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Miljøprojekt

Evaluation of the possibilities of substituting potent greenhouse gases (HFCs, PFCs and SF6)

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Preface

In the mid 1990s, an increase occurred in the Danish consumption of potent greenhouse gases concurrently with the phase-out of CFC, HCFC and other ozone-layer depleting substances.

Substitution of CFC

It was especially the use of HFC substances that increased. These substances are used as substitution of CFC and HCFC for certain purposes within refrigeration and as blowing agent of polyurethane foam. Simultaneously, another development occurred as more environmental alternatives were developed for many purposes, e.g. hydrocarbons in aerosol cans, cyclopentane in insulating foam in refrigerators and district heating pipes as well as hydrocarbons, ammonia and water in different types of refrigeration systems.

Synthetic produced substances

CFCs (fully halogenated chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), HFCs (hydrofluorocarbons), PFCs (fully halogenated fluorocarbons) and SF_6 (sulphur hexafluoride) are all synthetic produces substances. In addition, the substances are quite stable and have a long life in the atmosphere. This applies particularly to the fully halogenated substances, i.e. CFCs, PFCs and SF_6.

Ozone depleting substances

CFCs and HCFCs are ozone depleting substances and are included in an international convention (the Montreal Protocol), which ensures a phase-out of these substances. The consumption of CFC is (with few exceptions) prohibited in Denmark. The Danish consumption of HCFC is decreasing and must be phased out completely by 2002.

HFCs, PFCs and SF_6 do not contribute to the depletion of the ozone layer, as the substances do not contain chlorine or bromine. On the other hand, they contribute to the greenhouse effect. The UN Framework Convention on Climate Change regulates the greenhouse gases. The substances, which the countries have to reduce the emission of, are on the list of greenhouse gases (in the Kyoto Protocol). The substances are treated equally with carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Danish consumption

In 1999, the consumption of HFCs was approx. 980 tons in Denmark. The corresponding consumption of SF_6 was approx. 13 tons, while the consumption of PFCs was approx. 8 tons.

This is the reason why the present project has been subsidised by the Danish Environmental Protection Agency.

Phase-out of HFC

The Danish Environmental Protection Agency has just published a draft statutory order on phase-out of potent greenhouse gases (HFCs, PFCs and SF_6). These substances have a GWP (Global Warming Potential) from 140 to 23,900 compared to CO_2, which per definition has a GWP of 1.

In the course of a number of years, it is expected that the emission of these substances will reach what corresponds to approx. 2.5 to 3% of the emission of CO_2 in Denmark. This is the reason whey the government wants to limit the consumption and thus the emission of these substances.

In connection with the Budget for 2001, a tax was introduced on HFC, PFC and SF6. It was decided that an investigation should be carried out in the course of 2001 determining where an additional effort should be made to phase out the use of the substances as fast as possible with the lowest additional costs possible.

What is meant by additional effort is support for development of new technology, construction and test of demonstration system, development of education on the use of new refrigerants and forced implementation for the benefit of the environment, etc.

The Danish Technological Institute has prepared the reports ”Erstatning af kraftige drivhusgasser" (Substitution of potent greenhouse gases) for the Danish Environmental Protection Agency (Environmental project no. 456, 1999) and ”Ways of Reducing Potent Greenhouse Gases” for the Nordic Council of Ministers (Tema Nord 2000:552).

This report should be seen as part of the two above-mentioned reports, as this work focuses on areas where the situation is changed, or where there are special problems. Importance is attached to the field of commercial refrigeration in particular where the problems are the greatest and most complex.

Summary

The consumption of the potent greenhouse gases (HFCs, PFCs and SF_6) amounts to approx. 1,000 tons per year (1999). If this entire amount is emitted to the atmosphere, it will correspond to an emission of approx. 1.8 million tons of CO_2. In comparison, the Danish CO_2 emission was of 55.7 million tons in 1999. The present emission of these substances is however lower as a large part of the substances are accumulated in products.

The vast majority of the consumption is made up of HFC substances, which are used as an alternative to the ozone-layer depleting substances (CFCs and HCFCs). For that reason, a heavy increase occurred in the consumption of HFC substances through the 1990s. The consumption has however stagnated and during the last few years, a small decrease has occurred.

For the past years, a new technology has been developed and implemented without potent greenhouse gases in a number of areas, e.g. refrigerators, large refrigeration systems, insulating foam, flexible plastic foam, sound insulating windows and magnesium production.

In some areas, however, there are significant problems in using alternative technology. This applies especially to small commercial refrigeration systems with cooling performances below 20-30 kW and refrigerant charges below 10 kg.

The purpose of this project has been to evaluate the possibilities and requirement for subsidy in order for the Danish trade and industry to comply with the Ministry of the Environment and Energy's draft statutory order on phase-out of potent greenhouse gases (of February 2001).

The report points to a number of specific development projects and to a plan of action for the refrigeration industry. These projects are described in chapter 6 of this report.

The described projects can be carried out in the period 2002-2005. The total required subsidy in this period is assessed to be approx. 100 million DKK or approx. 25 million DKK per year.

1 Background

Consumption

In 1999, the industry in Denmark used approx. 980 tons of HFC substances, approx. 13 tons of SF_6 and approx. 8 tons of PFC substances. The table below shows the consumption and environmental impacts hereof:

	Consumption in 1999 in tons	GWP (100 years)	CO_2 equivalents, tons	Atmospheric life, years
HFC-134a	644.6	1,300	838,000	14.6
HFC-152a	35.8	140	5,000	1.5
R-404A	193.5	3,260	631,000	36.6, 48.3 and 14.6
Other HFCs	104.2	Various	(160,000)	Various
SF_6	12.7	23,900	304,000	3,200
PFC (C_3F_8)	7.9	7,000	55,000	2,600
In total	998.7		1,833,000	

The figures are from the Danish Environmental Protection Agency's analysis of the ozone layer depleting substances and potent greenhouse gases in 1999 (the Danish Environmental Protection Agency 1991). Tomas Sander Poulsen, COWI, has prepared this report.

3% of CO_2 emission

If this entire amount of substance is emitted to the atmosphere, it will result in an increased emission of greenhouse gases corresponding to approx. 1.83 million tons, which corresponds to approx. 3% of the total Danish emission of CO_2 (55.7 million tons in 1999). It should be emphasised that the figure represents the raw materials consumption and thus the potential emission of these substances. The real emission will depend on the extent of the collection and destruction of these substances.

The consumption of HFC substances has been heavily increasing as these in some cases are used as substitution for CFC and HCFC substances. The consumption is however stagnant, and a small decrease has occurred in the consumption from 1998 to 1999.

Seen from an environmental point of view, it is better to use HFC substances than CFC and HCFC substances as the impact on the ozone layer hereby is eliminated. CFC and HCFC substances are moreover very potent gases with significant GWP even though opinions differ about the exact contribution of the substances to the greenhouse effect. The substances contribute with two opposing effects: They are very potent greenhouse gases with GWP values of e.g. 4,000 (CFC-11), 8,500 (CFC-12) and 1,700 (HCFC-22). On the other hand, the substances contribute to depletion of stratospheric ozone, which is also a greenhouse gas.

It should also be mentioned that the contribution to the greenhouse effect from different HFC substances covers GWP values ranging from 140 (HFC-152a) to 11,700 (HFC-23).

Activities up till now

Danish Environmental Protection Agency

Through the Danish Environmental Protection Agency's programmes (i.a. the Cleaner Products Programme), a great deal of activities have been subsidised in order to develop products and production processes, which do not make use of HFC or other potent greenhouse gases. In co-operation with the industry, refrigerators and pre-insulated district heating pipes have i.a. been developed with hydrocarbons as blowing agent in the insulating foam as well as supermarket systems using natural refrigerants, use of water and inert gases in fire extinguishing equipment, etc.

Natural refrigerants

What is meant by natural refrigerants is use of naturally occurring substances, i.e. ammonia, hydrocarbons, CO_2, water and air. Some of these refrigerants can be produced chemically, e.g. ammonia.

The Danish Energy Agency

The Danish Energy Agency also subsidises the development of new energy-efficient refrigeration systems using natural refrigerants. Development of refrigeration systems using water as refrigerant (the LEGO system) can be mentioned as well as development of commercial refrigerators (bottle coolers, ice cream freezers and commercial kitchen appliances) using hydrocarbons as refrigerant and ammonia refrigeration systems as demonstration project in a large city hotel.

It should be mentioned that the total consumption of CFC substances was nearly 6,000 tons per year at the end of the 1980s. Most of the previous applications of CFC have thus been substituted by substances which are naturally occurring i.a. hydrocarbons in aerosol cans, hydrocarbons in insulating foam and in certain refrigeration systems, water for cleansing of electronic components, ammonia in certain refrigeration systems, etc.

2 Purpose and organisation of project

Purpose

The purpose of the project is within each field of application to describe:

- The area of application and why potent greenhouse gases are used.
- Whether an alternative technology is available. If not, whether an alternative technology is being developed and whether it is probable that this work will end successfully before 2004/05. Can efforts be made to further alternatives?
- The implementing rate of alternative technology.
- The evaluation of the implementing rate in the coming 5 years.
- The relative additional cost of alternative technology.
- Whether the relevant industries are ready to use (and service) the alternative technology? If not, what can be done to make the industry ready for it (including education/supplementary education)?
- Whether relevant semi-manufactured products/components are available. If not, when will they be?
- Whether there are other barriers to the introduction of alternative technology (higher energy consumption, problems with quality, problems with safety, etc.).

An overall evaluation has been made of the requirement for subsidy (including evaluation of the size of the subsidy) to develop alternative technology so that the use of potent greenhouse gases can be phased-out as soon as possible.

Method

The project is based on the previous projects mentioned in the preface, as relevant industries and/or industrial companies have been addressed with the purpose of investigating the implementing rate of alternative technology and evaluating the need for development activities.

In this connection it has to be emphasised that importance is attached to the view of the industry organisations and industrial companies on the matter.

Reference group

The Danish Environmental Protection Agency has appointed a reference group for the project. It consists of:

Helle Juhler-Kristoffersen, Confederation of Danish Industries
Teddy Hansen, Authorised Refrigeration Installers Association (AKB)
Tarjei Haaland, Greenpeace
Dorte Maimann, Danish Energy Agency
Frank Jensen, Danish Environmental Protection Agency (Chairman)

Project implementer

Per Henrik Pedersen, MSc, the Danish Technological Institute, Energy Division has implemented the project.

Organisation of the work

Report

The report is divided into types of substances, i.e. chapter 3 deals with the application of HFC substances and their substitution possibilities, chapter 4 deals with the application of PFC substances and their substitution possibilities, while chapter 5 deals with the application of SF_6 and its substitution possibilities.

During the project, the Danish Technological Institute has been in contact with a large number of Danish companies and technological institutes in order to obtain knowledge. This is reflected in the descriptions of the individual areas of application and substitution possibilities.

Nordic report

The Danish Technological Institute has concurrently with this report prepared a similar report for the Nordic Council of Ministers. The Nordic report deals more or less with the same areas as the Danish report. However, certain areas have been elaborated on, e.g. consumption of SF_6 in magnesium production, consumption of SF_6 in connection with production of power switches and emission of PFC substances in connection with aluminium production. These areas are typical for other Nordic countries.

The Danish report, on the other hand, elaborates on areas which are specific to Danish conditions, e.g. production of refrigerators, commercial refrigeration systems, refrigerated containers and sound insulating windows.

Appendix B of this report has been prepared in co-operation with the Nordic project and will also be included in the Nordic report. This appendix has been prepared in co-operation with Kim Gardø Christensen, MSc, the Danish Technological Institute, Energy Division.

3 Application of HFC substances and their substitution possibilities

HFC (hydrofluorocarbons) is the term for a number of substances produced by replacing a number of fluoride atoms on hydrocarbons, however, in such a way that hydrogen atoms are still left in the molecule. The most common HFC substances are:

	Chemical formula	Normal boiling point (°C)	GWP (100 years)	Atmospheric life (years)
HFC-23	CHF_3	–82.1	11,700	264
HFC-32	CH_2F_2	–51.7	650	5.6
HFC-125	C_2HF_5	–48.4	2,800	32.6
HFC-134a	CH_2FCF_3	–26.5	1,300	14.6
HFC-143a	CF_3CH_3	–47.5	3,800	48.3
HFC-152a	$C_2H_4F_2$	–24.2	140	1.5
HFC-227ea	C_3HF_7	–17.3	2,900	36.5

Mixtures

The term R-134a is frequently seen, in which "R" stands for Refrigerant. The term HFA-134a is also seen. It is the same as HFC-134a. HFC substances often form part of refrigerant mixtures numbered with the R-400 series or the R-500 series. In appendix A, a table of refrigerants and refrigerant mixtures is shown.

In Denmark, the HFC substances are mainly used as refrigerant in refrigeration systems and as blowing agent of polyurethane foam. HFC substances are however also use for a number of other purposes, e.g. as propellant in special aerosols. Abroad, HFCs are used for special fire extinguishing purposes.

This chapter is divided into main areas of application. Section 3.1 deals with the refrigeration industry and is divided into subsections dealing with household refrigerators and freezers, commercial refrigerators and freezers, etc.
Section 3.2 deals with polyurethane foam and XPS foam. Section 3.3 deals with fire extinction. Section 3.4 deals with aerosol containers. Section 3.5 deals with other areas of application of HFC substances.

