Workshop provided an opportunity for the draft papers (technology, market and barriers studies) to be reviewed and for stakeholders' views on the underlying issues to be explored. This paper provides a record of the processes and findings of the Workshop which was held in Schaffhausen, Switzerland from June 5 - 7, 1996. The Workshop programme is provided in Appendix I. The Workshop aimed to offer:

- an opportunity for amendments and guidance to be given on the three papers
- an opportunity for any additional barriers to considered for inclusion at the Workshop
- an opportunity for stakeholders to make a contribution to the main issues.

1.2. Structure of this Paper

This report provides a link between the Barriers Study Paper and the Technology Transfer Issues Paper by showing how guidance was given on the barriers and how the key findings emerged.

In the following sections we describe the objectives of the Workshop and how the programme and approach of the Workshop sought to meet them. The Workshop style was one that invited participants to contribute to the discussion of the issues in work groups through a structured approach called Metaplan. This approach allowed participants to present their ideas in a very visible and democratic way. In Sections 2 - 7 we describe the outputs and processes of each of the work groups (photographs of the output are provided in Appendix IV) by providing (largely unedited) descriptions of the brainstorming process, the development of a landscape of ideas and the recommended actions. We have provided brief summaries of the presentations made by the rapporteurs of each of the work groups and of some of the points raised in the ensuing discussions; in some cases we have used the written comments sent to us by the rapporteurs of each of the groups. Transcripts of the closing remarks made by Fraser Morrison, Deloitte & Touche Consulting Group, and Ken Newcombe, World Bank are also given. In the final section we provide some of the feedback that we received from some of the participants about the style and worth of the workshop.

1.3. Workshop Preparation

When the initiative was first conceived by the World Bank and the other sponsors, a Workshop was proposed as a means to bring together all the interested parties. It was felt that this would provide an opportunity for a better understanding of the real issues by the sponsors and offer a means for stakeholders to contribute in a participatory manner to any actions or interventions that might be considered appropriate.

A Workshop was considered to be an appropriate way for the issues, which are highly complex and technical, to be explored in an informal, constructive and participative manner. The participants, which numbered 73, at the Workshop included representatives from multilateral institutions, governments, industry and non-governmental organisations from both developed and developing countries. A list of participants is presented in Appendix II.

In view of the diversity of the interests of the stakeholders, which included commercial, political and environmental concerns, it was proposed that the workshop style should strive to allow the stakeholders to discuss and resolve the issues in a manner that would be effective, constructive and non-confrontational.
It was proposed that the use of moderated work groups with experienced facilitators would be the most appropriate means to address the issues and the "Metaplan" approach was agreed. This technique has proved to be highly successful in resolving highly contentious issues and can be used at various levels; it is commonly used in the corporate planning process of many organisations and for project planning within donor agencies. Metaplan uses visual aids and participants are encouraged to write their ideas on small cards which can be stuck on boards and presented to other participants. The "core" working material of the Workshop was the Inventory of Barriers set out in The Barriers Study paper; the inventory was enlarged onto poster size paper and used as a means to provide a focus for the Workshop. The Inventory of Barriers is provided in Appendix III.

The location of the Workshop was important in terms of providing a conducive work environment and a former convent (Paradies in Schaffhausen), now used as a corporate training centre, was selected. This location offered a large room for plenary sessions, smaller rooms for the work groups, a courtyard and cloisters for informal discussions and presentations, and provided a relaxed and informal atmosphere.

1.4. The Workshop Format

The Workshop was hosted by SDC, with their consultant, INFRAS, making all the practical and logistical arrangements, it was chaired by both Deloitte and Touche Consulting Group and The World Bank, and GTZ took responsibility for the moderated work groups.

The Workshop programme comprised formal presentations and moderated group work sessions which aimed to provide all participants with an opportunity to contribute. The Workshop ran over two and a half days and the full programme is provided in Appendix I.

The Workshop programme was structured so that each of the draft papers was formally presented by their respective authors. Through questions and comments from the stakeholders present, the aim was to reach agreement, or identify where further information was required, on:

- the technical case for hydrocarbon technology in the refrigeration cycle and to ascertain if it has any *technical advantages* over HFC based refrigeration technology in the CFC-free domestic refrigeration market; HC technology used in foam blowing is already considered to be a technically feasible option
- the *cost-effectiveness* (and possible cost advantages) of hydrocarbon technology when compared with other refrigeration technologies on a lifetime basis
- the *market opportunities* that exist, particularly in developing countries, for hydrocarbon technology, or where windows of opportunity exist to convert directly from CFCs to HC.

Key issues were selected to be the focus of the work groups for the following day. Work groups were formed to examine six of the barriers listed on the Inventory of Barriers from the Barriers Study paper. Representatives from each work group then reported their findings on the final day.

1.5. Metaplan

The style of Metaplan as a facilitation and moderation technique, is to encourage a form of open and transparent debate based on co-operation between the various parties. It seeks to strike a balance between aggression and total surrender, and between negotiation and discussion:

For group work to be undertaken on this basis, a few basic principles have to be followed:

- look at new ideas, rather than repeating old arguments and talking about what has already been said
- look to moving the process on, rather than holding it back
- take time, to make sure that all aspects are covered
- as the discussions are in English, be polite to those for whom it is not their first language
- ask questions before reacting too fast
- give the process a chance before dismissing it out of turn
- allow the whole group to participate and not just those who are "fast thinkers, fast speakers"
- don't let your temper get the better of you - take a deep breath first!

The way that Metaplan works can be shown in the diagrams overleaf.
Essentially, the process allows everybody to take part in a very visible, democratic way. The process, which is very structured, commences by widening the scope of the discussion so that all dimensions are included. Questions are the driving force of the process and, by the group voting on what is considered to be important, the issues become more focused.

Through the use of visual aids, ideas are written down on cards and pinned up on large boards; this means that ideas can be evaluated immediately and that results can quickly be seen.

For the process to work, the discussions are facilitated by a moderator who retains total neutrality and detachment from the issues. The group needs to be disciplined in following the principles of trust, understanding, generosity and openness so that they can be fully engaged in examining the issues.

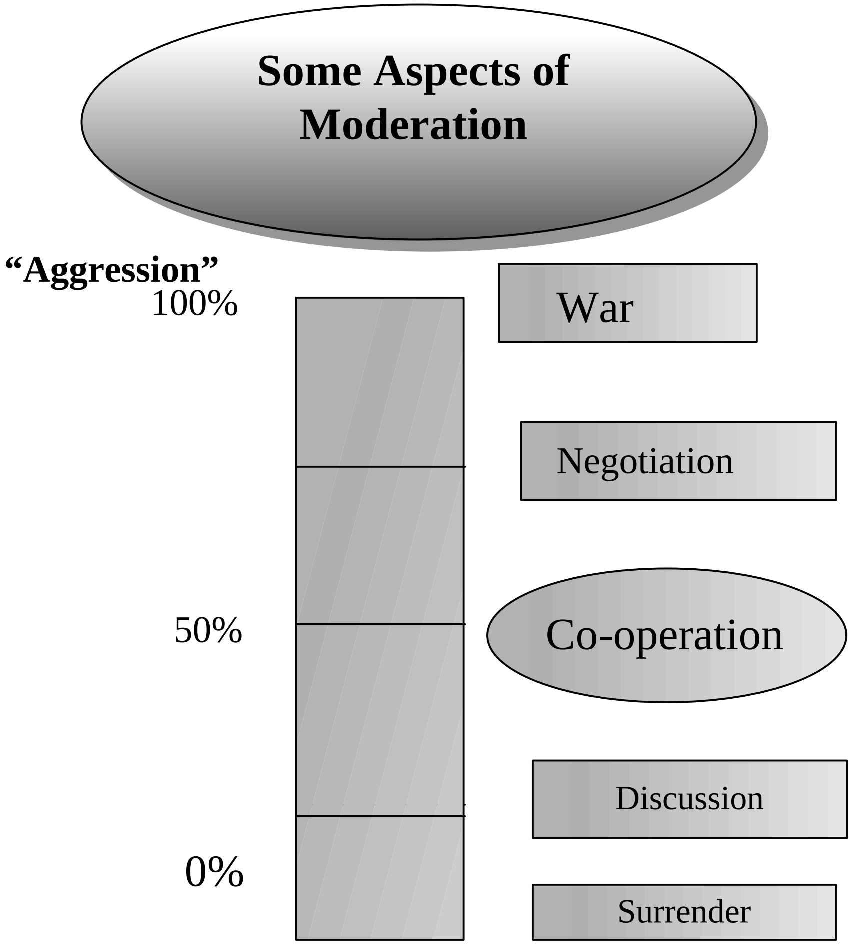
1.6. Proposed Structure of Group Work

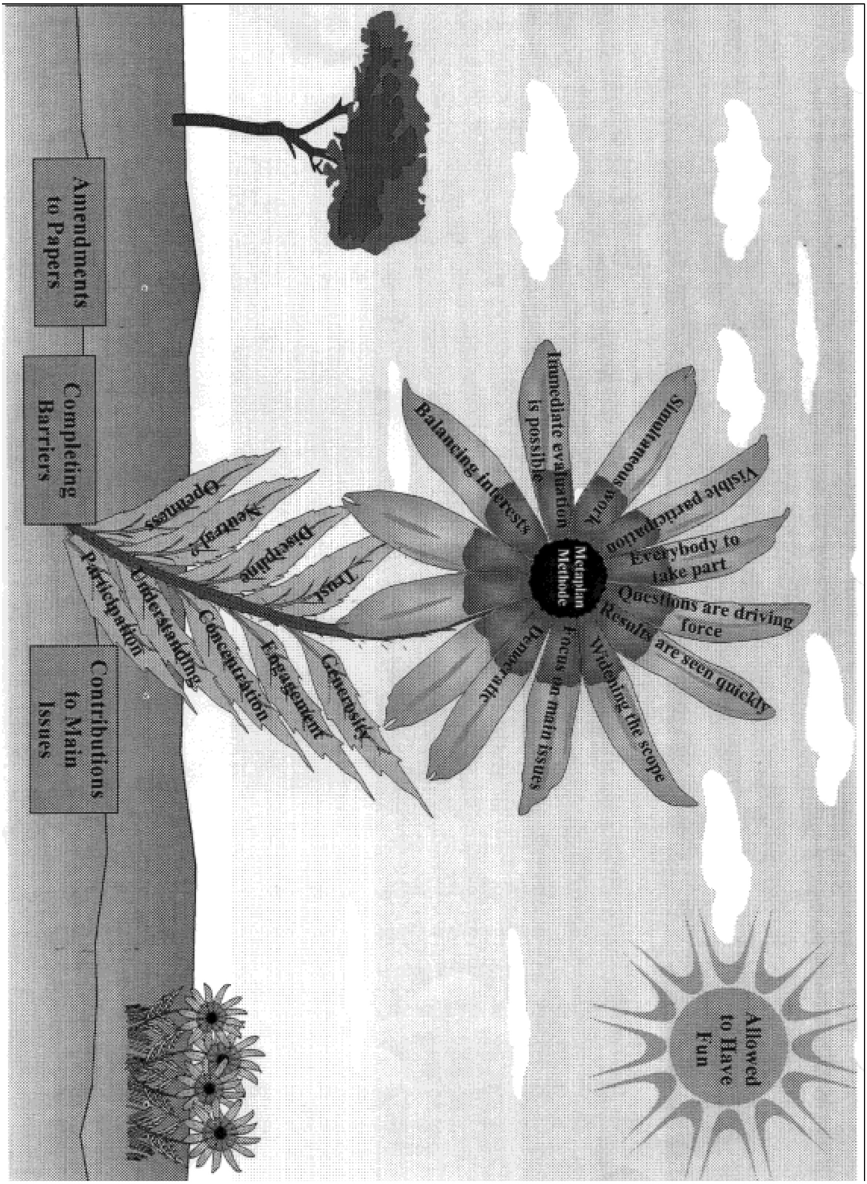
The core material for the Workshop was the Inventory of Barriers set out in the Barriers Study paper and participants were invited to add any additional barriers they felt were missing from the list. The original list of 41 barriers was augmented by a further eight barriers:

42.	Concern that there may in future be a move against HCs - as is happening with aerosol use in the USA
43.	Economy situation in Article 5 countries does not recommend the use of most expensive (HC) technologies
44.	HC technology may be surpassed by better HFC alternatives in the short term
45.	Non-traditional suppliers (without broad distribution basis) needed for HCs
46.	Higher incremental operating costs for HCs only partially covered by the Multilateral Fund
47.	For cyclopentane, there is an energy efficiency penalty, or redesign is required, or a more expensive compressor is required
48.	The existence of another alternative (HFC) technology provides key advantages (more energy efficient, more cost effective, non-flammable)
49.	Construction requirements between products within countries as well as internationally

In order to select the six barriers that were to be the focus of the group work, each participant was able to select and vote for the five barriers that they considered to be the most important and worthy of further investigation. To do this, each participant was given five adhesive coloured dots, as a proxy for votes, that they were to stick to the Inventory of Barriers.