3.1 The refrigeration industry

15,000 employees

Denmark has a large refrigeration industry with internationally known companies such as Danfoss, York Refrigeration, Gram, Vestfrost, Caravell, Elcold and others. It is assessed that approx. 15,000 are employed in the refrigeration industry, which has a turnover of more than 15 billion DKK per year. It is thus an industry of great importance to the Danish economy and employment.

The refrigeration industry produces a large number of products, which covers a wide spectrum. It could be refrigerators and freezers of which there is a large production. It could also be industrial refrigeration systems of which York Refrigeration (former Sabroe) is the world's largest producer. It could be components for refrigeration systems of which Danfoss is the world's largest producer, or it could be a small refrigeration company assembling a commercial refrigeration system in a supermarket.

In this section, the refrigeration industry is divided into main products. Subsection 3.1.1 deals with household refrigerators and freezers. This subsection comprises both the application of HFC as refrigerant in refrigeration systems and the application of HFC for insulating foam in cabinets as these application areas are closely connected.

3.1.1 Household refrigerators and freezers

1.5 million units per year

There are six Danish producers of refrigerators and freezers, i.e. Vestfrost, Gram, Caravell, Derby, Frigor and Elcold. In total, they produce approx. 1.5 million units per year, and the vast majority is exported. More than 1 million units are household units and almost half a million units are commercial units.

The sale in Denmark of household refrigerators and freezers has for years been approx. 300,000 per year. A large number of these have been imported from especially Germany, Italy and Sweden.

5,000 employees

It is assessed that approx. 5,000 employees are producing refrigerators, freezers and components for these. It is an industry of significant importance to the Danish economy and employment.

The story behind the phase-out of the CFCs and later the HCFCs in household refrigerators and freezers is described in detail in the report from 1998. For that reason, it will not be repeated here.

It should however be mentioned that all large producers in Europe have used cyclopentane as blowing agent of insulating foam for several years and that the market share for isobutane as refrigerant is increasing and in many places, it makes up more than 50%. In Germany it is close to 100%.

The new hydrocarbon refrigerators are just as energy-efficient as HFC refrigerators and there is no additional charge on raw materials and components. The conversion from CFC, HCFC or HFC to hydrocarbons is very expensive. This investment was however made several years ago by the large producers in Europe. In Denmark, the largest producer (Vestfrost) made this investment in 1993.

The small Danish producers have used HFC (or HCFC) as blowing agent of the insulating foam. HFC is used because it is still cheaper than cyclopentane, as cyclopentane requires a little more plastic mass in the foam. This aspect has however been compensated for by new plastic formulas.

According to the analysis of the Danish Environmental Protection Agency, 241.2 tons of HFC-134a was used in 1999 as blowing agent of insulating foam in "refrigerator and freezers, etc.". Moreover, 204 tons of HFC-134a and 24 tons of R404A were used as refrigerant in ”household and commercial refrigerators, freezers, etc.”.

Several of the small Danish producers have recently converted their production to hydrocarbons. This has especially occurred due to the introduction of an environmental tax on the HFC substances.

420 models

The Danish Electricity Saving Trust has analysed the number of hydrocarbons refrigerators and found that there were more than 420 models on the Danish market. Many of these were imported from Germany, Sweden, Slovenia and Italy.

However, the Danish producers still want to produce units using HFC refrigerant to countries demanding these.
The same applies to the United States where it is not possible at the moment to sell refrigerators using a flammable refrigerant. The new draft statutory order on ban on certain applications of HFCs, PFCs and SF_6 also permits production and export of refrigerators using HFC. Products with HFC, which are exported, will also have the tax on HFC refunded.

Economic barriers

The HFC free technology is available and it is only economic barriers, which may prevent it from being used. The economic barriers mainly consist of investments in production plants, as it is often necessary to rebuild the factory in order to develop special fireproof areas in connection with the foaming process and in connection with the charging of refrigerant.

In addition, investments have to be made in charging equipment for hydrocarbons. Furthermore, the personnel have to be trained. Finally, the new products have to be approved and laboratory tests have to be carried out in order to measure energy consumption, etc.

Hydrocarbon compressors

It can be mentioned that a completely new compressor technology is being introduced. Danfoss has thus introduced a series of compressors for household freezers. These are for isobutane and can operate with variable speed. In this way, large energy savings of up to 30-40% can be obtained.

The energy saving is not a result of the refrigerant, rather of the possibility of improving the control of the appliance. The new compressors are included in Danfoss' product programme and is expected to have an increasing sale in the coming years. The price is for the time being somewhat higher than conventional compressors.

It should however be mentioned that hydrocarbon compressors for direct current (12 V or 24V) are not available at the moment and that HFC-134a is used as refrigerant in small refrigerators and freezers for lorries, yachts or other applications for areas without supply voltage. Direct-current compressors for isobutane should be possible to develop, but it requires that the compressor producer makes an investment, and this implies that there is a market for these compressors.

Vaccine coolers

A great number of vaccine coolers are produced in Denmark for use in i.a. India. WHO and UNICEF co-ordinate the purchase of these and require that HFC-134a is used as refrigerant. Recently, there have been some indications that hydrocarbons will be another possibility in the future. This requires however that an infrastructure is established for service etc. of these appliances in the countries where they are used. The majority of the vaccine coolers use 220 V alternating current, but a small number of appliances with direct-current compressors are also produced which are driven by solar cells.

3.1.2 Commercial refrigerators and freezers

Ice cream freezers and bottle coolers

The same companies which produce household refrigerators and freezers (i.e. Vestfrost, Gram, Caravell, Derby, Frigor and Elcold) have a large production of commercial refrigerators and freezers as well. This is especially ice cream freezers and bottle coolers for shops, but also refrigerators for hotels, restaurants, bakeries, etc. to a lesser extent.

The production of bottle coolers and ice cream freezers takes place almost in the same way as the production of household refrigerators and freezers. The production comprises almost 500,000 units per year and the vast majority is exported.

The insulating foam is produced as mentioned above.

New compressors

Until recently, hydrocarbon compressors have not been available in the right size for commercial appliances. Danfoss Compressors has now a complete compressor programme for hydrocarbons. The small compressors (for household refrigerators and freezers and small commercial units) use isobutane (R600a) as refrigerant, while the large compressors for other commercial refrigerators and freezers use propane (R290) as refrigerant. They will be applicable in most commercial refrigerators and freezers.

Coca-Cola and Unilever

In Denmark, two development projects have been carried out which have been subsidised by the Danish Energy Agency. In these projects, a new compressor is used (developed by Danfoss Compressors), in which isobutane is used as refrigerant and which can operate with variable speed. In one of the projects, the Coca-Cola Company, Vestfrost and the Danish Technological Institute have developed a new type of bottle cooler, which through field test of 40 bottle coolers has shown an energy saving of approx. 40% compared to conventional bottle coolers. The saving is mainly due to the possibility of adjusting the cooling performance to the cooling requirement and more efficient fans, etc. This project has been a contributory factor in the Coca-Cola Companys decision to stop purchasing equipment using HFC from 2004 and to purchase equipment which has an energy consumption which is 40-50% lower in 2010. A variant of the bottle cooler was supplied to the Olympic Games in Sydney in 2000, and Vestfrost now markets the new bottle cooler in three variants. The Coca-Cola Company is the world's largest producer of soft drinks.

In the second project, test of 50 ice cream freezers with the same compressor showed a saving of approx. 50%. This project was carried out in a co-operation between Frisko Is (Unilever), Caravell A/S and the Danish Technological Institute. The saving is again due to adjustment of the cooling performance and cooling requirement as well as better glass lids.
Unilever has in a similar way as the Coca-Cola Company decided to stop the purchase of HFC containing appliances from 2005. Unilever is the world largest producer of ice cream.

Currently, a project is carried out between Gram Commercial A/S, the Danish Technological Institute and several potential buyers and users of commercial kitchen appliances. In this project, new types of commercial kitchen appliances have been developed using propane as refrigerant and having an energy saving of approx. 50%. In November 2001, ten new refrigerators and 10 new freezers will be set up for field test in selected commercial kitchens. Gram Commercial plans to market it appliances very soon.

150 grams

The present standard for household refrigerators and freezers (DS/EN60335-2-24 ”Safety of household and similar electrical appliances – Part 2: Particular requirements for refrigerators, food freezers and ice-makers”) specifies that the refrigerant charge for flammable refrigerants is limited to 150 grams. Strictly speaking, this standard does not embrace refrigeration and freezing for commercial use, but it is assessed that most of the commercial refrigerators and freezers will have a refrigerant charge smaller than this amount.

Large bottle coolers (two or three door models) using hydrocarbons as refrigerant have not yet been seen. It is recommended to commence a project in this area in order to demonstrate that hydrocarbons can be used.

3.1.3 Commercial refrigeration systems

Commercial refrigeration systems are systems, which e.g. are used for refrigeration in supermarkets, specialty shops, hotels and restaurants as well as in computer rooms. It can also be small refrigeration systems in the industry.

Supermarkets

Typical commercial refrigeration systems are e.g. found in supermarkets in which direct refrigeration has been used so far. The cooling compressors are located in a machinery room separate from the cooling place. The refrigerant liquid is sent through long pipes into the shop where it evaporates in the cooling surfaces in the fresh food and freezer display cabinets and other cabinets in the shop.

The refrigerant gas returns to the compressors. This principle is found in several different variants and sizes, from small bakeries or butcheries to computer centrals, hotels and restaurants as well as very large department stores with more than 50 cooling places.

In section 3.1.7, air-conditioning systems are described, but it should be mentioned that there is no clear distinction between commercial refrigeration systems and air-conditioning systems. Systems having several cooling places, including air-conditioning are frequently seen.

CFC or HCFC based refrigerants were previously used such as R-502, HCFC-22 and CFC-12. In recent years, many systems have been converted to HFC based refrigerants such as HFC-134a or R-404A. New systems have also been built which use HFC refrigerants. However, some systems have recently been built with indirect refrigeration (in Denmark and abroad) (cf. later).

Leakage

The field of commercial refrigeration is the most varied field within the refrigeration industry. A large number of companies sell and install refrigeration systems. The refrigeration systems are constructed of purchased standard components. Long pipelines are often involved and the leakage rate has previously been very high (i.e. approx. 20-25% of the refrigerant charge per year).

In recent years, the three refrigeration associations AKB (Authorised Refrigeration Installers Association), Danish Refrigeration Association and Selskabet for Køleteknik have done a great deal to improve the quality, so that the systems become more leakproof. This implies that the emission of new systems is reduced by approx. 10% per year.

High economic value

The commercial refrigeration systems constitute a very high economic value, as there are many of them. At the same time, there are a vast number of variants of refrigeration systems. In appendix B, an analysis has been carried out of the different types and status for alternative systems, which do not use HFC refrigerant.

According to the Danish Environmental Protection Agency's statement, 319 tons of HFC refrigerant was used in 1999 in ”Commercial stationary refrigeration systems and air-conditioning systems”.

	Consumption in 1999, tons
HFC-134a	110.6
R-404A	135.5
R-401A	15
R-407C	40
R-402A	8
R-507A	10
In total	319.1

Consumption of HFC refrigerant in commercial stationary refrigeration systems and air-conditioning systems in 1999. The figures are from the annual statement of the Danish Environmental Protection Agency carried out by COWI.

KMO

Due to the high economic value of existing commercial refrigeration systems, it will be sensible to let them continue in operation, but make them as leakproof as possible. When the refrigeration systems are to be scraped, the refrigerant should obviously be emptied out and sent to KMO (KølebranchensMiljøOrdning (the Danish refrigeration industry's environmental scheme)). Here, the refrigerant will either be regenerated and recycled or sent to destruction.

KMO is a voluntary scheme in the refrigeration industry and has been subsidised by the Danish Environmental Protection Agency.

Natural refrigerants

Natural refrigerants are substances naturally occurring in nature, e.g. ammonia, hydrocarbons, CO_2, water and air.

In Denmark and abroad, supermarket systems have been built in which natural refrigerants are used, i.e. ammonia or hydrocarbons. As these refrigerants are not permitted inside the supermarket, indirect refrigeration is used, i.e. a secondary coolant (brine) must be used.

In Sweden, Bonus Energi (a subsidiary of York Refrigeration) has built approx. 400 ”chillers” using hydrocarbon since 1996. Most of them are for air-conditioning, but a few have been installed in supermarkets.

In Denmark, two demonstration systems using hydrocarbons have been built in Odense and Beder near Aarhus respectively.

New analysis

The Danish Technological Institute has carried out a new analysis of commercial refrigeration systems. The analysis, which can be seen in appendix B, describes whether alternatives are available for a given application, estimates the additional costs of HFC free systems and estimates any additional energy consumption of HFC free systems.

In the analysis, commercial refrigeration has been divided into two parameters: type of system and application.

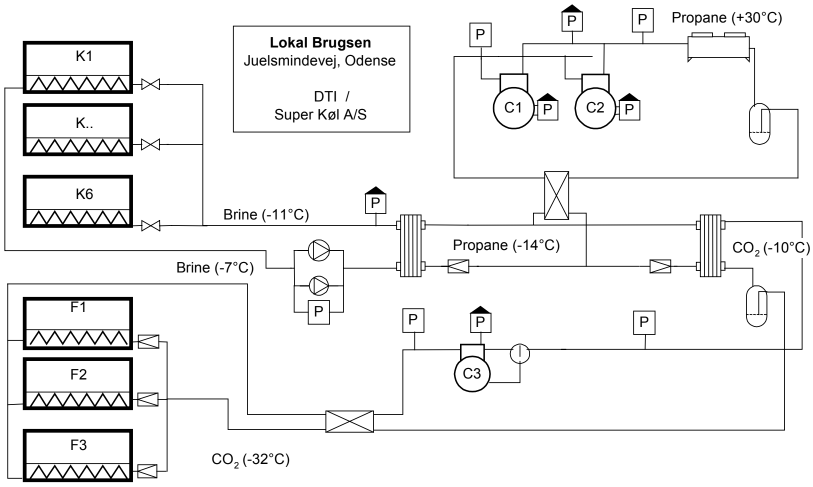
Types of systems are plug-in units, split units, chillers (liquid coolers) and compressor system. The last-mentioned is characterised by having many parallel evaporators, which is known from supermarket systems in Denmark.

Applications are divided into supermarkets, kiosks, specialty shops, hotels and restaurants as well as agriculture.

Supermarkets

In Denmark, there are approx. 2,200 supermarkets in which the main part of the refrigeration is performed by remote systems/compressor systems. In addition, there are approx. 2,000 grocer's shops in which the refrigeration either is performed by a remote system or a split unit in small shops.

The alternative technology is indirect refrigeration or semi-indirect refrigeration. Semi-indirect refrigeration is made by means of hydrocarbons as primary refrigerant. CO_2 is used for freezing purposes, while a traditional brine (e.g. glycol) is used as secondary refrigerant for refrigeration purposes.



Semi-indirect refrigeration system in Odense. Propane is used as primary refrigerant, while CO_2 is used for freezing purposes. A brine is used as secondary coolant for refrigeration purposes.

The additional costs of semi-indirect systems are of the order of 10% for large supermarkets and 15% for small supermarkets. The energy consumption is very much the same as for HFC systems (+/–5%).

Kiosks, specialty shops, etc.

Small plug-in units using hydrocarbons as refrigerant are being introduced on the market (bottle coolers, ice cream freezers and commercial kitchen appliances).

In large plug-in units it is possible to use indirect refrigeration, but this will result in a higher energy consumption (approx. 10%) and an additional cost of approx. 20%.

It is possible to use semi-indirect refrigeration, but such systems have not yet been fully developed. Such systems will have an energy consumption very much the same as HFC systems and will cost approx. 20% more.

Agriculture and market garden

Approx. 18,000 refrigeration systems have been installed in agriculture and market gardening. Most are used for cooling of milk, and it is assessed that it will be possible in the future to use hydrocarbons. There will be an additional cost of approx. 10%, and the energy consumption will remain the same (or a little less) than corresponding HFC systems. For more details, please cf. appendix B.

Evaluation of alternative technology

Alternatives for large commercial refrigeration systems such as supermarket refrigeration systems are available. It is more difficult with the small commercial refrigeration systems for small shops, etc. The limit is approx. 20 kW in cooling performance.

For small plug-in systems, alternative solutions are available for most applications.

	Type of system[2]					
		Plug-in		*Split system*	*Chillers*	*Machinery*
		Small	*Large*	-	-	-
Application[3]	*Supermarkets*	V[1]	X	X	V	V
	Specialty shops	V	X	X (V)	V (X)	X (V)
	Kiosks/service stations	V	X	X (V)	V (X)	
	Hotels	V	X	X	V	X
	Restaurants	V	X	X (V)	V (X)	-
	Agriculture	-	-	X	V (X)	X

[1] *The table shows primary types of systems used in applications*
V: Alternative technology is available; X: No alternative technology is available; -: no application
[2] *The applications for the different types of systems are air-conditioning, refrigeration and freezing. Air-conditioning is used in hotels and restaurants, but also in supermarkets and other retail trade to a great extent*
[3] *The different applications of refrigeration systems*

The analysis in appendix B demonstrates that even though alternative systems might use more energy (up to 10% more), the alternative systems will still contribute less to the greenhouse effect. This is due to leakage of refrigerant from the HFC systems.

This does not however apply to small compact refrigeration systems with small charges. In this case, the leakage rate is considerably lower compared to large ramified systems. The leakage rate for small compact systems is assessed to be approx. 5% per year. If alternatives (i.e. in practice hydrocarbons) cannot be used with direct refrigeration, the additional energy consumption resulting from indirect refrigeration will overshadow the contribution to the greenhouse effect from the HFC refrigerant. In that case, the HFC system will contribute the least to the greenhouse effect. This is the case if:

- Indirect refrigeration is required with the HFC free refrigeration system
- The refrigeration system is compact with a small refrigerant charge and a small leakage (5% per year or less).

This is the case for small refrigeration systems with a cooling capacity less than 20 kW and a refrigerant charge less than 10 kg.

Education

At the moment, a new education is being prepared for refrigeration installers at the technical College of Jutland in Hadsten, Denmark. The education will start in the autumn of 2001 or at the beginning of 2002. In this way, one of the problems with regard to construction and servicing of commercial refrigeration systems using hydrocarbons is solved. The education will focus much on safety and will be completed with an exam after which a certificate will be issued. The duration of the education will be one or two weeks.

There might however be problems with the education capacity (2,000 people have to pass through the system before 2006), and there might also be problems because the refrigeration companies do not have certificated employees to construct the first systems with hydrocarbons. An exemption scheme is being negotiated with the Danish Working Environment Service.

Legislation

The Danish Technological Institute has with subsidy from the Danish Environmental Agency and in co-operation with i.a. the Danish Working Environment Service, the Emergency Management Agency, the Electricity Council and York Køleteknik prepared the Danish report: ”Kulbrinter i mellemstore køleanlæg” ("Hydrocarbons in medium-sized refrigeration systems"). In this report, the legal issues have been clarified, and there is now clarification of the scope of the legislation, but there are still areas open to interpretation.

The report (Miljøprojekt 604) can be seen on the Danish Environmental Protection Agency's homepage. Even though the legislation has been clarified, the material can be difficult to understand for refrigeration installers, and it is assumed that it requires courses, etc. to communicate the information.

Components

After the new education has been organised and a systematic examination of the legislation has been made, the accessibility of components is the greatest hurdle. A number of components are available at the present moment and suppliers are carrying out the development work.

However, in certain areas components are not available. This applies especially to small refrigeration systems such as e.g. supplier-approved (propane) compressors for heat pumps and small commercial refrigeration systems. At Danish Refrigeration Days in 2001, it could be seen that the refrigeration wholesalers have started to include components and aggregates for hydrocarbons.

The Danish Technological Institute has in connection with the present project addressed the refrigeration wholesalers in order to collect information on which components they market for hydrocarbons. Six wholesalers have replied, and the replies show that there are an increasing number of components available. In Denmark, Danfoss A/S will market a number of components and automatic products for hydrocarbons for commercial refrigeration systems at the turn of the year 2001/2002. The replies of the wholesalers were published at a one-day conference on hydrocarbons on 28 November 2001 at the Danish Technological Institute. At Danish Refrigeration Days in March 2002, a paper will follow up on this issue.

Implementation

There is a need for small refrigeration companies to construct and test small refrigeration systems using hydrocarbons in order to practise the implementation of hydrocarbon refrigeration systems. There is a requirement for subsidy for the first systems which will be significantly more expensive that the subsequent systems.

In this connection, it should to be mentioned that the vast majority of the companies are unfamiliar with the new legislation, components and technology and it requires a certain practice before they become confident about building and maintaining hydrocarbon refrigeration systems. In this way, a forced implementation can be ensured.

In addition, it will be necessary (for a period) with external consultancy for refrigeration companies to solve problems, including a hot line for very acute problems.

The refrigeration industry is preparing a plan of action which i.a. takes some of the mentioned-above problems into account.

3.1.4 Industrial refrigeration systems

Process refrigeration

Industrial refrigeration systems are normally very large refrigeration systems used for process refrigeration within e.g. the food industry or the chemical/biochemical industry. In Denmark, traditional ammonia refrigeration systems are used for these applications and this refrigerant has been used for more than 100 years.

Ammonia refrigeration systems

More or less all dairies, abattoirs and breweries have large ammonia refrigeration systems. York Refrigeration A/S (former Sabroe Refrigeration) is the world's largest producer of industrial refrigeration systems, and it is mainly ammonia, which is used as refrigerant.

However, a number of large industrial refrigeration systems use HFC as refrigerant and in most cases, they could have used ammonia as refrigerant instead.

A growing tendency is seen (e.g. in the food industry) in which indirect system solutions are used more and more in order to reduce the refrigerant charge and prevent ammonia in workrooms, etc.

Ammonia is competitive in systems with a cooling performance higher than approx. 150 kW.

In small industrial refrigeration systems (lower than 150 kW), the situation is different. In this case, HFC is used as refrigerant and the situation is similar to that of commercial refrigeration systems and air-conditioning systems.

In the future, water and CO_2 will be used together with ammonia in industrial refrigeration systems. With subsidy from the Danish Energy Agency, a large demonstration system using water as refrigerant has been installed at LEGO in Billund, Denmark. Several industrial refrigeration systems using CO_2 have been installed abroad in i.a. cold storages and for freeze drying of instant coffee.

3.1.5 Mobile refrigeration systems

Mobile refrigeration systems are systems installed in cars, trains, aircraft, vessels or containers.

Refrigerated containers

Mærsk Line

Mærsk/Sealand Line is the world's largest carrier of refrigerated cargo and has approx. 100,000 refrigerated containers operating worldwide.

Previously refrigerated containers were equipped with a CFC-12 refrigeration system, and old containers with these refrigeration systems are still operating. Many of the new containers have been converted to HFC-134a.

Since 1993, all new refrigeration systems have been installed with HFC-134a refrigeration systems. Mærsk Container Industri has a large production of refrigerated containers in Denmark.

The leakage rate for this type of refrigeration system is very high due to the severe weather at sea.

Previously CFC-11 was used in the insulating foam. It has now been substituted by HCFC-141b. It is not known what Mærsk Container Industri will use as blowing agent, when HCFC-141b has to be phased out in accordance with national and international legislation for protection of the ozone layer.

Thermo King Container Denmark A/S in Langeskov, Denmark, produces refrigeration systems for installation in containers.

CO_2

It is problematic to use flammable refrigerants or ammonia in refrigerated containers. CO_2 has thus been suggested as refrigerant, and a development project has been carried out, which has been completed with interesting results. But at present, it is not possible to commercialise the technology, as there is no components (e.g. compressors) available on the market.

Air-conditioning systems in cars

Previously CFC-12 was used for this purpose, but since the mid-1990s HFC-134a has been used.

As Denmark has neither a car industry nor a hot climate, there have not been many industrial activities in connection with air-conditioning systems for cars so far. However, Agramkow Fluid Systems has produced charging equipment for the car industry.

An increasing prevalence of air-conditioning systems is seen in cars and it is becoming standard equipment in medium-sized cars.

CO_2

The car industry is involved in a number of projects with CO_2 as refrigerant. Demonstration systems are constructed for all large car makes, including Toyota, Mercedes Benz, Ford, Renault, Volkswagen, Audi and BMW. Information from the car industry mentions an introduction on the market around 2005. It is not know what the price will be.

Hydrocarbons

It should however be mentioned that hydrocarbons in some countries are used in car air-conditioning systems. This is the case in Australia, where several hundred thousand cars use these refrigerants. It is presumably a hydrocarbon mixture, which is used together with traditional equipment originally designed for CFC-12 or HFC-134a.

Discussions on fire and explosion danger have occurred in connection with use of hydrocarbons in car air-conditioning systems. Hydrocarbons could have been a natural choice as the car already contains several kilos of hydrocarbons already in form of service, diesel oil and propane gas.

Air-conditioning systems in aircraft

Cold air

For many years, air cycle refrigeration systems have been used for cooling of passenger cabins in aircraft. A simple Joule process is used in which the air is compressed and cooled by heat exchange with the surroundings. The air is then expanded in a turbine by means of which it is cooled. The process is not particular energy-efficient, but is used in aircraft i.a. due to the lightweight of components.

Air-conditioning systems in trains

Cold air

In Germany, a project has been carried out in which an air cycle refrigeration system has been developed and tested for trains. The project has been successful and approx. 60 units have been produced for ICE trains.

3.1.6 Heat pumps

A heat pump operates in the same way as a refrigeration system as the heat energy is absorbed from a source (e.g. outdoor air, soil, process water, air from livestock buildings, etc.). At high temperature, the heat is emitted to a heat carrier; e.g. central heating water or supply air for a house.

In the Nordic countries, it is especially Sweden, which installs household heat pumps. It is also Sweden, which produces the largest number of heat pumps. Approx. 25,000 units are produced each year by three large companies and approx. 2/3 of all new houses in Sweden are equipped with heat pumps.

In Denmark, approx. 1,000 and 2,000 heat pumps are installed each year. The total number is approx. 40,000 units.

The household heat pumps can be divided into five categories:

- Air/air heat pumps (heat source: outdoor air, heat drain: indoor air)
- Air/water heat pumps (heat source: outdoor air, heat drain: central heating system)
- Liquid/water heat pumps: (heat source: heat from soil, heat drain: central heating system)
- Discharge air heat pumps (heat source: discharge air from housing, heat drain: central heating system)
- Domestic water heat pumps: (heat source: discharge air from housing/outdoor air, heat drain: hot domestic water)

In the Nordic area, liquid/water heat pumps and discharge air heat pumps are the most important categories. Air/air heat pumps are also gaining ground.

Liquid/water heat pumps are mainly produced with R407 (or R404A) as refrigerant. Some units are produced with propane (R290) as refrigerant, but it is difficult to find a compressor supplier who will approve hermetic compressors for propane. There are no European owned compressor suppliers for the right size. The producers of heat pumps have to use American or Japanese owned compressor producers, and these have been reluctant to approve propane compressors.