The results of the voting were very visible and, from the 49 barriers, the following received the most votes:


Some Aspects of Moderation
"Aggression"
100%
50%
0%
War
Negotiation
Co-operation
Discussion
Surrender


Amendments to Papers
Completing Barriers
Contributions to Main Issues
Openness
Neutrality
Discipline
Trust
Participation
Understanding
Concentration
Engagement
Generosity
Metaplan Methode
Balancing interests
Immediate evaluation is possible
Simultaneous work
Visible participation
Everybody to take part
Questions are driving force
Results are seen quickly
Widening the scope
Focus on main issues
Democratic
Allowed to Have Fun

	BARRIER	NO. OF VOTES	
9.	Through commercial agreements e.g. joint ventures, licensing agreements etc., between developed and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology	29	Group A
28.	Consumers are more interested in the price of their refrigerator than ecological benefits	23	Group B
32.	There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry as a whole and especially to developing countries	22	Group C
2.	The investment costs for changing a production line to HC (costs for safety measures) are higher than for HFC-134a	16	Group D
31.	There is widespread ignorance about the disadvantages of synthetic replacements (e.g. 134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries)	15	Group E
14.	Manufacturers fear misinformation campaigns and adverse publicity against HC from the chemical multinationals as well as from competing manufacturers	12	Group F

Participants were then invited to sign-up for two work groups (one morning and one afternoon session) on a first-come-first-served basis, so that the numbers in each group were limited to 22.

The format of the group work was as follows:

	For consideration:	How?	Time (min)	Output
1.	What is the issue all about?	Brainstorming	15	List of ideas/issues
2.	What is most important?	Each participant votes with 3 "dots" (maximum of 2 dots in each field)		
3.	What is the real issue?	Discussion about the outcome: is this what you expected?	15	
4.	What action do you recommend? (no negative contributions to the discussion permitted)	Individuals create ideas and write them down on cards	10	Cards are stuck on boards to develop a "landscape of ideas"
5.	Where should we start in dealing with these actions?	Each participant votes with 3 "dots" (maximum of 2 dots in each field)	15	
6.	What are the first concrete steps?	Individuals create ideas and write them down on cards	10	Recommendations are presented
7.	Who should take up the actions?	Discussion about possible names (both from within the group and outside)	15	
8.	Who is going to present the results?	Volunteers from the group	5	

Suggestions were offered as to how the process should proceed:

- focus on the solutions, don't fight like heroes
- accept that the group includes a lot of people with very different interests
- the group should take each issue for what it is
- the focus should be on how the issues can be tackled
- there should be a particular focus on developing countries
- this is the "right" time (Kyros) rather than the "time" (Chronos) to do something
- trust yourself

1.7 Concerns expressed about the Workshop Process

Many of the participants at the Workshop were unfamiliar with the Metaplan approach to looking at issues and a number of concerns were raised. The chief concern was that the issues selected for further examination would not be the most important ones. As only six of the barriers were to be covered in detail, there was concern that the Workshop would not provide thorough coverage of the issues.

There was particular anxiety that some of the barriers included in the Inventory of Barriers were the perceptions of individual stakeholders and that some of the barriers were based on inaccurate information or an incorrect understanding of the issues. There was concern that the Workshop proceedings did not permit an opportunity for stakeholders to make formal representations to correct these barriers. In addition, there was concern that the dominance of certain groups at the workshop could adversely influence the workshop discussions.

There was also a fear that the conclusions of the workshop could be viewed as "industry consensus" and that the workshop outputs would form World Bank/Executive Committee policy.

These concerns were acknowledged as important. In the preparation for the Workshop, many of these concerns had already been expressed and the structure of the Workshop sought to deal with them. In particular, even though only 6 barriers were to be the subject of working groups, it was recognised that many of the reported barriers covered more than one issue and some of them related to similar points. Furthermore, the Metaplan approach allows the scope of the issue in question to be broadened, and then focuses attention on the important issues. For those issues that did not receive adequate attention, or for amendments to be made to the Workshop Papers, participants were invited to "post" corrections in a box provided at the Workshop, or to send their modifications to the study authors later. We have incorporated these amendments in the revised version of the Technology, Cost and Market papers and in the Technology Transfer Issues paper.

It was stressed by the Sponsors that it was doubtful whether the workshop would permit consensus to be reached and that policy decisions were not to be generated immediately from the workshop. The Workshop aimed to provide recommendations, if appropriate, and that this advice would not be binding in any way to the World Bank or to any convention.

2. Working Group "A"

"Through commercial agreements e.g. joint ventures, licensing agreements etc. between developed and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology."

2.1. Brainstorming

During the brainstorming session, the following issues were raised:

What is it all about?	*Votes*
1. The technology market is working for foam	0
2. Only a minority of conversion projects approved A2-A5 company tie-ups are funded by the MF (circa 20%)	0
3. Lack of confidence in HC refrigerant technology	10
4. Experts from implementing agencies were not fully informed as they were with HFCs and HCFCs; lack of "neutral" technology information	2
5. An Article 5 enterprise interested in HC technology (R600a) needs to make a special effort to get access to information	0
6. The barrier mentioned above is incorrectly perceived: the technology market for refrigerants is also working. Information flows are not visible to the public	2
7. Stakeholder market interests of key players are very influential in technology choice	0
8. Pattern of technology options adopted reflect the status of know how a few years back. Time schedule	1
9. Driving force for HFC-134a (e.g. in India) is due to the technology leadership of MNCs	13
10. Corporate policies of MNC refrigeration appliance users (e.g. Pepsi, Coca Cola) favour HFC-134a	0
11. Article 5 manufacturers need high degree of security that the choice he makes will be commercially successful	1
12. Decisions are shaped along manufacturers' expectations on which will be the dominant future technology option	4
13. Only a few competent technology suppliers in HC technology are available	12
14. Financial assistance received through MF does not cover full cost	7

Through the voting process, the "real" issues that emerged were the following:

- lack of confidence in HC technology
- lack of confidence in HC and HFC technology by A5 enterprises
- MNCs in driving seat
- only a few competent technology suppliers in HC refrigeration technology available

2.2. Recommended Actions

As participants considered what actions would be needed to address the issues identified above, a "landscape of ideas" was developed. A number of "clusters" emerged containing similar or related actions:

- improve information and "unbiased" technology support
- actions in Article 5 countries
- facilitate international technology transfer mechanisms

Cluster 1. Improve Information and "Unbiased" Technology Support

- there is a need to take local conditions of manufacturing and servicing for the choice of technology
- fair information must be given to Article 5 countries - no political matters
- obtain clear statement from potential Article 2 technology suppliers i) are they willing to transfer technology ii) what price for co-operation?
- involve people in the process who are experts in hydrocarbons Article 5 refrigerants and that have the knowledge and expertise on both aspects
- encourage more owners of HC so that technology choice is easier. Do not eliminate choice
- provide Article 5 countries with the opportunity to select a technology that is best suited to their individual market situation - not just the Article 2 solution ***(this point received the most votes for action)***
- competent HCT suppliers should take a more dynamic role in promoting/circulating HCT information
- it's hard to make a good recommendation: however, more information should be given to developing countries
- spread valid information/experience gained to Article 5 countries
- convince industry to publish "apples with apples" comparison of the two technologies
- MNCs should choose according to local conditions, like handling production, servicing etc.

How?

- expand capacity for technology transfer of companies - more products at reasonable costs
- have IIR organise a conference on i) R-134a/R600a ii) ??? alternative with reviewed papers and ensure neutral data
- neutral listing of pros and cons of both technologies
- encourage companies to make HC technology available
- create neutral international technology centre for assistance to Article 5 country government decision making
- technology evaluation by an independent international organisation including Article 5 members

Cluster 2: Actions in Article 5 countries

- create local source of HC technology assistance by i) demonstration projects ii) funding development in local research institutions (e.g. suitable in India and China) ***(this point received the most votes for action)***
- there is a need to generate information on safe servicing practice for HC refrigerators
- facilitate the development of independent R&D capabilities in Article 5 countries
- allow more time for confidence to develop in both HC and HFC technologies; reconvene in 2 years
- each Article 5 government has to consider local priorities and so decide for the adopted solution
- Article 5 governments must lead CFC phase-out

How?

- talk to HC refrigerant experts and involve them in the process
- Article 5 countries improve development ability with help from themselves and from Article 2 countries
- Article 5 countries must decide now which refrigerant has to be used in the country

Cluster 3: Facilitate International Technology Transfer Mechanisms

- MF buy HC technology and then provide it to all Article 5 countries through bilateral co-operation to certain countries
- meet again in two years (- in Paradies!)
- organise open "technology forums" to present fully and assess all available option
- UNEP technology option panel should give the technology recommendations to Article 5 countries in order to enhance their confidence
- re-think technology co-operation mechanism ***(this point received the most votes for action)***
- re-think allocation of funds
- study how technology can be better transferred to Article 5 countries

How?

- MF should revise its criteria e.g. fund Article 5 country to R&D technology
- ask ExCom to specify conditions for funding HC R&D and demonstration projects
- MF should be even more flexible with changes of technology for already approved projects
- make sure that resources go towards building national capacity for technology assessment
- fund "national or regional roundtables" on all technology options
- funding agencies to ensure applications have considered all options

3. Working Group "B"

"Consumers are more interested in the price of their refrigerator than ecological benefits."

3.1. Brainstorming

In the brainstorming session to establish what the issue was "all about", the participants identified the following:

What is it all about?	*Votes*
1. Looking at economic, rather than ecological benefits	5
2. Disposable income	0
3. No contradiction between ecology and economy in the long term	2
4. Lack of awareness of consumers (economic and ecology) technique	12
5. In the beginning, higher incremental costs (for HCs)	0
6. How do we make environmental benefit attractive to consumers	1
7. What difference is there between the cost of HC and HFC?	11
8. Market forces determine price	5
9. Different appliances cause different costs	0
10. Availability of raw materials (CFCs, components)	7
11. Regulation of Montreal Protocol	1
12. Additional transitional costs after MF funding	1

Two main themes emerged as participant voted for what they considered to be the most important:

- the need for cost studies
- the need for cost reduction

3.2. What action do you recommend?

Cluster 1: Cost Studies

- conduct cost studies to clarify the cost difference between HC and HFC
- comparative studies based on real experience
- find and analyse the difference in cost conversion between HC and HFC
- evaluation of real cost under long term scenario
- establish range of cost difference including raw materials, servicing costs, the technical advantages and disadvantages of HC and HFC
- find out the cost differences between converting from R12 to HC and from R12 to HFC

Cluster 2: Cost Reduction

- transfer appropriate and economical product design
- policies to encourage HC technology cost reductions
- reduce possible incremental costs
- work with suppliers
- extend markets

3.3. What are the first steps?

Five main conclusions/action points emerged:

1. Cost Studies

- bring together an auditing company with two major refrigerator companies (experienced in HFC and HC technology)
- study i) costs of production equipment ii) costs for development iii) costs for materials
- prepare unbiased product and life cycle cost study for Article 5 country conditions
- ask TOC refrigeration - include manufacturers, structure costs, Article 2 and 5
- commission TEAP for cost study under especially long term vision - not just the status quo
- each company with help from SDC and GTZ
- through a neutral agency
- ask TEAP to perform a cost analysis

- select an independent institution
- commission and independent body (TEAP?) to do the cost study in close collaboration with manufacturers, using their existing data
- ask independent organisation and manufacturers to provide a study
- conduct cost study that is independent and includes/evaluates refrigeration manufacturers' data.