Some heat pump producers have used non-approved R-22 compressors for propane, but this implies that the compressor supplier no longer is responsible for the compressor in case of error. This increases the risk for the heat pump supplier and a systematic error in the compressor can have serious consequences, even though it is not due to the refrigerant. Some large customers have however approved propane as refrigerant.

Discharge air heat pumps are produced with propane as refrigerant. Between 15,000 and 20,000 units have been installed in Sweden since 1996. The refrigerant charge is approx. 400 grams. Some of these have recently been installed in Denmark. They cost between 5 and 10% more than conventional HFC heat pumps, as it depends on one compressor supplier (summer 2001).

Most air/air heat pumps are produced in Japan and use HFC refrigerants. This type of heat pump can normally be converted to air-conditioning. This is however not the case in Denmark as this possibility has to be sealed if it should be subsidised by the state.

In Denmark, Vesttherm (Vestfrost) produces tap water heat pumps. HFC-134a has been used so far, but Vesttherm plans to change this to CO_2. At the moment, Vesttherm and the Danish Technological Institute carry out a development project, which is subsidised by the Danish Environmental Protection Agency.

Industrial heat pumps are produced by i.a. York Refrigeration, and ammonia and hydrocarbons can be used as refrigerant.

Refrigerant charge and leakage rate

A typical liquid/water heat pump contains approx. 2.5 kg of HFC refrigerant, while a typical tap water heat pump contains approx. 0.8 kg of HFC refrigerant. The refrigeration system is hermetic and this results in a small leakage rate.

3.1.7 Air-conditioning systems

Production of air-conditioning systems for housing has not taken place in Denmark so far. It is probably due to the fact that our climate does not necessitate air-conditioning in housing. An increasing marketing of air-conditioning systems is however seen in Denmark (often Japanese systems).

Propane

HFC based refrigerants are used. At the moment, this is the standard for approx. 7 million systems produced in Japan each year.

An Italian producer (DeLonghi) has produced approx. 60,000 small air-conditioning systems with propane as refrigerant. To the knowledge of the Danish Technological Institute, the charge is of a little more than 150 grams.

Large systems

Ammonia

The situation is different for large air-conditioning systems in office buildings, hospitals, etc. Refrigeration systems (chillers) are installed here which cool water for distribution in the building. The air is cooled in heat exchangers by means of the cold water.

A number of different refrigeration systems are used for this purpose, and CFC and other synthetic refrigerants have previously been used. Ammonia is a very good choice for this purpose, and hundreds of such systems have been installed in Denmark and other Nordic countries.

In appendix C of the report from 1999 on substitution of potent greenhouse gases, a reference list is included with 114 ammonia liquid coolers installed in Denmark by York Refrigeration (former Sabroe) from 1990 to 1998. These are installed in hospitals, large office buildings, industrial companies, airports, the pharmaceutical industry, the food industry and shopping centres.

Due to considerations as to competition, it has not been possible to update this reference list, but York Refrigeration has informed that in 1999, 19 liquid coolers using ammonia were installed and in 2000, 41 liquid coolers using ammonia have been installed in Denmark.

Hydrocarbons

Propane can be used in a similar way in liquid coolers for air-conditioning. York Refrigeration (Bonus Energi AB) has installed approx. 400 systems in Sweden. In Denmark, approx. 15 systems have been installed since 1999.

3.1.8 Low-temperature systems

Low-temperature refrigeration systems have a relatively limited application. Refrigeration equipment is produced which can cool laboratory specimens etc. to very low temperatures.

Heto-Holten

Heto-Holten produces laboratory equipment, including equipment for freeze drying and low-temperature (cryo-) freezers for hospitals, etc.

Normally, the equipment consists of a two-stage cascade system in which the first stage is an R-507 system. The first stage cools to approx. –50°C.
The second stage uses hydrocarbons as refrigerant either ethane (R-170) to approx. –80 to –90°C or ethene (R-1150) to approx. –100 to –120°C.

Some foreign competitors use HFC-23 or R508 for the low stage.

It should be possible to use propane in the first stage, and it will hardly change the safety aspects, as flammable refrigerants are already used.

Vestfrost

Vestfrost A/S has started to produce low-temperature freezers down to –80°C. Vestfrost has developed a cooling process in one stage, which reduces the price considerably compared to two-stage systems and makes the product competitive. A refrigerant charge with HFCs is used.
Vestfrost has developed a prototype in which a mixture of hydrocarbons is used. This prototype was presented at the exhibition Domotechnica 2001. According to Vestfrost, the prototype operates well. The energy consumption and performance are the same as for the HFC mixture, and the hydrocarbon version can be produced if there is a demand.

3.2 Polyurethane foam

According to the statement of the Danish Environmental Protection Agency, 241 tons of HFC-134a was used in 1999 as blowing agent of insulating foam (refrigerators, freezers, etc.) in Denmark. In addition to this, 59 tons of HFC-134a and 36 tons of HFC-152a were used for ”other”, which i.a. is production of flexible plastic foam and special aerosol cans. Generally speaking, the consumption is decreasing.

3.2.1 Insulating foam

In section 3.1.1, it has already been mentioned that HFC is used for production of the insulation in refrigerators and freezers and the alternatives have been described. This application will therefore not be dealt with in this section.

District heating pipes

More than half of the production of district heating pipes worldwide is produced in Denmark at ABB I. C. Møller, Løgstør Rør and Dansk Rørfabrik (Star Pipes).

Cyclopentane

Previously this production was large-scale user of CFC and HCFC, i.e. approx. 850 tons of CFC-11 was used in 1986. Hydrocarbons and cyclopentane in particular are now used as blowing agent for the insulating foam.

Approx. 1,500 people are employed at the factories of district heating pipes in Denmark. In addition to this, there are companies, which are employed with pipe laying and construction of entire energy systems, etc. Furthermore, there are companies, which are subsuppliers for the factories of district heating pipes. It is thus an industry of great significance for the economy and employment in Denmark.

Insulating panels
At least two companies (D.C. System Insulation and Prepan A/S) produce sandwich insulating panels for cold storages, etc.

HCFC

So far HCFC has mainly been used for this production. But some panels have also been produced with CO_2 added a little HFC for export to Sweden, which has prohibited HCFC panels.

Hydrocarbons can be used as an alternative, including cyclopentane. It will however require a large investment in production equipment. Panels with hydrocarbons are produced certain places abroad. In Finland, e.g. Hurre group Oy and Makroflex Oy produce sandwich insulating panels by means of hydrocarbons.

CO_2 "water blown" foam is another alternative. This foam has however a somewhat poorer insulating power compared to other solutions.

The greatest barrier to introduction of hydrocarbons is a large investment for conversion of the production equipment. The producers in question are small producers for whom it would be a relatively large investment.

It has been prohibited to use HCFC in production from 1 January 2002, and the Danish producers have to use alternative from this date. Prepan A/S has planned to use hydrocarbons, but this has not occurred yet.

Refrigerated containers

HCFC substances

HCFC substances are used for production of refrigerated containers.
The production could be converted to hydrocarbons (cyclopentane). This will however require a great deal of modifications, including safety during foaming with cyclopentane. In addition, it should be taken into account that any deterioration of the insulating power will result in modification of the construction of the containers. Mærsk Container Industri A/S informs that the conversion to cyclopentane can result in a deteriorated insulating value of up to 10%.

The greatest barrier to the introduction of hydrocarbons is assumed to be the drawbacks resulting from production stops, uncertainty of the quality, protection of the working environment and the economic consequences hereof.

Other types of insulating foam
There are a number of small producers of polyurethane foam for insulation, which use either HCFC or HFC for several different purposes. It may be

expensive for the smallest of these to invest in hydrocarbon technology, as heavy investments are required for fire protection.

CO_2

CO_2 blown foam can be used as an alternative, but it will have a poorer insulating power compared to foam blown with HCFC or HFC. For certain applications, the insulating power is not so crucial. It could be places where the construction implies that there are large thermal bridges or places where temperature differences are not great.

Rigid block foam

Many of the smallest producers of insulating foam have stopped producing the foam themselves. Rigid block foam (rigid slap stock) is used instead which is then cut for the right purpose. Frequently, the foam is only a smaller part of a large complex machine.

Isopentane

There is one producer of block foam in Denmark, i.e. LM Skumplast. Here HCFC-141b is substituted by hydrocarbons (isopentane) for foaming.

3.2.2 Jointing foam

Jointing foam was produced in Denmark until a few years ago (at Baxenden Scandinavia A/S), but this production has now been closed down. In Denmark and other Nordic countries, hydrocarbons have mainly been used in jointing foam since 1987. In Germany and other European countries, HFC is used along with hydrocarbons.

Jointing foam with HFC is however imported for certain purposes. Cans containing HFC foam can be used where there is danger of developing a flammable mixture with air and the use of hydrocarbons therefore is not possible. According to the analysis of the Danish Environmental Protection Agency, approx. 10 tons of HFC-134a was emitted in connection with use of jointing foam.

Hydrocarbons cheaper

Cans containing pure hydrocarbon propellant are considerably cheaper than cans containing HFC substances. The propellants have however different properties, so it is not possible to compare the cans on price only. The joint filling material has different properties depending on the propellant.

3.2.3 Flexible plastic foam

In Denmark, there are two large producers of flexible foam i.e. Carpenter A/S (former Brdr. Foltmar) and K. Balling Engelsen A/S.

The majority of the production is "water blown" i.e. a small amount of water is added to the production. Water reacts with isocyanate and develops CO_2, which is the actual blowing agent.

Part of the production has traditionally been produced with CFC-11 and later with HCFC substances as propellant. It is especially soft and light qualities for the furniture industry.

HFC-134a and HFC-152a

In recent years, a mixture of HFC-134a and HFC-152a has been used as propellant for this production.

The other Nordic countries only use foam, which has been blown with CO_2. An agreement has been entered about not producing foam with a density lower than 23 kg/m^3, in this way physical blowing agents are not required.

A new technology has been developed abroad, in which liquid CO_2 is used for production of flexible plastic foam in these qualities. The main barrier to surpass this technology is to invest in new machinery.

Carpenter A/S informs that it in the beginning of 2000 has stopped using HFC in the production and has started using liquid CO_2. An English Beameck system has been installed and in this way it is possible to produce light and fine qualities of foam for i.a. the furniture industry. The system costs have been approx. 5 million DKK, but the operating costs on the other hand are a little lower than the HFC technology.

K. Balling Engelsen A/S informs that it has decided to stop using HFC before 2004.

3.2.4 XPS foam

XPS foam stands for extruded polystyrene foam. It is a relatively expensive insulating product, which is used for special purposes. XPS foam is not produced in Denmark, but a good deal is imported from our neighbouring countries. XPS foam is i.a. used for insulation of foundations, below roads and railways, in special purpose machines, etc.

A good deal of XPS foam is imported from Sweden and Norway where three companies each use its own production method: one company uses HFC-134a, another uses HCFC and the third uses CO_2.

3.3 Fire extinguishants

In connection with the global phase-out of halons, some chemical substitutes have emerged; including one based on HFC-227 (e.g. Great Lakes FM-200). These are marketed very intensively across large parts of the world and it has also been tried in Denmark.

Ban on HFCs

In Denmark, the use of halogenating hydrocarbons has however been prohibited for fire extinguishing. Halon-1301 and halon-1211 are excepted, but they are now prohibited like CFC, etc.

Danish companies within fire extinguishing equipment have developed excellent alternative technologies. Inergen can e.g. be mentioned which is developed by Dansk FireEater. It consists of inert gases, i.e. argon, nitrogen and a little CO_2. Inergen can be used for fire extinction in computer centrals, control rooms, power plants, machine rooms, etc.

Ginge-Kerr Danmark A/S has a similar technology called Argonite. It consists of argon and nitrogen.

The technology of using inert gases for fire extinction has been very successful – also at international level. Foreign multinational companies thus market Inergen.

Other alternatives to chemical fire extinguishants are also available, e.g. CO_2 or foam fire extinguishing in machine rooms on vessels, better detectors combined with manual fire extinguishing, etc.

3.4 Propellant in aerosol cans and "foghorns"

Statutory order for aerosols

The statutory order for aerosols of the Danish Environmental Protection Agency prohibits the use of HFC substances in aerosol cans.

However, the ban does not apply to medical aerosol cans or "foghorns", as medical products are excepted, and the statutory order does not regulate the content in aerosol cans, where it is only a gas escaping from the can. But the minister for Environment and Energy has announced a revision of the statutory order, so that it comprises "foghorns".

Medical sprays
CFC-11 and CFC12 are still used as propellant in medical sprays, and in asthma sprays in particular. At the end of the 1980s, the consumption of these products made up approx. 29 tons of CFC substances annually. The products are not produced in Denmark.

For many years, alternative preparations have been available, i.a. powder which the patients themselves inhale into their lungs. It is however not all asthma patients who can do this.

Asthma sprays have been developed with HFC substances as propellant.

"Foghorns"
"Foghorns" with HFC-134a as propellant can be bought. It is an aerosol can with a plastic horn, and the appliance is designed to make a very loud sound.

It is assessed that spectators to football matches, etc. use most of the "foghorns", but they are also used on boats as a "foghorn" to warn other boats.

HFC free alternatives

Greenpeace Danmark has found HFC free alternatives in Denmark. There are several different types, in which one uses isobutane as propellant, while the other uses compressed air and can be recharged at a service station or by means of a hand pump. "Foghorns" with an electrically operated compressor are also available. Finally, manually operated "fog horns" are available which can be blown into or which can be activated by means of a rubber ball.