It was proposed that technical institutes and enterprise associations at a national level may take up this point

2. Cost Reduction

- technology transfer from European companies to A5 companies
- A2 to provide technology transfer for both product design and production of raw materials and components
- make available appropriate product design at affordable cost
- commission an *ad hoc* group to work with suppliers, technology transfer stakeholders and Ozone Units
- concentrate conversion actions on local component suppliers

It was proposed that ExCom and policy makers may take up this point

Point 3:

- convince maximum possible number of A5 manufacturers that HC technology is the best possible alternative

Point 4:

- provide technological information about HC refrigerant to help A5 refrigerator manufacturers in making decisions about non-ODS technology
- "create" a cost reduction plan (if really necessary)

It was proposed that donor agencies (e.g. KfW/GTZ, SDC, World Bank, UNIDO, UNDP, UNEP) may take up points 3 and 4

Point 5:

- get manufacturers and cost engineers to identify cost reduction opportunities and lobby for policies and standards that encourage these cost reductions

Proposed that technical institutes, NGOs and Ozone Units may take up this point

Other points:

- promote R&D to reduce HC production and servicing costs in Article 5 countries
- establish cost reduction programmes for refrigeration industry and technology institutes (funded)
- push cost reduction through manufacturers

4. Working Group "C"

"There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry as a whole and especially to developing countries."

4.1. Brainstorming

In considering the statement, the group added that confused messages were sent to *governments* as well as industry.

In the brainstorming session the group considered *what the issue was all about* and the following points were proposed:

What is it all about?	Votes
1. Which TEWI? The various different values for TEWI e.g. the Japanese TEWI, French TEWI mean that there is no clear starting point	0
2. Is the confusion about the future of the technology? Is the issue TEWI or the durability of the technology - will the technology become redundant in the near future?	10
3. Tool to make a decision for "a" country TEWI is a decision-making tool - is it application-specific or country-specific?	2
4. Each application has different factors Values for TEWI vary according to the different features of an application	0
5. Article 5 countries are "blank" TEWI is not an issue for developing countries and they don't enter into the debate	1
6. Can we as a group, in this timeframe, establish the lack of coherent evidence?	2
7. Assessment of environmental compatibility	9
8. Perhaps we have to accept the situation	0
9. There is a well-defined system - the difference comes from the data put in - TEWI is a valid system, but can fail on account of data quality	7
10. The danger is misinterpretation ("broad brush") The issue is too complex and when it is simplified it can send the wrong messages	1

11. It is only one aspect TEWI is only a tool, and a partial tool at that	6
12. The danger of a scientific "mantle" TEWI is not a common currency	0
13. Is it the right tool? Is TEWI the most appropriate tool or concept for decision-making	15

When the group came to vote on what they thought were the most important issues, the following received the most votes:

- is TEWI the right tool to make a decision?
- is there confusion about the future of the technology?
- assessment of environmental compatibility

The group expressed surprise that none of the issues were of specific relevance to developing countries.

4.2. The Landscape of Ideas

In thinking about actions, the group came up with various ideas that, through discussion, were presented in a "landscape" as follows:

Cluster A (14 votes)

The cluster that received the most votes related to the need to show how TEWI should be used in decision-making and for a clear understanding of the limits of TEWI. Recommended actions included:

- explain the limits of TEWI
- give a matrix of arguments, where TEWI is just one
- TEWI is one of several decision making parameters. Do not overestimate TEWI
- give a decision-making tree for Article 5 countries, giving TEWI as just one tool

Cluster B (13 votes)
A requirement for a clearer definition of the aims of TEWI emerged as an important issue and recommended actions included:

- define the concepts
- match the needs of local industry with the potential of each technology
- develop a list of decision factors with priorities for Article 5 countries
- define the needs: decision tool with respect to the environment
- sustainability labelling programmes

Cluster C (9 votes)
The third area that emerged related to energy efficiency; recommended actions included:

- energy efficiency must be accounted for
- look at efficiency
- emphasise the importance of energy source (e.g. renewable/fossil) in the TEWI calculation
- look at the design of equipment
- TEWI without a country coefficient - for export purposes
- avoid hiding GWP of refrigerant by overemphasising efficiency

Cluster D (8 votes)
The fourth cluster related to the refinement of TEWI; actions included:

- define a standard situation for TEWI assessment
- define a common scientific tool
- agree on methodology
- common measurement gauge
- develop specific TEWI definition for domestic refrigeration
- determination of TEWI for scientific situation

Cluster E (6 votes)
The final cluster related to

- get consensus on TEWI (concept, formation, input) on global basis
- develop the universal environmental impact assessment method
- define what should be included in environmental assessment

Other recommended actions, each of which received one vote, were:

- dissemination of unbiased, peer reviewed result to Article 5 countries, with case studies
- put all the information on an Internet site
- why is TEWI not the right tool

The following actions did not receive any votes:

- reject TEWI as a basis for any decision. It is a political tool, not a scientific tool
- number or open tool.

4.3. What are the first steps?

Suggestions were made for the first steps that should be taken for clarifying TEWI:

- a letter should be sent to the Multilateral Fund, by UNEP for example, requesting consensus on a common measurement gauge for Article 5 countries and household refrigerants
- scientific studies to be undertaken by technical institutions to get an idea on the common aspects of measurement
- leave TEWI as it is; it took 10 years to get this far and will take another 10 years to improve it
- explain the limitations of applying TEWI coefficients on a global basis
- publish a paper on the relative values of TEWI, by the OORG for example
- form a broader scientific TEWI group to get wider ownership of the issue
- Greenpeace could establish a position on how to assess environmental impact, and put this on the Internet
- ask IPCC to define the concept, via NGO pressure, to deal with the issue
- use existing agencies and combine work on TEWI - e.g. TEAP and IPCC
- ask the World Bank (or another institution) to look at the energy saving effect of new appliances in developing countries
- broaden the scope to establish LCAs
- prepare an information package on environmental and technological problems of HFC-134a and why they make HFC-134a a risky choice
- define the “aim”
- undertake a literature search for the arguments for/against TEWI and put this on the Internet.

5. Working Group "D"

The investment costs for changing a production line to HC (costs for safety measures) are higher than for HFC-134a."

5.1 Brainstorming

In the brainstorming session the group considered *what the issue was all about* and the following points were proposed:

What is it all about?	*Votes*
1. It also relates to foam (safety investment); pentane vs. non-flammable fluids	
2. Major dilemma is choice of refrigerant	
3. Safety investment required should cover entire product chain from manufacturing, warehousing, transport, consumer usage, service and disposal	13
4. Investment cost to adopt HC refrigerant are made higher by the fact that only R600a - and not HC blends - are considered a technical option	11
5. Blends of HFCs with HC may have a potential to substantially cut needed safety investment	1
6. Concentrate on proven commercially available technologies	
7. Evaluate not just safety but all appliance cost over lifetime (including servicing)	
8. Do not evaluate investment cost only, but also additional cost related to training and institutional cost	15
9. Answer: yes. Do we have to do anything about it?	
10. No insurance company would insure a manufacturer without having taken some appropriate safety measures	
11. Safety costs may be higher than need to provide an acceptable level due to lack of expertise	6
12. Local permits and safety standards are missing or are prohibitive	2
13. Evaluate the payback of HC technology against higher investment costs	9
14. Evaluate "community" cost outside manufacturers' site	

When the group came to vote on what they thought were the most important issues, the following received the most votes:

- investment costs for HC should be done over the product's lifetime and include other additional costs

- there are savings in HC technology over HFCs (relative), over a lifetime
- evaluate comparative cost under MF regime in Article 5 countries
- HC technology is more expensive for MF, but less expensive for Article 5 countries
  - does a payback take care of it?
- HC safety cost is a barrier for the MF
- 35% safety bonus is not enough to take care of additional cost for Article 5 enterprises
- uncertainty
- difference in cost HC vs. HFC-134a over lifetime questioned
- savings in HC over lifetime questioned

5.2. What Actions do you Recommend?

Cluster 1: Foam and Refrigerant Costing Base Established (22 votes)

- establish the actual safety costs separately for HC foams and HC refrigerants
- study cost items for safety
- provide a cost study to understand total conversion costs for HCs vs. the others
- define true investment costs for full lifecycle
- independent assessment of costs along lifetime including service and energy consumption
- make better use of HC blends to reduce investment costs

Action: Provide independent comparative assessment of lifetime cost, including safety

Cluster 2: MF Policies (15 votes)

- threshold future allowance to be increased from 35% to approximately 50% for HC-600a
- funds should be available for companies' projects above the 35% threshold
- the funding level should assume basic safety requirement
- the minimum safety cost should cover the national safety costs fully

Action: MF invited to reconsider safety cost threshold

Cluster 3: Refrigerant Cost Comparison (12 votes)

- clarify definitely if HC has cost savings in the long run
- identify the added cost for HC; concentrate on what is significant for the manufacturer

Action: Clarify if HC refrigerant has long term savings

Cluster 4: Model Projects (3 votes)

- evaluate countrywide or enterprise wide payback costs as the additional cost is also justified
- formulate model project proposal based on i) MF rules ii) without MF rules - to eliminate uncertainty

6. Working Group "E"

"There is widespread ignorance about the disadvantages of synthetic replacements (e.g. HFC-134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries."

6.1 Brainstorming

In the brainstorming session the group considered *what the issue was all about* and the following points were proposed:

What is it all about?	Votes
1. Availability of "hard" information Information required from manufacturers using HFC-134a	2
2. There is misinformation (e.g. 134a compressors have to be kept in sealed containers) Much of the information available is untrue	1
3. Strong imbalance of information In-depth information provided by some sources, and scant information from others	7
4. There is ignorance about servicing experience with 134a	10
5. Lack of manufacturing experience with 134a in Article 5 countries	2
6. "Street" servicing for HCs and HFCs i.e. servicing is often carried out the by informal sector	5
7. Lack of information on the "useful" life 134a appliances	3
8. Controlling influence of patents and proprietary information	1
9. Commercially driven promotion/information of 134a	6
10. Lack of professional technology transfer	6
11. Insufficient scientific information and research on environmental effects of 134a in all its applications	12
12. Cleanliness and contamination are critical	9
13. Hygroscopic ester oils	2

When the group came to vote on what they thought were the most important issues, the following received the most votes:

- insufficient information on environmental effects
- ignorance of servicing experience
- cleanliness and contamination and very critical

The group did note that points 5 and 7 were very similar and that their combined scores would have made them a front runner.

6.2. The Landscape of Ideas

In thinking about actions, the group came up with various ideas that, through discussion, were presented in a "landscape" as follows:

Cluster A (18 votes)

Two clusters each received 18 votes. This cluster related to the need for transparent, neutral and balanced information. Recommended actions included:

- provide Article 5 countries with fair information - no political matters; the 134a is overestimated
- neutral information on all aspects
- transfer information from SDC/GTZ/UNEP/European companies to Article 5 countries
- establish "balance" of information
- balance flow of information

Cluster B (18 votes)

The other cluster receiving 18 votes related to a requirement to initiate independent information; recommended actions included:

- start research on servicing in Article 5 countries (HFC and HC)
- more integrated analysis of information
- fund projects to create independent information
- acknowledge the scientific uncertainty and undertake independent research
- a scientific approach for comparison is required
- disseminate the results of the research on the issue of the environmental effects of 134a

Cluster C (8 votes)
The third area that emerged related to servicing; recommended actions included:

- widespread training with demonstration
- transfer of valid service experience to Article 5 companies
- demonstration of servicing of HFC based refrigerators in developing countries

Cluster D (8 votes)
The fourth cluster related to the experience of developing countries with HFC-134a; actions included:

- study research of the effects of manufacture and service conditions in Article 5 countries
- publish experience of those that converted earlier

The following did not receive any votes:

- HFCs are difficult to manage in Article 5 countries; compressor manufacturers consider HC blends
- information meetings in Article 5 countries/high schools
- safer service - people and products
- provide a study to determine all the effects of HFC on the environment
- evaluate servicing aspects of HC vs. HFC
- demonstration project HC and HFC in Article 5 countries
- publish a technical manual based on interviews with HFC and HC manufacturers

6.3. What are the first steps?

For Cluster A, the following suggestions were made:

- real, honest, credible, neutral information without any mistakes
- all information is currently available (we have to decide which will the final, definitive refrigerant to be use)
- solicit information; design a questionnaire for the required information and send it to the various sources

For Cluster B, the following first steps were recommended:

- produce dissemination videos, put them on the Internet, starring Madonna, Maradona and Ravi Shankar (!), on the environmental impact and technological problems of 134a after independent studyFor Cluster C:
- develop servicing module for HFC based appliances and arrange demonstrations
- arrange workshops demonstrating correct use of the fluid across Article 5 countries

Cluster D provoked the most suggestions:

- through questionnaires, investigate conversions in Article 5 countries to see if they would still have made the same decisions now
- try to make available the experience of long term manufacturers
- ExCom asks World Bank for information on implementation
- look at needs for Article 5 companies for refrigerant conversions through local government environmental departments
- collect all information available in Article 5 countries from industry and institutions which have been through the conversion process.

7. Working Group "F"

"Manufacturers fear misinformation campaigns and adverse publicity against HC from the chemical multinationals as well as from competing manufacturers."

7.1. Brainstorming

In the brainstorming session the group considered *what the issue was all about* and the following points were proposed:

What is it all about?	*Votes*
1. There must be reasons for attacking HC	
2. One argument is the safety issues at a consumer level and emotional concern	8
3. Argument on safety issue at the producer level	
4. Argument on safety issue at service level	3
5. Comparison of energy efficiency	
6. Dependence of chemical industry, misinformation by chemical industry	
7. Fear from HFC competitors	
8. Same environmental impacts of HFC and HC	
9. Misinformation of production costsand price	
10. No availability problems of HC	
11. Profits of HFC producing industry	1
12. Marketing pressure for HFCs is a lot higher than for HC	5
13. Expression of concern of commercial isolation	2
14. This barrier is conceived as a smoke screen for decision made in Article 2 countries	5

When the group came to vote on what they thought were the most important issues, the following received the most votes:

- safety for the consumer
- marketing pressure for HFCs is higher than that for HCs
- a smoke-screen for decisions made in Article 2 countries

7.2. What actions are required? - the Landscape of Ideas

Cluster A: Target Industry (2 votes):

- push the arguments for HC technology and handle it in all aspects

Cluster B: Building Local Credibility (9 votes):

- develop and publicise safety infrastructure (rules, implementing agencies, monitoring)
- fund independent assessment of safety and technology issues in Article 5 countries
- lobbying for policies and standards - establish safety standards

Cluster C: Target Public (10 votes):

- campaign among potential consumers highlighting the technology choices and identify their merits
- build consumer awareness about advantages
- campaign on high safety level of HC refrigerators
- inform people about HC technology
- build concern awareness about advantages of HC refrigerator to consumer
- spread more information in Article 5 countries about German enterprises
- information potential manufacturers in Article 5 countries on experiences with HC technology

Cluster D: Enhancing HC Market (1 vote)

- enhance marketing power of HC
- persuade HC suppliers to see market opportunity

7.3. What are the first steps?

Point 1

- find out in whose interest HC use is
- get campaigns started by these parties
- establish an international HC network to increase, share and publicly disseminate information

Point 2

- start the development of regional safety standards
- strengthen Article 5 regulatory agencies and build their credibility
- awareness project connected with R&D project

Point 3

- public interaction programmes to highlight HC refrigerant safety
- develop a marketing concept for HC refrigerator
- develop a media plan with people from media firms and NGOs
- TV movie on HC
- HC exhibition for fairs
- find a mechanism (World Bank, donors, Implementing Agencies) to build local credible information, legitimate and disseminate this information

7.4. Who should take it up?

Point	Names	Addressees
1	Ecofrig, GTZ, SDC, NGOs	NGOs, manufacturers, workshop participants, scientists
2	Ecofrig	Local safety authorities, manufacturers
3	GTZ	Scientists, Media

8. Summary of Presentations

8.1. Group A

"Through commercial agreements e.g. joint ventures, licensing agreements etc. between developed and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology."

The key areas that emerged as important in the initial group discussion were:

- a lack of confidence in HC technology
- the driving force of HFC-134a comes from the technology leadership of MNCs
- there are only a few competent technology suppliers in HC technology.

The group also double-checked that these issues were relevant for Article 5 countries and observed that:

- there is a lack of confidence both for HCs *and* HFCs
- in China, for example, there are only a few competent HC technology suppliers
- MNCs were observed to be in the "driving seat" in Article 5 countries

In considering actions that Article 5 countries could take, the following issues were identified as important to resolve:

. a desire/belief that Article 5 countries should have their own technology know-how/information/capacity to make their own decisions, without a reliance on Article 2 countries
. for the information supplied to Article 5 countries to be fair
. for technology transfer mechanisms to facilitate point 1.
. for flexibility within the Multilateral Fund for projects that have already been approved so that they can be changed if necessary (it was observed that this facility currently exists, but that it was a difficult process)

During the discussion a number of questions and points were raised. In particular, given the small base of HC technology suppliers, it was considered that a different technology transfer mechanism might be required and that an independent global body might be able to facilitate this.

In addition, because of the lack of HC technology suppliers, it was observed that equal information about technology choices would not necessarily provide equal choice for manufacturers.

It was noted that the traditional process for technology to be transferred between Article 2 and Article 5 countries is with mature technology; with HC technology this is not the case as many Article 5 country markets lack capacity to judge and assess emerging technologies. The mechanisms for assisting technology transfer were also considered e.g. the funding of incremental costs and financing the cost of licences to produce branded goods and questions were raised about calculating the cost of technology transfer.

8.2. Group B

"Consumers are more interested in the price of their refrigerator than ecological benefits."

Feedback received from Dr Ajay Mathur, TERI - India and Maria Lucia Gomez, INTI - Argentina

In the opening session, the Group considered the following aspects: that consumers' priorities are price, especially when they have low disposable, that there is no contradiction between ecology and economy in the long term, but that environmental benefits are not made attractive to consumers because of a lack of awareness. It was also considered that HC technology has higher incremental costs possibly because of the availability of the component parts.

The Group focused on cost differences between HC and HFC technologies (particularly in refrigeration) and on the nature of the cost differences. The Group felt that if these cost differences are significant, then enhancing public awareness about the advantages of HC technologies is essential. The Group decided to address these two issues (the nature and the magnitude of the cost difference, and public awareness enhancement); however, due to lack of time, the Group could only focus on the first issue.

The Group decided to address the issue of cost differences through two strategies:

- assessing the costs and cost differences between HC and HFC technologies, and
- stimulating cost reduction in HC technology

The aim of the cost study would be to provide an unbiased and consistent comparison of costs The study would examine both production costs, as well as life cycle costs of this technology in the long term (i.e. after the technology and the production processes have been matured). However, it was recognised that cost studies would not be definitive because of the difficulty of gaining access to information from manufacturers (although it was suggested that donor agencies do already hold this information in the project funding submissions. The emphasis of actions should, therefore, be on the cost reduction strategy by creating an environment in which the production costs of HC refrigeration can be minimised e.g. through expanding markets.

The specific actions that were identified by the Group are:

- **commission the cost study -** the World Bank/SDC/GTZ could commission a broad based cost study to assess the production and life cycle cost of HC and HFC technologies, and estimate the potential for cost reductions in HC technology. This study should be carried out by an independent body, such as the TEAP (or refrigeration TOC) or an independent management/audit consultant
- **technical information for manufacturers -** refrigerator manufacturers in developing countries need technical information in order to make technology choice decisions. It is felt that in the absence of appropriate information, these manufacturers are not able to critically assess both HC and HFC technologies. The Ecofrig project in India has been crucial in providing such information, and similar projects may be initiated in other target countries. SDC/GTZ could examine the possibility of launching such initiatives
- **enhancing technology absorption -** the manufacturers of refrigerators of developing countries should be provided with technical support to assess HC technologies and install them so as to exploit all their efficiencies. National technical institutes and industry associations could be involved in providing this support
- **streamlining component supplies -** the component/vendor system for HC technology is not yet established, and a support system to streamline this process is required. The global shortage of isobutane compressors implies that the ExCom may need to examine the priority and timing of compressor conversion projects. In addition, global networking of component suppliers and refrigerator manufacturers needs to be established. GTZ could take the lead in enabling such a network

- **developing an appropriate institutional environment -** the long term cost reduction processes would only be initiated in the presence of an institutional environment that provides the requisite incentives. Performance standards, tax policies and fiscal incentives may be developed for this performance. NGOs, policy research organisations and industry associations should identify such incentives, as well as lobby for their adoption in developing countries

Following the discussions and questions, a number of points were made about undertaking a cost study; for example the need to take a long term view in cost studies was considered as well as the need to involve manufacturers in providing cost information and whether they would co-operate. It was acknowledged that each situation in a developing country would be unique and that a cost study would be unable to incorporate factors such as tariffs and other protectionist measures.

TERI would be interested in initiating and participating in the following actions that were identified during the Group presentations:

- **assessment of technology support centres -** the domestic refrigerator conversion process in India, particularly in the perspective of HC technology adoption, is indicated that the refrigerator manufacturers require technical support in evaluating technologies, designing the HC based manufacturing process, and in the testing of HC refrigerators. These activities are low value added, and are therefore not generally provided by international technology suppliers, but by local consultants, In the absence of local consultants for HC technology, technology support centres that can provide this activity are essential. TERI would initiate the establishment of such a centre in India which could also provide support services to other countries in the region
- **establishing the institutional framework to promote HC technology -** the adoption and acceptance of HC technology would be enhanced by the presence of an institutional structure that provides incentives which capitalise on the advantages of this technology. Consequently, energy efficiency and environmental impact enhancement should be promoted in national policy structures. TERI would work with the Bureau of Indian Standards and the Indian Ministry of Environment and Forests to develop and adopt standards, fiscal and tax policies, and environmental impact assessment policies that promote the adoption of HC technologies.

8.3. Group C

"There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry (and government) as a whole and especially to developing countries."

The presentation went through the process by which the group had come to its action points. The key issues that emerged during the brainstorming process concerned questions about the future of refrigeration technologies, the use of TEWI as an assessment of environmental compatibility and whether TEWI was the right tool.

In the landscape of ideas, three key areas emerged: the importance of energy efficiency savings, the use of TEWI in decision making and how this could be improved, and for the limits of TEWI to be explained.

In considering action points, various recommendations were made. For example, in acknowledging the difficulties and uncertainty about the use of TEWI, it was suggested that an implementing agency, such as UNEP, could write to the Secretariat and the Parties of the Protocol to seek ways for this to be resolved.

A package of information was requested on the problems of HFC-134a, both in production and on the environmental issues.

It was also suggested that indirect global warming effects should be included in TEWI and a request was made that the World Bank could investigate energy savings/energy efficiency of new equipment in developing countries.

8.4. Group D

"The investment costs for changing a production line to HC (costs for safety measures) are higher than for HFC-134a."

The presentation for this Group took a slightly different approach; instead of talking through the process that led the Group to reach its action points, the presentation started with a discussion of the action points and worked backwards to show the linkages with the initial brainstorming.

The key action points were similar to those suggested by the other groups, namely for information and studies. But in recognition that studies are rarely definitive, it was suggested that a basic framework was required to understand the costs involved. The Group concluded that HC is still an emerging technology and the technology transfer of a technology in that stage is difficult. The specific action points that were recommended to help overcome these issues were the following:

- a definition of cost items
- model projects
- a review of MF policies
- a review of safety standards
- refrigerant cost comparison.

The "real" issues facing HC technology were the payback on investments, the need to reduce uncertainty and for investment costs to be considered over the lifetime of the product.

It was suggested that foams should be included in all cost analyses and indeed that wider issues should be considered, so that all costs should be identified, rather than just those associated with investment. One suggestion was for the price of HC technology to raised as a signal of quality.

The ensuing discussion covered many of the suggested action points. The drivers of companies' commercial decision making were considered and it was noted that these include i) what the market wants ii) what market leaders are doing and iii) what technology is available and what the capacity is to adopt a particular technology (particularly in developing countries). In recognising how these impact on strategic decision making, it was suggested that influence needs to be exerted on this decision making process, for example, through the policies of the Multilateral Fund, market pressure or through an assessment of lifetime costs.