3.5 Other areas of applications

There is a small amount of HFC in special cans for cooling of electronic components during repair of electronic equipment. When liquid HFC escapes, the piece, which the liquid drops hit, is cooled.
It is possible by means of this method to establish whether the component is defect. The amount is assessed to be modest, i.e. a few tons per year at the maximum. Experience shows that it is difficult to find an alternative, as hydrocarbons may cause problems due to danger of fire from electrical equipment. CO_2 might an alternative. AGA A/S in Sweden and Denmark has prepared a brochure on this, but it is uncertain whether the product is marketed.

A small amount of HFC-23 is used in connection with production of electronic and optical microchips. This issue is dealt with in chapter 5.

The Danish Technological Institute does not have knowledge of other uses of HFC in Denmark.

4 Application of PFC substances and their substitution possibilities

PFC substances are perfluorocarbons, i.e. substances developed on the basis of simple hydrocarbons where all hydrogen atoms have been replaced by fluoride atoms. It is substances like CF_4, C_2F_6, C_3F_8, etc.

Stable substances

These substances are very stable and have thus a very long atmospheric life. They are at the same time very potent greenhouse gases. However, only small amounts of these substances are used in the Danish industry, and the main area of application is in refrigeration systems.

There is a certain emission of PFC abroad in connection with production of aluminium, which is produced from aluminium oxide (alumina) in an electrolytic process. The PFC substances are only developed when a special effect occurs (i.e. the anode effect), in which the electric voltage grows fast by means of which PFC substances (CF_4 and C_2F_6) are developed locally. The fluoride atoms come from cryolite (Na_3AlF_6) acting as a catalytic converter in the process. Norway and Iceland have in recent years done much to reduce development and emission of PFC substances.

A great deal of the substance C_6F_{14} is used abroad in the electronic industry.

Chemical formula	R-number	Normal boiling point (°C)	GWP (100 years)	Atmospheric life (years)
CF_4	R-14	–127.9	6,500	50,000
C_2F_6	R-116	–78.2	9,200	10,000
C_3F_8	R-218	–36.8	7,000	2,600
C_4F_{10}			7,000	2,600
C_4F_8			8,700	3,200
C_5F_{12}			7,500	4,100
C_6F_{14}		+58	7,400	3,200

In 1990, the global emission of CF_4 was approx. 15,000 tons and it fell to approx. 10,500 tons in 1995. In 1990 and 1995, the global emission of C_2F_6 was approx. 2,000 tons.

4.1 PFC in refrigerant mixture

Drop-in

According to the analysis of the Danish Environmental Protection Agency, approx. 6.4 tons of C_3F_8 (R-218) was used in 1999 as refrigerant in a special mixture. The refrigerant is used as a “drop-in” substitute for CFC-12 in refrigeration systems. The consumption is stagnant and was approx. 8 tons in 1997.

The refrigerant mixture is known under several terms, including Isceon 49 (R-413A) consisting of approx. 88% of HFC-134a, 9% of C_3F_8 and 3% of isobutane. According to Kølebranchens MiljøOrdning (KMO) (the Danish refrigeration industry's environment scheme), there are approx. 2,000 systems charged with R-413A in Denmark.

The Danish Technological Institute has demonstrated that systems with Isceon 89 exist, which is a mixture of HFC-125 (86%), C_3F_8 (9%) and propane (5%). It is a refrigerant which has been developed as a "drop-in" substitute for R-13B1 and is used for low-temperature purposes (–40 to –50°C).

New mixtures are emerging all the time, but the industry is very cautious about using refrigerant mixtures, as there is doubt about the concentration of the remaining mixture after leakage, and because it is not desired to transport more types of refrigerants than is strictly necessary in the service vans.

Prolonged life

The mixtures can be convenient to use if prolonged life is desired for a system, which originally was designed for CFC refrigerant. The only reason for using these mixtures is to prolong the life of old refrigeration systems. It is possible to avoid this application either by converting the refrigeration systems for HFC refrigerant or keep the systems tight until they have to be scrapped.

4.2 Other applications of PFC substances

A small amount of PFC substances are used for producing electronic and optical microchips in Denmark. This application is described in chapter 5.

Moreover, an amount of PFC is used for cleansing of electronic components. The total amount of PFC used for cleansing electronics was approx. 1.5 tons of C_3F_8 in 1999.

It can also be mentioned that a PFC substance has been tried to be sold abroad as a fire extinguishant as substitute for halons. This application of PFC is prohibited in Denmark (cf. section 3.3).

5 Application of SF_6 and its substitution possibilities

Danish consumption

SF_6 (sulphur hexafluoride) is a heavy gas. According to the analysis of the Danish Environmental Protection Agency, 12 tons of SF_6 was used in the Danish industry in 1999. It is corresponding to the levels of previous years. The glass industry (sound insulating windows) is the largest area of application, then comes the industry of distribution of electrical energy and metalworking factories.

In addition to this, there are some very small areas of application. The Danish Technological Institute is informed that the substance is used for production of electronic and optical microchips and as a tracer gas. There are probably also other areas of application, e.g. laboratory use and medical applications.

Chemical formula	R-number	Normal boiling point (°C)	GWP (100 years)	Atmospheric life (years)
SF_6	R-7146	–63.8	23,900	3,200

Global consumption

The global consumption of SF_6 is approx. 7,500 tons per year and it is increasing. The vast majority (approx. 6,000 tons per year) is used as dielectric material in high-voltage installations in connection with the rapid expansion of the electricity supply in new growth areas, i.a. in Asia. In the "old" industrialised countries, this expansion took place some years ago, and the use of SF_6 for electric installations is relatively low due to recycling of the substance.

Magnesium production is the second largest area of application worldwide (approx. 500 tons per year). Other areas of application are degassing of aluminium and cleansing of electronic components.

5.1 Sound insulating windows

SF_6 (sulphur hexafluoride) is a gas at normal temperatures and atmospheric pressures. SF_6 is used in some sound insulating windows, where SF_6 is used in a mixture of i.a. argon to fill the space between the glass panes. The purpose of this is to damp acoustic pressure waves and thus protect against noise from the outside.

7.2 tons of SF_6

According to the analysis of the Danish Environmental Protection Agency, 7.2 tons of SF_6 was used for this purpose in 1999. The use of SF_6 for this purpose is decreasing and was approx. twice as high in the mid-1990s.

A large part of this production is sold in Denmark. There are approx. 10 producers of this type of sound insulating windows in the country.

According to the analysis of the Danish Environmental Protection Agency, there is a direct emission of SF_6 in connection with charge of the panes, and this loss varies between 10 and 20% depending on the equipment and procedures used. Previously this emission was much larger.

The charged SF_6 is first accumulated in the windows, but the substance will escape to the atmosphere, when the panes puncture.

As there are no schemes for collection or recovery arrangements (which would be difficult to establish), it is expected that all SF_6 will end up in the atmosphere. As this type of windows has been produced for many years (15-20 years), it is expected that there is emission constantly from old with SF_6 in connection with puncturing or scrapping. If it is assumed that the average life for these windows are 20 years, we are reaching the stage where the real emission is equal to the raw materials consumption.

SF_6 adds only a little to noise reduction. The other contributions come from the structure of the window, the thickness of windows and lamination with different materials. Besides, the thermal insulating properties of SF_6 are not very good.

Cleaner Technology effort

In accordance with recommendations in the report from 1999, a Cleaner Technology project was initiated in which Delta Akustik og Vibration carries out a more precise analysis of the production of sound insulating windows (which panes and types of windows, number, areas of application with regard to types of traffic noise, expected life, etc.). Laboratory measurements are carried out on a number of windows (with SF_6). Parallel measurements are carried out on the same windows without SF_6. The project should conclude on the significance of SF_6 for the sound insulating.

There are certain indications that SF_6 is being phased-out. Energy marking of windows has been introduced, and one of the criteria for becoming an energy class A window is that SF_6 must not be used in the production. In addition, a tax of 400 DKK per kg of SF_6 in the production has been introduced.

5.2 Gas protection in light-alloy metal foundries

According to the analysis of the Danish Environmental Protection Agency, 0.7 tons of SF_6 was used in 1999 as gas protection for production of light alloy. The consumption has now been stopped.

Magnesium

Casting of magnesium parts takes place at the company Metallic A/S. SF_6 was used in a mixture of other gases (CO_2 and atmospheric air) for protecting liquid magnesium from catching fire, when the metal is cast into machine parts.

Liquid magnesium is very flammable and will catch fire if it get in contact with the oxygen of the air.

Metallic also casts pieces in aluminium, zinc and brass, but SF_6 is only used in connection with magnesium.

Magnesium is a very light and strong metal. Thus, the car industry has started to use magnesium parts in cars to a greater extent.

SO_2

Metallic has built a new production facility for casting of magnesium parts and closed down the old facility. SO_2 is used in closed machines instead. This new technology is developed in co-operation with Norsk Hydro.

Aluminium production

Degassing of aluminium

According to the company DISA, SF_6 is used for degassing of aluminium melter before casting. Previously "chlorine gases" were used for this purpose and it was quite problematic due to the working environment.

SF_6 is introduced into the liquid metal in small bubbles, and gas (i.a. hydrogen) diffuses into the bubbles, which then rise to the surface and are released to the atmosphere.

Worldwide, there are more than 20 Disamatic casting machines for aluminium production. This market is increasing steadily as aluminium is used for machine parts, i.a. in the car industry to a greater extent.

DISA has earlier tested this technique at its test foundry, but does not at the moment use SF_6 for this purpose.

5.3 Insulating gas in electric power switches

SF_6 has a remarkable dielectric strength. Because of this, the substance has been used as insulating gas in certain high-voltage installations. In principle, there are two different areas of application:

- As arc-breaker in power switches
- As isolator in compact distribution systems

Consumption

According to the analysis of the Danish Environmental Protection Agency, the consumption of new SF_6 for these purposes was approx. 4.8 tons in 1999. The installed amount is approx. 56 tons (T. S. Poulsen, COWI). The substance is in closed containers, which is collected and recycled in connection with maintenance or taking down of the equipment. The emission occurs thus by accident or unforeseen leakages.

There are no Danish producers of this equipment. But large international companies such as ABB, Siemens, Group Schneider, Ahlstrom and Ormazabal sell the equipment. The switches are charged with SF_6, when they are imported to Denmark.

There are approx. 600 transformer stations of the 10-20 kV level in Denmark, and these can be equipped with either SF_6 or vacuum switches.

The price is more or less the same, and there is a keen competition between the producers. It is thus possible to purchase SF_6 free switches for 10-20 kV transformer stations. Spacial problems can be associated with this and it may require a replacement of the entire station.

In addition, there are approx. 60,000 10 kV/400 V distribution substations. The equipment can be based on SF_6 both as switches and isolator, but there are also other SF_6 free solutions. Due to the large number, the reliability, maintenance and small dimensions play a decisive part.

Alternatives are on the other hand not available in the high-voltage area, i.e. from approx. 60 kV and higher.

According to Henrik Weldingh of DEFU (Research Institute for Danish Electric Utilities), a new technology does not appear to be on its way. New semiconductors may however be available on the market in the future, but this requires a technological breakthrough, as there are too large losses in the technology known today.

The other application within the high-voltage area is as insulating gas in compact transmission cables. E.g. high-voltage cables of 400 kV from the generator and out of power plant buildings are carried in pipes of 20 metres filled with SF_6. This prevents flashover to the pipe material and thus also short-circuiting of the high-voltage cables. The alternative is that the cables are placed with larger distance between them, where atmospheric air is the isolator.

As there are no Danish producers of the equipment, it does not seem reasonable to commence a development project in this area. It can be chosen to install a SF_6 free switch in the 10 kV system, if it is desired to use technology, which does not contain potent greenhouse gases.

Recycle

COWI has carried out a project with subsidy from the Danish Environmental Protection Agency with the purpose of describing a method for reducing the emission of SF_6 in this sector (Miljøprojekt no. 592, 2001). In the project, an analysis of the problem has been carried out, and the investigation demonstrates that most electricity companies do not collect SF_6. The project has moreover demonstrated that cleaning equipment is available, which can clean SF_6 to the desired cleaning degree (> 99.9%). Finally, an entire recycling system is described based on collection of return bottles, cleaning and recycling.

It is expected that this system will be commenced by the industry of distribution of electric energy, if possible, with an initial subsidy from the authorities.

5.4 Tracer gas and other laboratory purposes

According to the analysis of the Danish Environmental Protection Agency, there has been an insignificant use in Denmark in 1999 by "Research institutes". Previously approx. 0.5 tons was used for this purpose, but an increased focussing on the environmental impact of the substance has probably resulted in a reduced consumption and the use of alternatives.

Tracer gas

DMU (National Environmental Research Institute) uses a small amount of SF_6 as tracer gas in connection with testing dispersal in the atmosphere. These tests are carried out in order to test mathematical models for dispersal, and this type of tests make up the basis for i.a. standards for chimney heights, etc.

The consumption is very low. The application of SF_6 as tracer gas is due to a number of special properties of the substance, which make it difficult to replace, including that it is precise and traceable in very low concentrations, and it has a very low occurrence in the atmosphere. Tests have been carried out abroad with a PFC substance, but it is also environmental problematic.

DMU assesses that there is no usable alternative, but that the amount used should still be limited and monitored in connection with tests.

There are approx. five Danish laboratories, which carry out ventilation tests. Small amounts of SF_6 are used as tracer gas for indoor tests. The measurements are used for assessing the dispersal of pollution, leakage from heat exchangers and assessment of short-circuiting between airflows, etc.

The Danish Technological Institute has earlier used approx. 2 kg per year for these tests, but has started to use nitrous oxide (N_2O) to a greater extent.

5.5 Microchips

A number of companies have developed microprocessing technologies and optical components, which are the technological basis for production of semiconductor components, biochips and optical fibres. This applies to IONAS A/S, which produces microchips, Grundfos (former ADC), which i.a. produced sensors for pumps and boiler systems and Lucent Technologies Denmark, which produces optical fibres.

The characteristic feature of these processes is that they by means of the industrial greenhouse gases HFC, PFC and/or SF_6 substitute the use of other chemicals, e.g. SiF_4, which is problematic with regard to the working environment.

In the production process of optical fibres, microchips and sensors, no relevant alternatives are available now or in the very near future for substituting the use of greenhouse gases.

Another characteristic feature of the use of these processes for production of e.g. optical fibres for optical cables, etc., microchips and sensors for pumps, etc. is that they contribute to positive environmental benefits.

Generally speaking, it applies to the production of products using these gases that the greenhouse gases are broken down completely or partially during the production process itself.

Microchips

Microchips can increase the communication through fibreoptic cables by a factor 10. Common to Danish companies like IONAS, which produces these chips, are that they use production technologies, which are implemented from the Micro- and Nanotechnology Research Center (MIC) at DTU. It is a technology, which is used worldwide (with small variants).

Small amounts of SF_6, HFC-23, PFCs (especially CF_4, but also a little C_2F_6 and C_2F_6) are used in the process. The consumption in Denmark is assessed at the moment to be a few hundred kg, and it is moreover assessed that the consumption will be in the order of 1 ton per year, when the companies, which are in the melting pot, come into production.

Microchips are produced by IONAS A/S during a process where the chips are corroded with the greenhouse gas, so that the end product does not contain these gases. MIC informs that the majority of the gases are destroyed during the processes. This applies both to SF_6 and other substances in the processes.

Sensors

Grundfos also uses small amounts of SF_6 for producing a type of sensors with the purpose of reducing the energy consumption in pumps. The environmental department of Grundfos has carried out life cycle calculations on how many CO_2 equivalents the energy saving corresponds to by use of sensors compared to the SF_6 consumption used for producing the sensors. The calculations show that the energy saving in the pumps quickly compensates the additional emissions of SF_6.

Fibreoptic cable

Lucent Technologies Denmark produces optic fibres for use in the production of fibreoptic cables.

For production of optic fibres, fluoride compounds have been used worldwide during the past 20 years. After the phase-out of CFC-12, C_2F_6 has been used and lately SF_6. The gases are broken down in the process at temperatures of 2000 degrees Celsius, and fluoride is bound in the glass and becomes to optic fibres.

The reaction products are subsequently cleaned. Due to the extremely high heat development during the process, there is no emission from here. Thus, there is not contributed to the greenhouse effect.

The substitution of SF_6 for production of optic fibres has not yet been found, as the properties of fluoride compound have to be used in the glass. Fluoride compounds from other and more degradable chemicals are not desired for working environmental reasons. The alternative SiF_4 is e.g. toxic. It is moreover in case of errors that a gas emission during production of optic fibres will occur.

Project proposal

MIC is of the opinion that it will be relevant in co-operation with production companies in this industry to carry out a project which comprises the following activities:

- Measurement of discharge air and installation of metabolic balances
- Participation in international discussions and initiatives in the area, including participation in conferences, etc.
- Preparation of outline for changed process, which results in less emission to the atmosphere
- Possibly implementation through test systems and measurements.

The aim is to reduce the emission to close to zero.

5.6 Other applications of SF_6

The Danish Technological Institute does not at the moment have knowledge of other uses of SF_6 in the Danish industry than the above-mentioned.

Reportedly, large amounts of SF_6 (of the size of 100 tons per year) are used in Germany as blowing agent of car tyres, but this application is not known in Denmark.

Nike sports shoe

The Danish Technological Institute is also informed that SF_6 is used in soles of Nike sports shoe. According to a letter from Sarah Severn, Director for Nike Environmental Action Team to Greenpeace Danmark (dated 12 September 1997), approx. 288 tons was used in the year 1 April 1996 to 31 March 1997. The substance is used in Nike's air models, and all soles are produced in the United States.

Nike informs in September 2001 to Greenpeace Danmark that it has started to phase-out the use of SF_6 in its products, and at the end of 2002, no sports shoe or other Nike products will be produced with SF_6. From 1 July 2003, there will no longer be sent products containing SF_6 on the market. Nike expects that the consumption in 2001 will be reduced by 80% compared to the consumption in 1997.

6 Evaluations and recommendations

Many activities have been initiated in order to develop new technology for substitution of HFCs. As it has been described in this report, the Danish Environmental Protection Agency and the Danish Energy Agency subsidise a great deal of activities within this area. Many results have been obtained, and good results are expected of the initiated projects.

However, in a number of areas, development projects have not been initiated yet and some areas have special problems. This is described in chapters 3, 4 and 5 of this report.

Below is a list of the specific development projects in areas having special problems and the refrigeration industry's plan of action.

The outlined projects are formulated so that the industry is able to satisfy the Ministry of Environment and Energy's draft statutory order on phase-out of potent greenhouse gases (from February 2001). In other words, the completion of the outlined projects has to ensure that a rapid phase-out of the use of HFCs, PFCs and SF_6 occurs.

The outlined projects are all related to the Danish industry and are formulated in core areas where the Danish industry is in a strong position internationally, and/or where there are large economic or business interests.

In this connection, it can be mentioned once more that the Danish refrigeration industry is very large with many employees even by international standards. It is therefore obvious that a number of projects have been outlined for the development of new environmentally friendly products within this industry. It is also obvious that a plan of action is outlined for the implementation of natural refrigerants in connection with installation and service within the refrigeration industry.

As mentioned earlier in this report, a number of activities take place abroad to develop products without HFC, PFC or SF_6. Many of these activities take place in areas where we do not have any particular industry in Denmark (e.g. in the car industry). Obviously, development also takes place in areas where we have a large industry. It is expected that the suggested projects follow the development at an international level.

A very large part of the suggested activities are in the area of commercial refrigeration, and it is also here that the largest consumption of the potent greenhouse gases takes place. The suggested activities should ensure that energy-efficient refrigeration systems using natural refrigerants are developed and that a forced implementation of these is commenced at an early stage.

Outside the refrigeration area, a project has been outlined with the purpose of ensuring a greater collection of SF_6 in the electricity industry.

Finally, a project has been outlined with reduction of emission of potent greenhouse gases within production of microchips. There are great expectations for the growth potential of this business in Denmark in the future.

6.1 Specific projects (development of new technology and products)

In this section, a number of specific development activities are listed and amounts for the requisite subsidy in DKK are estimated. In addition to the stated amounts, it is expected that there is co-finance from an external source, e.g. producers of the stated products, so that EU's directive on state subsidy is observed.

Commercial refrigeration

For a number of applications within the commercial area, no competitive alternative technology is available on the market. The systems in question will be in the area ranging from approx. 1 kW up to 30 kW and the charges will be between 200 grams and 10 kg. The area will comprise the following types of systems:

- Large plug-in appliances (e.g. small supermarket display cabinets with built-in refrigeration system)
- A wide range of specialised machines (ice machines, soft drink machines, draught beer coolers, etc.)
- Split systems (air-conditioning, cold storages, fresh food and freezer cabinets for supermarkets and small shops)
- Small remote systems for supermarkets, etc.

New methods have to be applied in order to make the new systems competitive and efficient. A number of them are mentioned below:

- Reduction of charges
  It is suggested that a number of projects on development and application of new types of heat exchangers are carried out (microchannels and oval tube types)
- Development of competitive and efficient components, which can be used for charges above 150 grams
- Development of competitive and efficient systems within the mentioned applications (i.a. more efficient indirect systems and remote systems have to be investigated)
- Risk investigations when using hydrocarbons, so that e.g. hydrocarbons can be used directly in category B in certain cases
- HAZOP investigations, new methods for preventing an explosive atmosphere and discussions with legislative authorities (understanding and interpretation of legislation)

Total budget for these activities is approx. 10 million DKK per year in the next four years.

Bottle coolers

Development of large bottle coolers using natural refrigerants (approx. 1.5 million DKK). Small bottle coolers using hydrocarbons as refrigerant have been developed and marketed, but larger bottle coolers (having 2 or 3 doors) are not yet available on the market. It is the intention that Danish producers together with large users/branded goods companies participate in the project. Its aim is furthermore to reduce the refrigerant charge. Prototypes are produced and a small series for field test for a period.

Direct current refrigerators

Development of refrigerators with direct current compressors using natural refrigerants (approx. 1 million DKK). It is suggested that a co-operation with Danish producers of direct-current refrigerators for i.a. storage of vaccine for less developed countries, private use in areas without power supply and in lorries, etc.

Heat pumps and air-conditioning

Application of natural refrigerants in heat pumps and small air-conditioning systems. At the moment, a project is carried out on application of CO_2 in domestic water heat pumps (subsidised by the Danish Environmental Protection Agency). For the large systems (>2 kW), commercially available components for CO_2 and hydrocarbons are not yet available. For air/air heat pumps, including smaller air-conditioning systems (split units), it is not possible directly to use hydrocarbons, as leakage in the refrigerant system will result in discharge of refrigerant in the conditioned rooms with danger of fire. The charge in this type of system is typically limited to 150 grams. This is why CO_2 is an interesting alternative, and since components typically used in this type of system also are used in a number of other applications within the refrigeration industry, this is very interesting. Calculations carried out in the previous project on CO_2 as refrigerant in domestic water heat pumps demonstrate that it in most operating conditions for heat pumps is possible to obtain an efficiency which is just as good or even better when using CO_2 compared to the traditional HFC refrigerants.

It is therefore suggested that the following projects are commenced:

1. The application of CO_2 as refrigerant in split units (air-conditioning and heat pumps) (approx. 1.5 million DKK).
2. Application of hydrocarbons in small air-conditioning systems, heat pumps and dehumidifiers (project dealing with ”safe components”) (approx. 2 million DKK).
3. Application of refrigerant mixtures (of natural refrigerants) with temperature glide in the heat exchangers. In this way, an efficient thermodynamic process in air-conditioning and heat pump system is expected (approx. 1 million DKK).

The results of these projects will be directly applicable within large parts of the refrigeration industry. The mentioned subsidy amounts are estimated amounts for the requirement for external subsidy.

Containers

Project on refrigerated containers. A project has been carried out in which it has been investigated whether CO_2 can be used as refrigerant. Interesting results have been demonstrated. However, components have not been available. When these are available, another project should be commenced (approx. 5 million DKK).

Change of 150 grams limit

Assessment of whether it is possible to increase the unofficial limit of 150 grams of hydrocarbon refrigerant in refrigerators to a higher value in certain situations. This limit was originally introduced by compressor suppliers, who were afraid that in connection with leakage from household refrigeration cabinets, flammable mixtures might arise in a kitchen, etc. The limit is still used – and it also applies to completely different appliances. In the project, analyses have to be carried out which should make it possible to use larger amounts of refrigerants in situations where a potential leakage will not result in a greater risk (approx. 1.5 million DKK).

Electricity industry

Expansion of the collection system and increased recycling of SF_6 in the electricity industry (approx. 0.5 million DKK).

Microchips

Investigation of the possibilities of reducing the emission of potent greenhouse gases in connection with production of microchips (electronic and optical chips) (approx. 3 million DKK).

Information

General communication of information on the use of natural refrigerants, etc. It is about further education of consultants, writing of articles, participation in Danish and foreign conferences on alternative technology and legislation in the area, etc. (approx. 1 million DKK).

6.2 The refrigeration industry's plan of action

The four associations: Selskabet for Køleteknik (under the Society of Danish Engineers), Danish Association of Refrigeration, Authorised Refrigeration Installers Association and the Danish Heat Pump Association have together prepared the enclosed note for efforts to be carried out within 2006. Please cf. the enclosed proposal from the associations in appendix C.
The associations have sent an application to the Danish Environmental Protection Agency, which should concretise the plan of action. For use of this note, the associations have prepared a draft with a list of the planned activities and the costs of these. Due to the short time, which the associations have had for the preparation, there may be uncertainties to the amount.

It is an estimate comprising all the subjects. The total estimate for the implementation of the plan of action is 113 million DKK for four years. It is the estimated total additional costs for the industry. The outlined activities may result in subsidy of approx. 44 million DKK, i.e. approx. 11 million DKK per year in four years (when permitted subsidy percentages are considered for development, etc., cf. EU's legislation on state subsidy). The requisite subsidy amount is calculated with the following subsidy percentages: development activity: 25%, information activity: 100%, courses: 50% (some of the remaining 50% can be financed by other ministries) and 50% for mixed information and development activity.

6.3 Total evaluation of the requirement for subsidy

The table below shows the activities mentioned in sections 6.1 and 6.2.

Activity	Subsidy per year in 4 years (million DKK)	Subsidy in total (million DKK)
Development of new commercial refrigeration systems using natural refrigerants	10	40
Development of large bottle coolers		1.5
Refrigerators with direct-current compressors		1
Heat pumps and air-conditioning		4.5
Refrigerated containers		5
General information		1
Possibility for increasing 150 grams limit		1.5
Collection in electricity industry		0.5
Microchips		3
The refrigeration industry's plan of action	11	44
In total	25.5	102

The Danish Environmental Protection Agency has asked the Danish Technological Institute to assess the size of overlap between the specific development projects, which are mentioned in section 6.1 and the refrigeration industry's plan of action in section 6.2.