The issue of cost analysis covering lifetime costs or initial costs was raised; one suggestion was that disposal costs should be included in cost assessments. In considering lifetime costs, a question was raised as to uses this information; as manufacturers are primarily concerned with up-front investment costs, should lifetime costs be a policy issue and dealt with via regulators, government etc. It was suggested that lifetime costs are an economic issue and depend on the market; in developed countries, a refrigerator is expected to have lifetime of 10-15 years, whereas in a developing country, the lifetime is expected to be greater than that because the entry level price is significantly higher in relative income terms. The lifetime costs are dependent upon how the servicing of a refrigerator is done. It was questioned that *if* the lifetime cost of HC for example, is lower, would this justify a higher up-front investment? It was suggested that this depends upon the mechanisms that drive this process and that most of the decisions are made on the basis of capital investment decisions i.e. by the MF, not rate of return over a long period of time.

It was suggested that for conversion projects funded by the Multilateral Fund, capital investment is the main issue and achieving the best rate of return on that investment over a long period of time is not the main driver. This position of the MF fund was clarified with respect to the 35% discount offered for HC conversion projects; the figure of 35% is not a threshold, but a mechanism to improve the cost effectiveness of a project to bring it into the field. It was stressed that the role of the Multilateral Fund is in ozone depletion and that of its resources of $400 million, $130 million is devoted to domestic refrigeration. The MF expressed concern that in some countries other ODP substances, such as aerosols, were not receiving the same degree of attention or support and that this might affect their phase-out schedules. This leads to the need to prioritise ODS phase-out and finding the most cost-effective solutions. Conversion of domestic refrigerators is considered to be important because of the rapid market expansion. It was pointed out that the MF does not provide funding for energy efficiency as this is the domain of the GEF; this could often lead to inefficiencies as one project proposal submitted to the MF can also be submitted to the GEF.
This issue led to consideration of the incentive framework within the climate change protocol; concern was expressed that there was no effective incentive framework and so decisions have to rely on economic incentives.

8.5. Group E

"There is widespread ignorance about the disadvantages of synthetic replacements (e.g. HFC-134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries"."
Feedback received from David Gibson, Dewpoint Consultants Ltd.

In considering this statement, the Group recognised that there was an inherent premise that HFC technology *did* have disadvantages and that there was an implicit bias towards HC technology i.e. that ignorance of the *disadvantages* of the opposite choice was a *barrier* to acceptance of HC technology. The initial bias in the statement was firmly rejected by developing country representatives who wanted "neutral", "fair" information about HC technology.

The Group expressed surprise that a statement about the "environment" (that the long term environmental effect of HFC-13a is unknown) received the largest number of votes, yet there was no environmental dimension in the statement. During the group work, words like "information" predominated and during the voting, "service" received support.

In terms of the recommended action points, two areas emerged as being important - service and information. The “workplace” referred to in the statement was interpreted as including the “*service*” environment as well; in the majority of cases it was indicated that HFC-134a was thought to be vulnerable in service operations, but that its disadvantages could be managed in factories. There appeared to be two distinct types of information requested; scientific-based information i.e. using laboratory results and practical information from manufacturers using both types of technology.

The initial steps recommended by the Group were for fair, unbiased and neutral information to be provided through studies and questionnaires. One idea was for an anonymous questionnaire; this would involve a local developing country expert to canvas local manufacturers for practical engineering questions to which they want the answers. The local expert would refine and consolidate these into a questionnaire that would then be answered in an anonymous fashion by developed country manufacturers.

The discussion that ensued after the presentation focused on servicing problems in developing countries. That there is scant information on servicing problems in developing countries was attributed to the fact that refrigerator servicing in developed countries is not an important issue and that there is an insufficient body of experience of developing country servicing issues in developed countries.

8.6. Group F

“Manufacturers fear misinformation campaigns and adverse publicity against HC from the chemical multinationals as well as from competing manufacturers.”

Feedback received from Brian Joyner, Regulatory and Technical Resources

The initial discussions of the group related to the "chemical multinationals” aspect of this statement and it led to acceptance that HCs are also chemicals and the products of chemical processing, although not involving synthesis stages.
The key issues that emerged in “what is it all about” were the following:

1. **safety issues:** at production, servicing and consumer levels, but primarily at the consumer level where there is an additional element of an emotional (possibly irrational) fear in respect of potential for serious household incidents

2. **marketing:** the pressure or "push" to secure HFC sales is much greater than that for HCs, possibly because HFCs have a higher profit margin than HCs
3. **hidden agenda:** the barrier as presented could be a smoke-screen for pro-HFC decisions already taken in Article 2 countries.

In view of time constraints, the group noted the third point but did not consider it further because it is a difficult topic to explore and a number of different interpretations could be made. Of the fourteen issues listed, two specifically related to "misinformation" by the chemical industry and to "costs/prices"; neither of these received any votes in the Key Issues voting process.

The **recommended actions** were the following:

- to build consumer awareness (at all levels) on HCs and HC technology in Article 5 countries
- to fund independent assessments of HC safety and technology - and to do this in Article 5 countries with involvement of local agencies to ensure local ownership
- to develop local policies and standards that do not discourage HC use.

The **first steps** that were identified were:

- to identify those whose interests are best served by the use of HCs
- these people to campaign, as "project champions"
- to build credibility of Article 5 country regulatory agencies (bolster confidence)
- fund pro-HC publicity using all types of media.

A number of organisations were proposed/nominated to consider taking up these actions. These included manufacturers of HCs and equipment - such as Calor Gas, workshop participants, scientists, local safety authorities, NGOs, and donor agencies such as GTZ and SDC.

During the presentation the question of "misinformation" was raised again and the discussion led to broad acceptance that there is a clear distinction between statements that are deliberately false, and the sort of selective or partial wording that a manufacturer may legitimately employ in advertising when stressing the merits of a particular brand or type of goods in competition with others. It was suggested that sufficient *basic* information does exist, but that its accessibility and credibility would be improved if it was compiled by an independent organisation.

There was also a discussion about the information that was available but because it was so disparate, it was difficult to access. It was considered that much of the information is currently biased and needs to be expressed by a legitimate independent organisation.

Another view was that the role of the consumer should not be overstated as they are not the main decision maker in technology choice.

9. Concluding Remarks

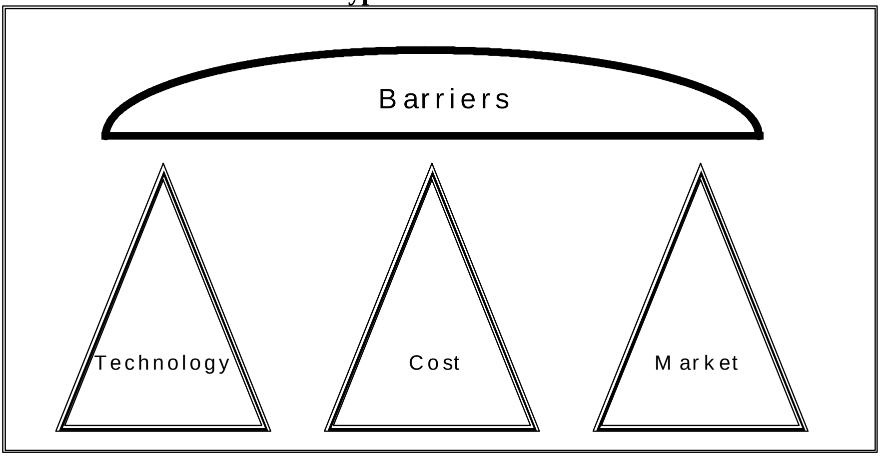
This is an edited transcript of the concluding remarks at the workshop. The editing has attempted only to make the text more readable than the verbatim transcript.

9.1. Fraser Morrison, Deloitte & Touche Consulting Group

To summarise (which is enormously difficult and I am going to miss out lots of connections) I have been sketching a model over the last few days during the workshop, which I will now try to share with you. I would be terrified if I was interrupted, as it is not complete and it is not necessarily coherent, but it is at least a building block.

We started with a hypothesis.

Slide 1: The "Pillars" of the Hypothesis



The hypothesis was that there is technical superiority in some situations for HC refrigerants applied in the domestic market. Some people are arguing over different parts of the total cost, that there can be cost equality, or near cost equality, or even cost superiority for HC as a refrigerant in domestic refrigeration compared with HFC-134a. And some people are arguing that the timing is right, or not inappropriate, for these preferences to be expressed in the market because there are still enough opportunities in Article 5 countries to choose the appropriate technology. But, for some reasons, called "*barriers*", it is not happening, and certain interpretations have been expressed as to what these barriers were. So the first thing I though we would do is talk about where we have got to with that hypothesis.

I do not feel all comfortable that the technical argument is well made. I do not think this workshop has reached any consensus that says there is technical superiority either in manufacture or use for HC technology. People may disagree with that but I do not see that we are there yet, and the cry for more information says that. On the cost front, the messages seem to be something like this. At the manufacturing cost level, *"well, HC technology is a bit more expensive than HFC and so something should be done about helping HC technology to get a cost advantage"*. We will come to why that is an issue in a minute. But maybe over time, the cost reduction trends and other improvements in training and so on will close the gap (or maybe it won't be closed - or may be the gap is not all that big anyway), and so maybe there is some prospect, a little bit of hope, that volumes will permit economies of scale and then there will be a cost advantage in production for HC technology for some applications in some markets over HFC-134a. And thirdly, (and on this I do not think there is any confusion or dissension or doubt) however complete or incomplete the data presented in the market study there are major opportunities still to win hearts and minds in the number of conversions to one technology as opposed to another, because lots of decisions still are open in Article 5 countries.

So, to some extent, the hypothesis does not stack up. The technical side is not conclusive, the cost side is not conclusive and therefore why are we worrying about barriers? And that's what these three days have all been about.

So I am going to try and give you a summary of what I think we have been talking about over the last three days.

Slide 2: A New Structure

Decision makers	Manufacturers	Consumers	Institutions
The decision	Which technology?	Which refrigerator?	Intervention?
Issues	Technical cost	Price, ownership cost	Environmental benefits

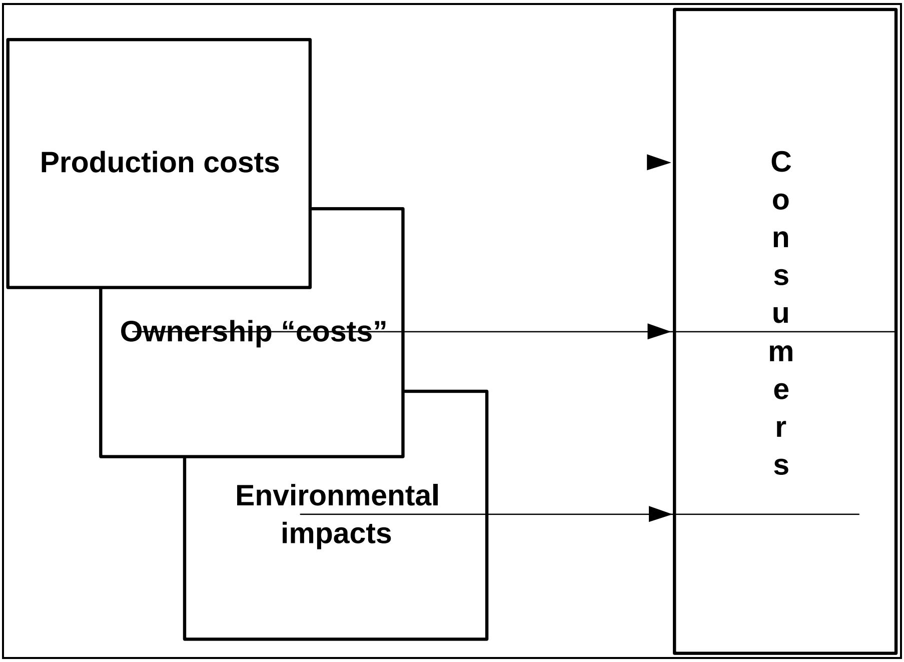
I think one group of people here have been talking about refrigerator manufacturers' technology choice decisions in developing countries; that is the second column of the slide. Individual, separate, not-subsidiaries-of, not-wholly-tied-to Western giants, individual manufacturers in Article 5 economies, who in management and technology terms have a degree of independence, have big decisions to make on *"what technology?"*. The next column, the next decision-maker, is the consumer, and there has been a lot of discussion about the influences that one might want to bring to bear on the consumer, how the consumer decision is made, and so on. And then, the third set of decision-makers, or players if you like, which I am collectively loosely calling "institutions" I do not just mean in executing what they are required to do, or what they are supposed to do by a secretariat, such as the Multilateral Fund, and which only follow the rules that are laid down for them, or the executive committee that will follow the decision of its parties, and so on, I am talking about the whole institutional framework. The decisions essentially are as follows: the manufacturers are saying, *"what options have I got and which technology do I choose?*. The consumer is saying, *"which refrigerator do I buy, which technology do I go for, what is my buying decision guided by?"*.

If there were very strong signals one way or the other coming through to the manufacturer or to the consumer then this workshop would not need to take place.

We have had discussions about the technical evaluation (and by the technical evaluation we mean all the criteria in the manufacturer's decision that were listed at the beginning of the workshop by Stephan Sicars and by Whirlpool) as to what needs to be taken into account when making a decision about refrigerants - the technical trade-offs. And we have also got a related family of questions about costs. The reason cost is important at this point (and on cost we just mean the manufacturing cost of delivering the product to market) is because the price at market affects what the consumer buys and that is because in large part the consumer is far more interested in cost than he is in lifetime ownership cost. The reason we have talked about ownership cost, about servicing and the rest of it is because the consumer does not seem to take that into account. We want him to have some information on lifetime ownership cost so he can take these into account because he can not make the right decision without it. In the same way for example, he has to recognise in the decision to buy a Mercedes that it has a fabulous re-sale value, so he buys a Mercedes for economic, as well as personal reasons. Only if the consumer has that information can he capture in the individual's decision the cost advantages claimed over the lifetime of the technology, and so make the right decision. So the manufacturer is going to go the right route by reflecting consumer preferences and we won't need any interventions by the institutions.

If there were to be interventions by the institutions, the grounds for that would be because there are environmental externalities that are not being internalised in the pricing mechanism. Some of the arguments we have heard are that we need to know more about these environmental benefits for two reasons. One is to pass it through as part of the premium that the consumer is prepared to pay (take the German model: *"we pay a premium price for a premium product because it has environmental benefits; we the consumers have a responsibility to do that"*); the other is that the environmental benefits have to be reflected through the institutional framework which has to some extent to subsidise or internalise whatever the externality is and change the balance. So that is my logical framework - a sort of market model. Let me show you how I think this works.

Slide Three: The Market Model



Manufacturers in Article 5 countries faced with this technical decision are saying to themselves, "we are told that both of these technologies are feasible; we have seen them demonstrated in different manufacturing environments; the criteria that we ought to be using to make our choices are well understood, but the technical superiority in any one application area or one product over another is not established; there are serious informational problems here that may never be resolved, but even if these are resolved, it may be that the same technical assessment process, applied with the same degree of rigour in different manufacturing environments, with a different climate, with a different quality of workforce, with a different degree of workplace discipline, will give different answers".

So we do not necessarily win either now or in the future the "green battle" (hydrocarbons are regarded just for today as shorthand for a "green" answer); we do not necessarily win the entire battle just by getting the technical assessment right because we do not know what the problem is. In the workshop, there was a lot of discussion about informational issues in relation to the technical assessment in manufacturing, and in the next slide, I have characterised Group F as having been involved in that issue.

Slide Four: Technical Appraisal

- Both technologies are feasible
- Criteria for choosing are understood
- Technical superiority of either technology is *not* established
- Technical Assessments *may* give different results in different environments

Major issues

- Information Discussed by Group: **F**
- Risks Discussed by Group: **A**

There was a lot of discussion about risks. It is important here to say that the market model we saw earlier, if you think about it at all, completely ignores not improperly, contributions from the Multilateral Fund, because the risks that we are talking about are big, frightening risks for manufacturers making decisions. There is the risk that they may bring to market an HFC-134a product that fails in service in one or two years and kills their brand name because they are not able to manage the technology as well as it has been managed in the West; there are risks that they have the factory blowing up when they start using HC refrigerants and that's not good for anybody; there are the risks that there are accidents in the home which involve explosions which again damage their brand name that they are desperately trying to build up in a ferociously competitive market where there are already players that are established. So these players are manifestly risk averse and working in the markets they do, they are in the business of trying to manage out all the risks they can, and so technology risks are things they want to avoid. To the extent that there has been discussion about misinformation or whatever else, it is a discussion about understanding the risks and managing and reducing them. When we were talking about technology transfer and technical co-operation arrangements, this was about risk minimisation and about how the same quality of comfort can be given to manufacturers facing technology choice decision by the HC community as from the close and supportive relationships they may have with an HFC supplier or compressor manufacturer. So in the technical appraisal, we have already reduced the significance of the MF in the signal making mechanism because some of these risks are big and spectacular in the marketplace.

So I think we can therefore look at the market something like this; the production cost element is the driver in the "price to market" and the consumer in most developing country markets would choose the cheapest product to meet his needs, if he had a choice of product, given the nature of these markets. And if the production cost is not the least, then the next element in the decision making process for the consumer is to persuade him to take into consideration the total ownership cost of the product in his decision making to swing his personal judgement in favour of the product which whilst not the lowest priced at market may have the lowest lifetime ownership cost. Remember, this is the marketplace - the thing about Germany and the reason why one can't buy an HFC refrigerator there, is because no one will buy them - if people would buy HFC refrigerators, manufacturers these would supply them. The reason HC refrigerators are not predominant in the UK market is because consumers do not recognise and value extra benefits of HC refrigerators whatever that they may be, to offset the higher price when it comes to market. If we can overcome these higher initial prices by the consumer to recognise lower ownership costs then he influences the manufacturers' decision and that's why there is so much discussion about the consumer.

Slide Five: Production Cost Appraisal

- Technical issues → Cost implications
- Production costs → "Price at market"
- Relative costs
  - Not firm
  - Changing
  - Dependent on location

Major issues - Production

- Information Discussed by Groups : **D, E + A**

Let us look at the production cost appraisal process. The first thing is that the three pillars approach to the hypothesis has collapsed - there are only two pillars as all the technical issues have got cost implications - a technical problem is a cost problem. The production cost drives the price to market and we know from the information we have available that the cost differences in the production of HC and HFC are not firm in the sense that there is no established cost base. The costs are definitely changing in the sense that as experience grows, markets grow and the rate of change is now visible, and it depends where you are doing it and it is different for each manufacturer, so there are a series of uncertainties in there, which will never be eliminated. So the major issues at the moment on production seem to be informational, with the question behind it as to whether some types of information can ever be obtained through Groups D and E, and to some extent, A, were talking about various aspects of information needs.

Slide Six: Ownership Costs

- Influence on purchasing decision
- Uncertainty about
  - Reliability
  - Servicing
  - Energy efficiency
  - Safety

Major issues - Ownership

- Information Discussed by Group: **E**
- Purchasing decision Discussed by Group: **B**

We will now look at the ownership cost issue and link it back to what I have already said. The argument is that the ownership cost information can have an impact on a purchasing decisions in the marketplace. There is enormous concern, doubt, and uncertainty about the reliability of the equipment. Is it the different countries where it is manufactured that makes it more or less reliable? What about warranty implications, what are the brand management implications, what are the recall implications? There is an enormous issue, as we heard in the last session, about the servicing implications and perhaps we cannot alter that, but in any case, the technical choice decisions will be made, and may be the horse will have bolted before we know enough about servicing implications.

Although some of you may disagree, there seems to me to be less certainty about the energy efficiency differences than were cited at the beginning. It seems to me we have to revisit some of those arguments and understand the difference in positioning, which is certainly not clear. It is not surprising, given the stimulus for change in this technology has been driven by the Montreal Protocol, and is quite remarkable for an industry that has been sleeping in terms of technical development for 30 years. It has woken up and started to rethink of re-engineering and resizing everything it has been doing in technical terms instead of - as somebody put it last night - just rethinking the shape of a door handle. There is also great uncertainty about the safety issue, and "misinformation" is one of the words quoted here, a genuine competitive battle in which selected information plays its part. People do not know about safety; they don't have comfort, they don't know how the safety experiences will be transferred; all these are affecting the decision makers we have talked about in Article 5 countries. And that safety issue does not just impact on the ownership cost argument about the consumer, it also impacts on the "cost to market" decision that the manufacturer incurs. We heard a lot of discussion in Group B on some of those issues and some in Group D as how we could alter the purchasing decision. Well, it is a market place with millions and millions of decision-makers, and it is a big challenge and I'll say no more than that it is a fine judgement as to whether you can start altering the decision-making values that consumers in Article 5 countries use in purchasing their first refrigerator.

Slide 6: Environmental Benefits

- No agreement
- Important only if
  - Clear preference
  - Need to change the *consumer* decision
- Institutional intervention justified

Major Issues

• Measures	Discussed by Group: **C**
• Influencing the consumer	Discussed by Group: **E**

Finally, the environmental benefits argument. The argument here is if all that has gone before does not give clear preference, then we should at least know if there is a fundamental environmental impact, an environmental advantage of one technology over another. I am not sure that anybody has convinced anyone of that over the last few days. There is no agreement yet and it is another informational issue; but it is only important, in my view, if there is a clear environmental preference for one technology over another and if there is a need to change the consumer purchasing decisions from one technology to another in order to reflect any externalities. If the things we have already discussed (production cost and ownership cost) that we talked about worked out in favour of HC technology, we would find HC technology preferred by chance rather than by introducing institutional responses. So we need to know the environmental benefits to know that there is an issue, and we do not have consensus in any sense that there is an issue. But if we know it and we observe that the cost trends are going in the right direction, that the consumer is becoming more and more aware, then we may not need to do anything about it. The only case for institutional intervention is if there are environmental benefits from HC technology which are not being reflected in manufacturers' and consumers' decisions. So the structure of the argument here takes us to the point that a lot of the attention has been spent on thinking about manipulating markets, thinking about costs, thinking about information, thinking about these decisions at the operating level, focusing on the balance of investment decisions by the company, focusing on the purchasing decision by the consumer and not an awful lot, surprisingly, on the environmental benefits. People who talked about TEWI were really talking about how to measure, how to get some fix on it a standardised way, in a transportable and transparent way to report these measures of environmental benefits. The people in Group E were essentially saying *"if we can find out more and establish more and then tell the consumer through informational techniques, we can make them become like a German consumer and make them prepared to pay more so they capture some of the externality"* - I think that was the argument.

Slide 7: The Information Issues

- Not known/incomplete
- Not trusted
- Not definitive
- Not applicable to A5Cs
- Not accessible
- Who will use it?

The informational issues that we have all been talking about are very complex and they apply to all stages in the model I have described. But, this information typically isn't known, it doesn’t exist yet, and there are holes for research. Information that is available is not trusted - it is a competitive market and people are using information for competitive ends, and we have heard everything from assertive to sorrowful justification for that behaviour in our discussions. Information is not trusted because the sources and the motivations behind the sources are not trusted. It is not a shared agenda. The information is not definitive in the sense that it does not give us the answer we want; it is grey, it’s moving, it is overlapping. It is not applicable to Article 5 countries, it is only established in

Germany and Article 2 countries and we don't know, we can't tell Article 5 countries' decision-makers what it is going to be like for them because nobody knows. It is not accessible. We have heard lots of people saying the information is available and lots of Article 5 countries saying "No we don't have it, we haven't got it, it is not available to us". There is an information transfer problem of mega proportions from what I hear. And there is also this question of to whom is it to be made available. Who is the user of this? Is it the Ozone Unit? No, of course it is not. Yet, how do you get the information to the management of a factory. So I have chosen information because a whole lot of what has been said comes back to a better understanding of how to make available to the users what it is they need to know. You may argue, that some of those requests are unreasonable; they don't take account of what is possible to measure, they don't take account of competitive positions and therefore can't fulfil those gaps.

Slide 8: Technology Transfer

- Relative capacities
- Corporate strategies
- Risks and uncertainties

In our organisation when we use moderation techniques similar to those we have been using over the last few days, we have an expression about naming a rhinoceros, or not naming a rhinoceros. A rhinoceros is this big dark fearful animal which is out there in the long grass just outside the corral and everyone is terrified of it and nobody ever names it, nobody mentions it. The metaphor says there is a topic, a subject, an issue, which is so basic and so frightening that nobody is prepared to talk about it, and the use of that metaphor is intended tohelp people take the rhinoceros' head and put it on a table and point it at you and have you tell me about your rhinoceros. What is it that is out there that is so frightening that you are not talking about it? And what has happened over the past three days, in my judgement, and I say this with some passion, is that people who had not been naming the rhinoceros head on Wednesday were talking to each other in a totally civilised and balanced way this morning about that rhinoceros.