Generally speaking, the activities do not overlap. There has however been a small overlap between projects within commercial refrigeration in section 6.1 and areas with development activities in section 6.2.

It is assessed that this overlap is of maximum 10 million DKK, but reservations have to be made as this is expected to be more precisely determined in the preliminary project of the refrigeration industry's plan of action.

The total requirement for subsidy in the four year period 2002-2005 is approx. 100 million DKK corresponding to approx. 25 million DKK per year.

7 Literature list

The following literature have been used in the report:

- Miljøprojekt Nr. 456, 1999 (Danish Environmental Protection Agency): "Erstatning af kraftige drivhusgasser" (Substitution of potent greenhouse gases). Per Henrik Pedersen, Danish Technological Institute.
- Tema Nord 2000:552 (Nordic Council of Ministers): "Ways of reducing consumption and emission of potent greenhouse gases". Per Henrik Pedersen, Danish Technological Institute.
- Arbejdsrapport nr. 580, 2001: "Ozonlagsnedbrydende stoffer og drivhusgasserne HFC'er, PFC'er og SF_6 – 1999" (Ozone depleting substances and the greenhouse gases HFCs, PFCs and SF_6 – 1999). Thomas Sander Poulsen, COWI.
- Environmental Project No. 300: "Polyurethane Foam without Ozone Depleting Substances; Experience from Danish Industry". Danish Environmental Protection Agency, 1995.
- Environmental Project No. 301: "Going towards Natural Refrigerants; Experience from Danish Industry". Danish Environmental Protection Agency, 1995.
- Environmental Project No. 312: "Going towards Natural Fire Extinguishants; Experience from Danish Industry".
- Scandinavian Refrigeration (Scan Ref) 4/1997. Article on Swedish supermarket refrigeration system using hydrocarbons as refrigerant.
- Kathryn Ellerton, Allied Signal Inc: "Recent Developments and the Outlook for Global Sulfur Hexafluoride", International Magnesium Association Fifty Four, Toronto, June 1997.
- Letter from Sarah Severn, Director, NIKE Environmental Action Team to Tarjei Haaland, Greenpeace Denmark. Dated 12 September 1997.
- Environmental Report, Norsk Hydro, 1997.
- Letter from Hannah Johnes, Director of Corporate Responsibility, Nike Europe, Middle East and Africa to Tarjei Haaland, Greenpeace Denmark. Dated 6 September 2001.
- Brochures from Danish and foreign companies.

Appendix A: Refrigerants and refrigerant mixtures

The table below shows the most common refrigerants consisting of single substances.

Substances	R-number	Chemical formula	ODP value	GWP value (100 years)
Halon-1301	R-13B1	$CBrF_3$	10	5,600
CFC-11	R-11	$CFCl_3$	1.0	4,000
CFC-12	R-12	CF_2Cl_2	1.0	8,500
CFC-115	R-115	$CClF_2CF_3$	0.6	9,300
HCFC-22	R-22	CHF_2Cl	0.055	1,700
HCFC-124	R-124	CF_3CHClF	0.03	480
HCFC-142b	R-142b	$C_2H_3F_2Cl$	0.065	2,000
HFC-23	R-23	CHF_3	0	11,700
HFC-32	R-32	CH_2F_2	0	650
HFC-125	R-125	C_2HF_5	0	2,800
HFC-134a	R-134a	CH_2FCF_3	0	1,300
HFC-143a	R-143a	CF_3CH_3	0	3,800
HFC-152a	R-152a	C_2H4F_2	0	140
HFC-227ea	R-227ea	C_3HF_7	0	2,900
PFC-14	R-14	CF_4	0	6,500
PFC-116	R-116	C_2F_6	0	9,200
PFC-218	R-218	C_3F_8	0	7,000
Isobutane (HC-600a)	R-600a	$CH(CH_3)_3$	0	3
Propane (HC-290)	R-290	C_3H_8	0	3
Ethane (HC-170)	R-170	C_2H_6	0	3
Ethene (ethylene)	R-1150	CH_2CH_2	0	3
Propylene (HC-1270)	R-1270	C_3H_6	0	3
Ammonia	R-717	NH_3	0	0
Carbon dioxide	R-744	CO_2	0	1
Air	R-729	-	0	0
Water	R-718	H_2O	0	0

The table below shows refrigerant mixtures in the 400 series (zeotropic mixtures). The ODP and GWP values can be calculated on the basis of the values for the substances in the table for single substances, weighting on the basis of the mixture ratio between the individual substances.

R-number	Substances	GWP value (100 years)	Concentration in weight-%
R-401A	HCFC-22/HFC-152a/HCFC-124	1,082	53/13/34
R-402A	HCFC-22/HFC-125/HC-290	2,326	38/60/2
R-403A	HCFC-22/PFC-218/HC-290	2,675	75/20/5
R-403B	HCFC-22/PFC-218/HC-290	3,682	56/39/5
R-404A	HFC-143a/HFC-125/HFC-134a	3,260	52/44/4
R-406A	HCFC-22/HC-600a/HCFC-142b	1,755	55/4/41
R-407C	HFC-32/HFC-125/HFC-134a	1,526	23/25/52
R-408A	HCFC-22/HFC-143a/HFC-125	2,743	47/46/7
R-409A	HCFC-22/HCFC-142b/HCFC-124	1,440	60/15/25
R-410A	HFC-32/HFC-125	1,725	50/50
R-412A	HCFC-22/HCFC-142b/PFC-218	2,040	70/25/5
R-413A	HFC-134a/PFC-218/HC-600a	1,774	88/9/3
R-414A	HCFC-22/HCFC-124/HCFC-142b/HC-600a	1,329	51/28.8/16.5/4
R-415A	HCFC-22/HFC-23/HFC-152a	1,966	80/5/15

The table below shows refrigerant mixtures in the 500 series (azeotropic mixtures).

R-number	Substances	GWP value (100 years)	Concentration in weight-%
R-502	CFC-115/HCFC-22	5,576	51/49
R-507	HFC-143a/HFC-125	3,300	50/50
R-508A	HFC-23/PFC-116	10,175	39/61
R-508B	HFC-23/PFC-116	10,350	46/54
R-509A	HCFC-22/PFC-218	4,668	44/56

Appendix B: Commercial refrigeration systems

This appendix is written in co-operation with Kim Gardø Christensen, MSc in Engineering, of the Danish Technological Institute.

Commercial refrigeration systems are systems used for refrigeration in supermarkets, specialty shops, hotels and restaurants, i.e. in the area of trade and service, agriculture and market garden.

According to the statement of the Danish Environmental Protection Agency /1/, 319 tons of HFC refrigerant was used in 1999 in "Commercial stationary refrigeration and air-conditioning systems".

	Consumption in 1999, tons
HFC-134a	*110.6*
R-404A	*135.5*
R-401A	*15*
R-407C	*40*
R-402A	*8*
R-507A	*10*
I alt	*319.1*

Consumption of HFC refrigerant in "Commercial stationary refrigeration and air-conditioning systems" in 1999. The figures are taken from the annual statement of the Danish Environmental Protection Agency carried out by COWI Consult.

The commercial area of refrigeration is the most diverse area within the refrigeration industry. A large number of companies sell and install refrigeration systems. The refrigeration systems are often constructed of purchased standard component. In some commercial refrigeration systems (i.e. supermarkets), long pipelines have been used and the leakage rate has previously been very high (of the order of 20-25% of the refrigerant charge per year). In recent years, the association AKB (Authorised Refrigeration Installers Association), Selskabet for Køleteknik and the Danish Association of Refrigeration have done much to reduce leakages and in this way reduce the emission. This implies that the emission of new supermarket refrigeration systems is reduced to approx. 10% per year.

The commercial refrigeration systems constitute a very high economic value, as there are many of them. At the same time, there is a vast number of different refrigeration systems and an analysis of the different types and status for alternative systems not using HFC refrigerants is therefore carried out in this part.

The section is divided into two subsections in which the first deals with types of systems as these are divided into four categories: Plug-in units, split units, chillers and machinery, while the second deals with applications divided into supermarkets, specialty shops, kiosks, hotels, restaurants and agriculture. Finally, a total evaluation of the commercial area of refrigeration is made.

B.1 Types of systems

Plug-in

Plug-in refrigeration systems are primarily used in the area of trade and service. It is small units such as bottle coolers and ice cream freezers, and larger units such as small refrigeration cabinets and various single-purpose machines.

The plug-in appliances can be divided into large and small systems. The small plug-in units can use hydrocarbons, while the large are problematic because the charges with hydrocarbons will exceed 200-300 grams. The large plug-in refrigeration systems (above approx. 2 kW in cooling capacity) are used in many different places in various respects. Many supermarkets still use many large plug-in appliances/cabinets in the form of refrigeration cabinets and display cabinets with own compressor and condenser. These cabinets are also used to a great extent in the rest of the retail trade, in kiosks and in service stations as well as in the hotel and restaurant industry. The large plug-in cabinets are often cheap, prefabricated units, which are easy to install and cheap to service. Moreover, these cabinets have the advantage compared with remote refrigeration cabinets that they can easily be moved to other locations in the shop. This flexibility is prioritised highly in some shops. In addition to the types of systems mentioned, there are a number of single-purpose machines, i.e. multicoolers for soft drinks and beer in bars and restaurants, ice machines e.g. in fish monger's shops and other types, in which capacities and charges are so large that it cannot be justified immediately to use hydrocarbons as refrigerant. It is assessed that it will be necessary to use indirect refrigeration in many of the applications where plug-in equipment has been used previously.

Split units

The split units cover a wide range of applications. The units consist of two units. The first unit: the evaporator is placed in the cold storage or in the room where the air-conditioning is desired. The second unit: the compressor and condenser part (in total called the condensation unit) is often placed outdoors or in basements. This part emits heat to the surroundings. The split units are often prefabricated (primarily for air-conditioning) where the refrigerant has already been charged at delivery. When the two units are connected, a capsule is broken and the refrigerant can flow from the condensation part to the evaporation part. This type of unit is supplied by e.g. Panasonic, Toshiba, Carrier and Daikin (primarily for air-conditioning). The split units can also be made by installing a condensation unit from e.g. Danfoss, to which an evaporation surface can be connected, if desired.

The split units are used widely within the retail trade and the hotel and restaurant industry. They are used for cold storages, air-conditioning and remote refrigeration cabinets. The use of the split units is advantageous compared with the plug-in systems as the condenser heat is not emitted to the room itself and noise problems are avoided.

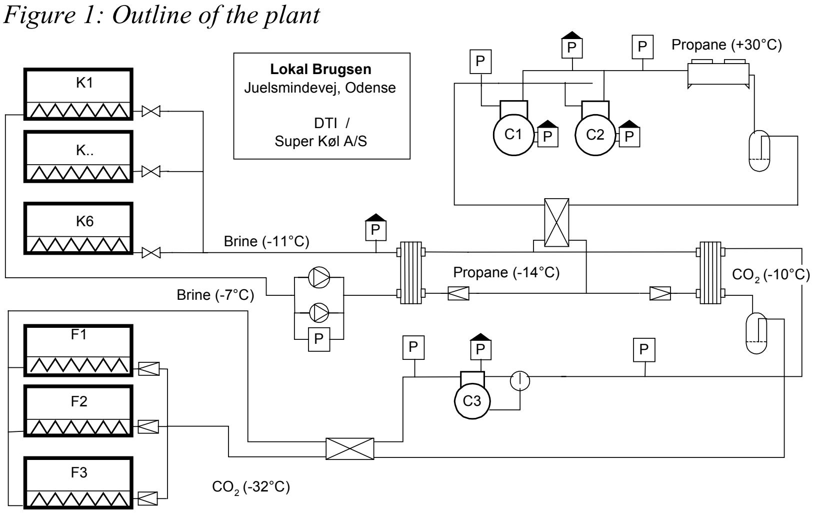
The split units have one problem with regard to conversion to other refrigerants. The use of hydrocarbons for air-conditioning or in connection with appliances/cabinets placed in public places will hardly be allowed unless the charge is limited. CO_2 is an option, but the system will probably be considerably more expensive in the small units i.a. due to the high pressures and thus the increased requirements for components. Furthermore, it will be difficult with CO_2 to compete with regard to energy with optimised, conventional HFC units. However, hydrocarbons could often be used e.g. by using indirect refrigeration, but it has to be kept in mind that the equipment is small especially in connection with refrigeration in specialty shops, kiosks, service stations and restaurants. In this field, it is hard to find competitive alternatives. As to price, small indirect units will be considerable more expensive than the conventional split units and the energy consumption will undoubtedly also be higher.

Chillers
Chillers (or liquid coolers) are compact refrigeration systems, which cool a liquid, e.g. water for process refrigeration or air-conditioning in large buildings, etc. In this area, there are no problems as the equipment by definition is indirect and hydrocarbons therefore can be used with certain modifications of the equipment. The chiller systems are often large prefabricated systems with capacities above 20 kW. Moreover, some equipment using hydrocarbons as refrigerant is already available on the market today. Prefabricated chillers for capacities below 20 kW cooling capacity are not yet available with natural refrigerants.

Compressor systems (Machinery)
Compressor systems are used widely in medium-sized and large supermarkets. Moreover, compressor systems are used in large cold storages and in refrigeration systems within the agriculture. What characterises the systems is that a number of remote cabinets/evaporators are parallel coupled on the evaporator side, while the condenser also is remote coupled. The compressor system, which typically has cooling capacities above 15-20 kW, is placed in a machine room, while the condenser is placed outdoors e.g. on the roof of the building.