And that rhinoceros is something like this. The two competing technologies - and they are competing technologies - are supported by totally different relative capacities to transfer the technology to Article 5 countries. But the corporate strategies driving the willingness to transfer that technology and to whom it is transferred are not consistent, are totally inconsistent, with the vision of the Montreal Protocol, with the concept of fair and more favourable terms of access to technology on a government-to-government basis, on a country-to-country basis. So, the corporate sources that have that technology do not make it available on these terms to the companies that need it under the circumstances that exist now, and that is the rhinoceros' head and it is a problem because the risks that face the decision-makers are big risks. They are not about getting a 35 per cent discount for safety costs, they are about the factory blowing up, they are about the rumour on the street that you won't make HFC-134a work in India, and that way you will suffer loss of market share and exposure to risk. People, it seems to me, are aware of those risks and don't know whether they can manage them, and therefore have to look to a safe option. I guess that this whole area, how the process really can work compared with the concepts implicit in the Protocol, is the rhinoceros head.

Slide 9: Results

- Understanding
- Respect
- "Missings"
- Clarification of issues
- Actions proposed

Well, that is the end of the passion, and I have two slides left. Bill Rahill, our client, rightly at the time, wanted us to present to you some results. I may have done this - I don't know - but I certainly have not got much more to say about the results except to talk about the process. I think we, rather you, as I am an observer not a participant, have achieved a huge increase in individual and collective understanding of each other and your positions, and I hope that you have gained a respect for people who in the past confused personality with goals and we have got to where a new level of dialogue is now possible, and I think you felt and experienced that this morning. The people who were talking to each other in civilised ways on Friday morning were people who were talking to the wall on Wednesday about the things you were angry about, and that is tremendous. I think we have identified a whole load of what we call "missings"- what is not happening, what needs to be done about it - but we have not got much further. But, we have certainly clarified what the issues are for individuals, and for the study team. Interestingly for you, we have generated a whole set of proposed actions - not proposed actions which somebody else should do something about, but the process has taken you somewhere down the line of *"yes, I'll do that, I'll take the first step in trying to do something"* and I hope you feel that that is possible. There is absolutely no promise that this workshop has an authority to decide anything; nothing that you have decided can be supervised, can be instructed. You cannot be promoted or demoted for doing or not doing something you committed to do in this workshop; there is no authority whatsoever. The only thing that is achieved IS achieved because you have had enough space, enough confidence as a result of what you have been through to take away these things, and that is why we need to know about them, just to have the comfort that we did achieve something. When we write it down in the final report we are not saying *"You committed to action. Have you written your letter to the Secretariat of the various institutions yet?"* That is not the game. The game is the opposite. You took it on because you wanted to. Feel free to go and do it and make the first step.

Slide 10: Next Steps

- Individual and group actions
- Report: papers → draft → final
- Inputs:
  - Corrections
  - Additions
  - Actions
- Follow-up?
  - Groups
  - Everyone

So, what are these next steps? As individuals, you take an action. I'd like to think that the groups , although you were not together for long enough, the groups might have some coherence, and might have a group concept of some sort. For me, I have to produce a report - so please help me in the way I requested earlier. Our outputs will be reviewed as our client wishes, and we will produce a final report. Your additions, by way of corrections, actions etc., will be welcome.

Can I ask you - Shall we finish it here, or is there something that you want to do that's more? If you do, it's yours - it's not ours. The groups are only people and you know who everyone is and you can maintain dialogues within this global village and develop networks and there could be some group momentum there. It's up to you. And if everyone here thought that not only the process was worthwhile but also more importantly that the results were worthwhile, and that it should be reviewed in the near future we have to make our pleas to the various sponsors now - the World Bank, GTZ, SDC and so on that that is something you'd like to follow up.

And that's the end of my piece - I've done my best to summarise; and I' m not going to ask for responses now. If you think I have missed anything, please let us have your comments in writing.

9.3. Ken Newcombe, The World Bank

I have to say how delighted I am in the roles of the Swiss and German Governments - our partners in facilitating this event and there are very many people to say thank you to. I would like to make a personal vote of thanks to Peter Stoermer and Klaus Meyersen on the German side for their critical role in this and of course to Jean-Bernard Dubois and Othmar Schwank on the Swiss side as they have been the key people who have made this happen. And of course, the facilitators: to Fraser and Jessica, it has been a marvellous experience having you facilitate this. I am also delighted with the role of my colleague Bill Rahill who has done most of the work for the World Bank. He is the Team Leader from the Montreal Protocol team, so thank you very much.

This has been a fascinating experience not just because of the topic which has been controversial but because of the process, I have learned a great deal about the process, and I can assure that I believe you and I will take away an enriched understanding of this business and the choices that we face but of the process and I can buy that in our own business planning elsewhere. To my mind it has been two dimensional this process: a formal process of people with very different opinions to express in an orchestrated and civilised way but also the fact that in the corridors, in informal gatherings, a dinner or the sort of discussions we had this morning we are able to form new partnerships and cut deals. There are many, many things that have happened simply because we all keep together. We haven't had the opportunity to exchange views and get to know each other before so I feel that I am leaving here with a whole new set of partnerships and a much greater opportunity for my Institution to be effective. It has been effective because the array of stakeholders is truly representative of the stakeholders in this business. And it is impressive that so many people with so much pressure on their time whether it is the NGO or the private sector, by the time we come here and exchange views that has made it truly effective. I don't know whether we have missed any major stakeholders, I can't see anybody who is very obvious by their absence here.

In the short-term we can carry away with us all this information and I hope and trust that we can facilitate this information, almost in the form that you have it, is available. If you were not sure what was said at a certain point, or what the choices were, what was discussed and the issues, you have it in this format then we will do our best to make it available to you. My commitment to you is that we will absorb this, we are already as a team, the Bank team have absorbed a great deal. We will go over this again, take away the essence and we expect to hear from you. If there is something you want to say or ask and you haven't had the opportunity, then please do.

What is the Bank's business here, what is our role from this point on? I said to you in the opening remarks that I wanted to reiterate the Bank's business is environmentally sustainable development. In the last couple of years you have helped us redefine sustainable development as a global phenomenon. There is not much point in having sustainable development at a national level if the impact of that development on the global eco-system simply undermines the integrity of the eco-system and makes it impossible for us to survive as nations and it is the global impact that we are discussing today with respect to the technology.

We need to take into account the market structure and the national and global environmental impact. We know how markets work, that's our business. We know and respect the role of the private sector in making money for it and our business is ensuring that there are properly functioning markets because we feel there are properly functioning markets, that would be good for the environment, but there are some caveats to that. There are some Ifs: The first "if" is if the true environmental costs of good conservation are reflected in marketing transactions, then prices to the extent that they can internalise these costs. What is particularly fascinating about the Montreal Protocol is that it is the first instance globally that I know of where Governments have decided to internalise the global costs in a marketplace. They have imposed on themselves, on their consumers, the cost of more environmentally friendly technology from a global perspective, because the problem with a global environment is missing markets. There are no markets for a world-environment benefit and the Montreal Protocol is creating a market for the protection of the ozone layer. We will see this repeated time and time again in the 21st Century. The protocols arising from climate-changing conventions, the protocol required for this area, respecting international waters, the great oceans of the earth, we will have to learn how to internalise the global environmental impact of micro-processes. Markets will work effectively if that happens.

Secondly they will work effectively if consumers have all the available information in making their choice about the goods and services they want and be able to express their preferences as to the extent to which they want to incorporate environmental, social and cultural sensitivity in these decisions. I am not just talking about consumers with a sense of every individual impact, but all market-players, at all levels, or manufacturers in this case. People who have to make hard distinctions about what to invest in. Because whilst we may have an idealistic view that consumers drive the market, we all know that's not quite the case. We know that major corporations can put a product out on the market and leave the market, which would never have been conceived of by individual consumers and the decisions within corporations like any very large bureaucracy, including the one I work in, are taken in some extent out of priority. The information doesn't quote the individuals who run strategic plans, the function of Area Manager up to CEO, making up the strategy and business plans and product development, doesn't happen.

So many opportunities go begging because of distortions in the information flow. Information flow is a much more subtle thing, we all realise that, and simply ensuring that there are active NGOs, there are active newspapers that are affecting our environmental choices but finally if you have before you all of the available information, on all of the things you would like to express a preference about, it is only meaningful if you can actually follow it through. It is not very useful if you discover that people know about hydrocarbon technology in developing countries if they can't express a preference to get a hydrocarbon refrigerator. If they can't be assured that getting a hydrocarbon refrigerator is going to have exactly the same service quality as any other choice. It's important to mention on functioning markets that you not only have a preference, but a preference to lead to a guarantee of quality and service, reliability of any of the preferences that you make. So precisely what is the Bank's role? Precisely it is the usual tool-kit that will develop and continue to develop to make markets better informed in their choices. That means good analysis of what the true environmental costs are of any assumption on the surface? That is much more difficult than possibly you can realise, we are certainly nowhere near where we need to be, even with the available tools. We have very poor environmental economic analysis. In my institution I hesitate to say that we are behind, perhaps we are leading in many respects. Some people regard the Bank as having good economic analysis, I can tell you it is way behind where it should be in reflecting the true environment costs of goods and services. We can do much better exchanging experiences across the world, best practice, good practice, is not exchanged adequately between market places. There are very important information barriers. We can mobilise capital, the Bank has been very good at mobilising public capital, but that's not as relevant as it used to be anymore.

The International Development Association, the single biggest vehicle for channelling concessional finance from the rich to the poor is a declining institution, declining pool of resources, both in absolute dollar terms in itself but is under the significance of public capital globally. At the end of the 1980s there was a crossover point where a lot of private capital to developing countries for investment purposes exceeded development assistance for the first time, now it is at least three times that, and growing so rapidly it makes development assistance in dollar terms more or less insignificant in the next century. You have to ask yourself what sort of value added can you provide for the use of scarce public funds?

But we mobilise public capital wherever it seems to be with this very high value added, that's why we are working in tandem with some European partners,. An effort to mobilise $35M, close down Russian CFC production, we feel we can close down 80% of Russian CFC production inside eighteen months, $35M is mobilised. That's a good use and role for the Bank in mobilising scarce public moneys but how much more of an important role is there in mobilising private capital? Private capital, a general standing behind entry into major marketplaces of big financial institutions and private capital that we are all familiar with the developed world. For example providing the guarantee for Citibank in the capital market on a dollar to dollar basis on our balance sheet, not our money but Citibank's money, goes into the marketplace and if they have a positive experience they won't be needing it a second time around. MIGA, the Multilateral Investment Guarantee Authority of the Bank, stands behind many major corporations, in politically risky developing country environments, providing an insurance policy if something goes wrong, we will pay the price.
But in the global environment area in the last two to three years we have made a much more innovative approach: We have recently established the Renewable Energy and Efficiency Venture Capital Fund providing a small amount of grant moneys, to leverage a large amount of pure private sector venture capital, to increase the rate of return on that investment by setting an actual risk level to get into a business much more globally-friendly than they would otherwise have been. We provide contingent financing and an example of that would be to stand behind one of the Argentinean Petroleum companies when they re-inject their gas. They don't know whether they are going to make money out of it or not, nor what the response of the oil people will be to oil recovery but input may be required out there and they would not risk their own money but they will if we stand behind them.

What I would like to say to you is that these are all tools we have available to use in this business. I am not going to give you any specifics of what is on my mind because it is half-baked, half-cooked but with all these tools that the Bank is developing I think we would have opportunities to make this business work better, make markets work better, give our consumers better choices, and to get better technologies, so I want to hear from you what you think our options are to use these tools which we’re certainly thinking about, and to me it’s a very exciting time because the thoughts are quick and fast as a result of the exchange.

So let me say one more time it has been a great pleasure to be here. I want you to express your thanks in the usual way one more time to the facilitators, to Fraser and his team and to the Governments concerned who have made all this possible.

10. Critique of the workshop

10.1. Some Feedback

Jochen Winkler, ASERCOM

- the input was not always “balanced” and “unbiased
- the expertise of attendees was not always made use of
- it was a well organised workshop (and well prepared)
- efficient, productive group sessions
- next steps clearly elaborated.

Tony Hetherington, Officer-in -Charge, Multilateral Fund

- let me say how valuable the workshop has been in presenting a great deal of useful information and analysis on an important topic
- the Fund Secretariat was not able to address ... issues (on institutional barriers) at the workshop itself.... opportunities to avoid factual inaccuracies and to facilitate a more informed debate on policy and institutional barriers were not realised.

Dr Gert Baumann

- congratulations for an excellent workshop ... you were able to summarise the achievements well and point out the unfinished work
- the real benefit of the workshop was the exchange of ideas and viewpoints with different stakeholders ... it became clear that the different backgrounds/experiences have led many of us to quite different endpoints.

Brian Joyner, Regulatory and Technical Resources

- it was a stimulating event, very well conducted
- although there may have been a feeling on the part of some at the start that the outcome was pre-conceived, ... this was fully dispelled by your closing remarks and summary/conclusions.

11. Appendix I: Workshop Programme

Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market

Workshop, 5 - 7 June, 1996,
Schaffhausen, Switzerland

PROGRAMME

DAY 1	Wednesday, 5 June	Presentation and discussion of study findings: technology, markets, barriers
08.30	Departure from Hotel Chlosterhof (Stein) by bus	
0845	Departure from Hotel Kronenhof (Schaff-hausen) by bus	
09.00	Registration	Registration desk at Klostergut Paradies
09.30	SESSION 1: plenary	Chair: B. Rahill, World Bank
	Official Opening Session	W. Fust, Director of SDC, Switzlerland G. Dresrüsse, GTZ, Germany
	Introduction to the study	B. Rahill, World Bank „Assessment of the Prospects for Hydrocarbon Technology in the Global Domestic Refrigeration Market2
10.00	SESSION 2: plenary	Chair: F. Morrison, Deloitte & Touche Consulting Group (D&TCG)
	Introduction to the workshop	1. O. Schwank (INFRAS, Zürich): Findings of MARKET STUDY 2. St. Sicars (FKW, Hannover): Findings of TECHNOLOGY STUDY 3. St. Sicars, (FKW, Hannover): COST COMPARISON Each presentation is followed by a short discussion; a general discussion on all three presentation follows.
10.15	Inventory of Barriers	K. Meyersen, Moderator: Introducing the Barriers Inventory
10.30	Tea / Coffee Break	
11.00	Summary Reports on Studies	
13.00	Lunch Break (buffet)	Refectory
14.30	SESSION 3: plenary	Chair: B. Rahill, World Bank

	Article 5: Country Case Studies	1. D. Xu (NCLI, China) and X. Song (NEPA, China): CHINA - The State of Hydrocarbon Technology 2. M.L. Gómez (INTI, Argentina): ARGENTINA Case Study 3. A. Mathur (TERI, India): INDIA: Hydrocarbon Technology in the Indian Refrigerator Market Each presentation is followed by a brief discussion; Concluding discussion in the Case Studies.
15.30	Presentation of Analysis of Barriers	F. Morrison and J. Irvine (D&TCG, London): THE BARRIERS STUDY, Discussion
16.30	Tea / Coffee Break	Foyer
17.00	SESSIO 4: plenary	Chair: F. Morrison, D&TCG
	Barriers Evaluation 1	K. Meyersen, Moderator THE BARRIERS: Amendment of the inventory barriers
18.00	Barrier Evaluation 2	Joint selection of most important barriers
19.00	Derive schedule for next day	Moderator
19.20	Closing remarks	Chair
19.30	Cocktail, offered by Georg Fischer AG, followed by dinner	Klostergut park (open air) or cellar
	Dinner	Refectory
21.30	Last transfers to hotels (by bus)	

DAY 2	**Thursday, 6 June**	**Joint work on a better understanding of barriers**
08.00	Departure of bus from Hotel Chlosterhof (Stein)	
08.10	Departure of bus from Hotel Kronenhof (Schaffhausen)	
08.30	**SESSION 5: plenary/ working groups**	**Chair: F. Morrison, D&TCG**
	Morning start (plenary)	Welcome and brief summary of the day before
08.45	Introduction to Group Work	K. Meyersen (Moderator) Introduction to small group work and group formation

09.15	Group Work, first session	BARRIERS A - C (in group rooms) 3 simultaneous working groups, with support of moderators Tea / Coffee break by individual groups during session Preparation for presentation (2 participants assisted by moderators)
12.00	Lunch break	Refectory
13.00	Group Work, second session	BARRIERS D- F (group rooms) 3 simultaneous working groups, with support of two moderators; Preparation of presentation (as above)
15.30	Tea / Coffee Break	Foyer
15.45	**SESSION 6: plenary**	**Chair: F. Morrison, D&TCG, Co-chair: B. Rahill, World Bank**
	Recommended actions	Introduction (Chair) Presentation of Group Work (first two presentations)
16.45	Closing remarks; outline of evening programme	Chair
17.00	Transfer by bus to city centre for evening programme, or transfer back to hotels	
17.30	Optional organ recital and brief City Tour	St. Johann Church in Schaffhausen
18.30	Reception by City of Schaffhausen	Münster (Allerheiligen), welcome address by W. Widmer, member of Town Council, Schaffhausen
19.30	Transfer to Büsingen (by bus)	
20.00	Dinner	at the „Alte Rheinmühle“ in Büsingen (German enclave within Switzerland), Dinner hosted by GTZ
	Transfer back to hotels	

DAY 3	**Friday, 7 June**	**Recommendations and Action Plans alternatively: optional visit to H. FORSTER AG (refrigerator factory)**
08.00	Transfer from hotels to „Klostergut Paradies“ or to Forster AG (optional factory visit from 9.00 am to 11.30 am, afterwards: transfer to „Paradies“	
08.30	**SESSION 6 (contd.)**	**Chair: F. Morrison (D&TCG); Co-Chair: ‘B. Rahill, World Bank**
	Recommended Actions (contd.)	Presentations of Group Work (last four presentations)
10.00	Tea / Coffee Break	
10.15		Presentations of Group Work (last four presentations, contd.))
11.00	**SESSION 7 (plenary)**	**Chair: F. Morrison (D&TCG); Co-Chair: B. Rahill, World Bank**
		Chairs Other issues: Suggestions, discussions, agreements on actions
12.30	**SESSION 8 (plenary)**	**Chair: B. Rahill (World Bank); Co-Chair: F. Morrison (D&TCG)**
	Review of Actions and Commitments	Chairs
13.20	**Closing of Workshop**	**K. Newcombe, World Bank**
13.30	Lunch (optional)	Refectory of „Paradies“, including visitors of fridge factory
14.00	First transfers to airport by bus	

12. Appendix II: List of Participants

Assessment of the Prospects of Hydrocarbon Technology
in the Global Domestic Refrigeration Market
Workshop 5-7 June 1996
Schaffhausen, Switzerland

LIST OF PARTICIPANTS

Name	**Company /Organization**	**Address**

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13. Appendix III: Inventory of Barriers

Inventory of Barriers

	Issue	*votes*
1.	Continued availability of CFC in developing countries	6
2.	The investment costs for changing a production line to HC (costs for safety measures) are higher than for HFC-134a	16 see Group D
3.	The benefits of scale economies have not yet been fully exploited for the production of component parts for HC refrigerators	1
4.	HC-600a compressors are not yet available at competitive prices in some regions of the world - creates dependence on imports	7
5.	HC-600a compressors require a higher displacement volume compared with CFC-12/HFC-134a which may involve extra production costs	10
6.	There are safety risks associated with the storage of HC refrigerant in large quantities in manufacturing plants	3
7.	There are perceived safety risks associated with the storage of HC refrigerators in warehouses	1
8.	Developing countries may not be able to produce HC refrigerants of appropriate quality and purity	0
9.	Developing country manufacturers may lack adequate R&D facilities for the redesign of models to HC technology	3
10.	The payback on the investments in CFC to HFC conversion in developed countries prevents major changes in the short term	0
11.	Developing countries are not always able to "leapfrog" technologies due to weak implementation capacity/different working practices	2
12.	There are cost implications involved in the servicing of HC refrigerators - distribution of the refrigerant, staff training and charging equipment	6

13.	The costs involved in setting up servicing facilities for three refrigerants (CFC-12, HFC-134a and HC-600a) are seen as prohibitive	4
14.	Manufacturers fear misinformation campaigns and adverse publicity against HC from the chemical multinationals as well as from competing manufacturers	12 see Group F
15.	HC technology promoters within non-governmental organisations have suffered from a lack of commercial respectability	0
16.	The economic recession in Europe has restricted new investment in new technologies which is preventing a rapid second conversion to HC	1
17.	The high growth rates in many developing countries do not create sufficient pressure for innovation by refrigerator manufacturers	0
18.	There are potential product liability issues in the event of an accident	8
19.	Through commercial agreements e.g. joint ventures, licensing agreements etc. between developed and developing country manufacturers, the parent company's technology is transferred which, in most cases, is HFC technology	29 see Group A
20.	There are perceptions of safety hazards in the home	3
21.	There is a perceived risk of damage to refrigerators through consumers tampering with HC refrigerators in cleaning/defrosting	2
22.	HC is marked as a "German" technology which implies German interests world-wide this makes it difficult to promote with any political neutrality	1
23.	US enterprises are reluctant to consider technologies they can not sell in their domestic market and this strongly influences developing countries	9
24.	Some developing countries are more engaged in seeking financial support from developed countries for CFC phase-out than actively committing themselves to CFC phase-out activities	2
25.	There is a lack of information/signals in favour of HC technology from the national/political level to manufacturers and consumers in developing countries	6
26.	The labelling of refrigerators is still poor and consumer unfriendly in many countries	1

27.	The information made available to consumers from manufacturers is often distrusted; they are not given adequate information on the effects of their technology choice on operating costs (energy consumption) and on the environment	1
28.	Consumers are more interested in the price of their refrigerator than ecological benefits	23 see Group B
29.	There is inadequate information on the actual risk and scale of safety issues (e.g. commonly used appliances such as lighters, spray cans, cooking gas, use larger quantities of flammable substances and are potentially more dangerous than HC refrigerators)	9
30.	The potential for blends of HCs as a transitional option in developing countries has not been fully considered, and the possibilities for retro-fitting CFC-12 refrigerators have been overlooked	4
31.	There is widespread ignorance about the disadvantages of synthetic replacements (e.g. HFC-134a imposes strict cleanliness and moisture control discipline in the workplace, which can be difficult to achieve in developing countries)	15 see Group E
32.	There is a lack of coherent and credible evidence on TEWI for both HCs and HFCs which sends confused messages to the industry as a whole and especially to developing countries	22 see Group C
33.	There is a lack of coherent information on the economic advantages of HC in developing countries	2
34.	Cheap imports of HFC-134a refrigerators undercut HC refrigerators' market potential in some developed countries	1
35.	The Multilateral Fund and Implementing Agencies are not well-informed about alternative refrigeration technologies in general and have failed to inform clients in time and in an unbiased manner	4
36.	The MF does not devote sufficient funds to adaptive research and development and for demonstration or pilot projects	10
37.	The project consultants used by the Implementing Agencies are often biased towards synthetic fluid technologies and are insufficiently informed about HC technologies	3

38.	The project rules for HC conversion projects funded by the MF are based on the rules used for synthetic fluids - this is an illustration of their inability to cope with emerging technologies	1
39.	The eligibility criteria for the funding of incremental investment costs for HC-600a conversion projects are inadequate	4
40.	The lobby of international chemical companies are able to apply protectionist influences for the continued use of HCFCs and HFCs	6
41.	Safety standards in many countries do not include provisions for the use of flammable fluids in domestic refrigerators	5
42.	Concern that there may in future be a move against HCs - as is happening with aerosol use in USA	2
43.	Economy situation in A5 countries does not recommend the use of most expensive (HC) technologies	0
44.	HC-Technology may be surpassed by better HFC alternatives in short term	5
45.	Non traditional suppliers (without broad distribution basis) needed for HCs	2
46.	Incremental (higher) operating cost for HCs only partially covered by the Multilateral Fund	3
47.	For C-Pentane energy efficiency penalty or redesign or use of a more expensive compressor	6
48.	The existence of another alternative (HFC) technology that provides key advantages (more energy efficient, more cost effective, non-flammable)	9
49.	Construction requirements differ between products within countries as well as internationally	2

10 INDEX

C

D

E

F

G

H

I

J

N

O

P

Q

R

S

T

U

V

W

X

Y

Z

INDEX