In Denmark and especially in Sweden, several compressor systems have been built in connection with supermarkets using hydrocarbons as primary refrigerant. In the shop, CO_2 is used as refrigerant on the freezing side, while conventional brines are used as secondary refrigerant on the cooling side.

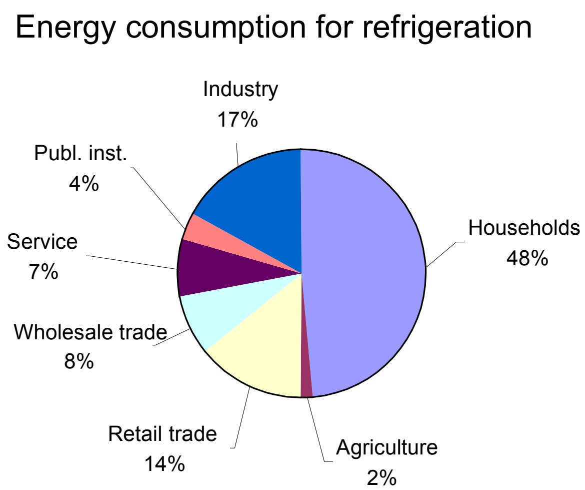
Figure 1: Outline of the plant



The figure shows a schematic outline of the semi-indirect refrigeration system with propane and CO_2 in the demonstration system in LokalBrugsen in Odense. /2/.

B.2. Applications

Approx. 15% of the total Danish energy consumption is used for refrigeration and freezing equipment. DEFU has calculated the energy consumption for refrigeration trades and households in 1993 /3/.



	GWh/year
Household	1900
Agriculture/ market gardening	66
Retail trade	555
Wholesale trade	311
Service	290
Public institutions	142
Industry	676
Total	3940

Energy consumption for refrigeration in Denmark /3/.

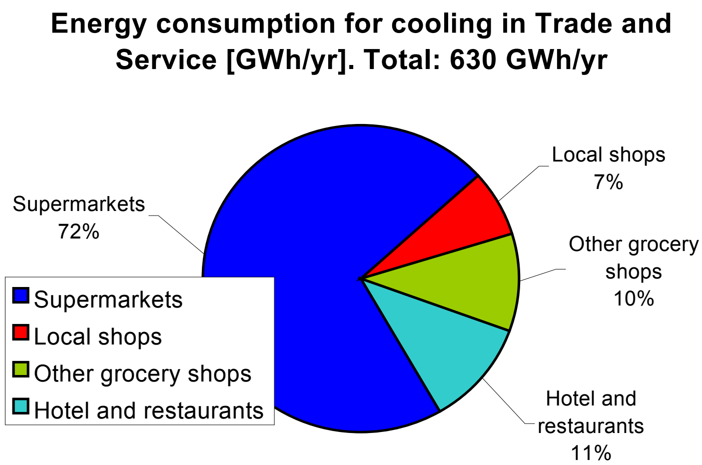
As it appears, the energy consumption is primarily dominated by the private households which make up 48% (1900 GWh/year). For the rest of the trades, the individual consumption stems from few dominating consumption groups /4/:

Retail trade: 14% (555 GWh/year): Refrigeration of food in

		supermarkets and shops
Industry:	17% (676 GWh/year):	Food processing and chemical industry
Wholesale trade:	8% (311 GWh/year):	Mainly refrigeration and freezing storages
Service:	7% (290 GWh/year):	Restaurants, hotels and air-conditioning and computer cooling in banking, insurance and retail services
Agriculture:	2% (66 GWh/year):	Milk cooling system, cooling of root crop, fruits and vegetables

Commercial refrigeration consists of the area of trade and service, agriculture and market gardening.

Energy consumption and refrigerant charge in trade and service
The total annual energy consumption for refrigeration and air-conditioning within trade and service is estimated to be approx. 870 GWh per year, of which approx. 240 GWh is used for air-conditioning per year. Of the 630 GWh per year used for refrigeration purposes, 450 GWh per year is used for supermarket refrigeration.



The figure shows the energy consumption for four different categories within the area of trade and services.

In the following the area of trade and service is divided into four categories:
Supermarkets and grocer's shops: This area covers the area traditionally understood as daily retail shops from small to large systems.
Local shops: This area covers service stations and kiosks
Other grocer's shops: This area covers all specialty shops like retail butcher, cheesemonger's shops, etc.
Hotel and restaurant: This area covers hotels, motels, inns, restaurants, coffee shops, canteens and catering.

Supermarkets and grocer's shops
Supermarkets are the largest consumers of refrigeration equipment within trade and service. In Denmark there are approx. 2,200 supermarkets, where food is displayed in both refrigeration and freezing display cabinets. The major part of refrigeration and freezing equipment in supermarkets has been connected to remote systems (machinery), however plug-in units are very common. In addition, there are approx. 2000 small grocer's shops. The refrigeration systems are primarily designed as compressor systems/remote systems or in the small shops as a split system.

Supermarkets range from very small to very big shops. The figure below shows the division of load on refrigeration and freezing respectively for different supermarkets.

	Refrigeration performance REFR	Refrigeration performance FREEZING	No of cooling spaces	Charge (R404A)
Grocer's shops	Approx. 5 kW	Approx. 3 kW	2-3	10-20 kg
LokalBrugsen/ Dagli'Brugsen	Approx. 10 kW	Approx. 5 kW	5	20-50 kg
Netto/Fakta	15-30 kW	10-20 kW	10	50-150 kg
Føtex/SuperBrugsen	40-80 kW	30-50 kW	15	200-500 kg
Bilka/ISO/OBS	100-300 kW	60-150 kW	25	500-1500 kg

Cooling capacities and refrigerant charges for different sizes of supermarkets.

The total charge for groceries is approx. 350-400 tons.

The systems are typically large. It is demonstrated both in Denmark and in other European countries how systems with natural refrigerants can be used.

Alternative technology:

Compressor system: The systems can be used either indirect or semi-indirect with hydrocarbons and CO_2

Price: +10% for the large systems /+15% for the small systems.
Energy consumption: ±5%

Split-system: The systems will typically be indirect using hydrocarbons and traditional brine (development is required).
Price: +20%
Energy consumption: +10%

Kiosks and service stations
It is estimated that approx. 1700 service stations and 900 kiosk are available in Denmark /5/. Plug-in equipment and split equipment are mainly used in these shops. The entire refrigeration energy consumption is approx. 45 GWh per year. The number of systems changes with the size of the shop. It is estimated that 4-8 systems have been installed in the shop, where the main part is smaller plug-in systems, which can be delivered with hydrocarbons as refrigerant. The refrigerant charge is approx. 10 tons.

Alternative technology:

Compressor systems: The systems can be either indirect or semi-indirect using hydrocarbons and CO_2 (development is required).
Price: +20% for these systems (relatively small, which explains the high additional costs).
Energy consumption: ±5%

Split system: The systems will typically be indirect systems with hydrocarbons and a traditional brine (development is required).
Price: +20%
Energy consumption: +10%

Plug-in systems: The small plug-in systems are already available on the market, but there is no immediate alternative to large systems (development is required). It will probably be necessary to replace the large plug-in systems with indirect refrigeration.

Price: ±5% for the small plug-in systems/+30% for the large systems (indirect refrigeration).
Energy consumption: -5% for the small plug-in systems/+15% for the large ones (indirect refrigeration)

Other food shops/specialty shops
This area covers all specialty shops like butchers, fish- and cheesemonger's shops, bakeries and others. The shops are very differently equipped because special equipment adapted to the purpose of the shop has been installed.
As an example, a production bakery has the following equipment:

- 1 large dopple freezing cabinet for sweets
- 1-2 cooling areas for production
- 1 cold-water system (12°C) for cookies and bread
- 1 refrigeration cabinet in the shop (3-5 m)
- 1-2 coolers for cookies and bread
- 1 cold-air system for window display

	No. of shops /5/	Estimated number of installations per shop
Butcher's shops and sandwish shops	878	5
Fish and venison	313	4
Chocolate and candy	572	1
Fruits and vegetables	716	2
Cheesemonger's shops	157	3
Bakeries	141	6
Total	2,636	

Number of other food shops and estimated number of refrigeration installations

The energy consumption for this area is approx. 65 GWh/year and the total refrigerant charge is estimated to approx. 20 tons.

The systems are primarily plug-in or split systems. Some of the equipment is purpose-made, i.e. flake ice machinery at fishmonger's shops.

Alternative technology:

Compressor system/parallel system: The systems can be either indirect or semi-indirect using hydrocarbons and CO_2 (development is required).
Price: +20% for these rather small systems
Energy consumption: ±5%

Split system: The systems will typically be indirect using hydrocarbons and a conventional brine (development is required).
Price: +20%
Energy consumption: +10%

Plug-in: The small plug-in systems are already available on the market, but no alternatives are available yet as far as large systems are concerned (development is required). It will probably be necessary to replace the large plug-in systems by indirect refrigeration. Some of the special equipment will be very difficult to convert.
Price: ±5% for the small plug-in/+30% for the large system (indirect).
Energy consumption: -5% for the small plug-in/+15% for the large systems (indirect)

Hotels and restaurants
Except from the small units, i.e. coffee shops, cafeterias and grill bars, some restaurants are equipped with cold storage for animal products, cooling storage for vegetables and a smaller freezing area. In addition, there is a varying number of refrigeration and freezing cabinets in the kitchen area, including cooling cabinets, ice cube machinery, draught beer coolers and bottle coolers.

Typically, these systems are separate plug-in or split units (4-6), and a central refrigeration system is rarely used.

	No. of shops /4/	Estimated no. of refrigeration installations per shop
Hotels, motels and inns (with restaurant)	984	6
Restaurants and large coffee shops	4,531	4
Cafeterias and grill bars	2,989	2
Canteens	1,023	6
Catering	607	4
Total	10,134	

Number of hotels, restaurants, canteens etc.

The energy consumption for this part is approx. 70 GWh, whereas the refrigerant charge is estimated to 40 tons.

Alternative technology:

Compressor system/parallel systems: The systems can be indirect or semi-indirect using hydrocarbons and CO_2 (development is required).
Price: +20% for these rather small systems.
Energy consumption: ±5%

Split units: The systems will typically be indirect using hydrocarbons and a conventional brine (development is required).
Price: +20%
Energy consumption: +10%

Plug-in systems: The small plug-in systems are already on the market, but no alternative is immediately available for larger systems (development is required). It will probably be necessary to replace the large plug-in systems with indirect refrigeration. Conversion of some of the purpose-made equipment will be difficult.

Price: ±5% for small plug-in systems/+30% for the large systems (indirect refrigeration)
Energy consumption: -5% for the small plug-in systems/+15% for the large systems (indirect refrigeration).

Agriculture
The primary energy consumption for refrigeration in the agriculture is based on refrigeration of milk tanks used for milking and cold storages for crops (root crop, fruit and vegetables). The total refrigeration energy consumption is approx. 66 GWh per year.

Typically, a split system including a condensing unit placed on the roof or behind the building is used.

	No. of manufacturers /4/	Energy consumption /charge [GWh/yr.]/ [tons]
Milk producers	13,209	50/10 /6/
Farming + fruit plantation	4,531	16/25

Refrigeration installations in agriculture

Alternative technology:

Split systems (indirect): The systems are typically indirect systems using hydrocarbons and a conventional brine (development is required).
Price: +20%
Energy consumption: +10%

Split systems (direct): Hydrocarbons might in the future be accepted in small amounts may be accepted under category B according to EN-378, if sufficient safety consideration has been taken. Category B is an area where no public access is allowed, only the permanent staff /7/. The systems will thus be cheaper and more energy-efficient than an indirect system. Because handling of ammonia is known by agriculture already, use of hydrocarbons may not represent any obstacle. (Development is required).
Price: +10%
Energy consumption: +0%

B.3 Estimation

As far as the small systems are concerned (the large plug-in refrigeration systems including split and condensing units), the main problems are concentrated on replacement of HFCs. In connection with small air-conditioning systems in buildings with public access, the use of hydrocarbons and ammonia is hardly possible. Use of CO_2 is possible, but due to high pressures and a bad thermodynamic circuit process (in the relevant temperature area), further development work for introduction of this refrigerant is required. Furthermore, it is a major question whether direct use of hydrocarbons will be common in connection with refrigeration/freezing areas. The staff will belong to Category B, however it is not quite clear what kind of further measurements are required. This matter should be handled in such a way that a number of rules for this application is made possible. Alternatively, direct or semi-direct systems can be used, which are reasonably competitive primarily on the larger systems with refrigeration performances above 20 kW.

Energy consumption, refrigerant leakage and greenhouse effect
A refrigeration system using HFC refrigerants contributes to the green house effect in two ways: the indirect contribution from the production of the electricity, which is used for operating the system. In Denmark, this amounts to approx. 0.78 kg CO_2 per kWh. In addition, the direct contribution from the emission of refrigerant could be mentioned.
The sum of the two contributions makes the total. In Denmark and abroad, calculations of the entire contribution from many different refrigeration systems have been made.

If systems using natural refrigerants which use less energy than similar HFC systems can be used, the matter is clear: Systems with natural refrigerants are the most environmentally friendly solution when it comes to the greenhouse effect.

Those places, where direct refrigeration with natural refrigerants or semi-direct refrigeration can be used, the energy consumption will in general not be higher than of similar HFC systems. These systems will therefore be advantageous seen from an environmental point of view.

Indirect refrigeration with a brine (e.g. a water/glycol mixture) will generate a loss because of the necessary heat exchange between the primary and the secondary refrigerant. In that way, the energy consumption will be a little higher because of the demand for lower evaporating temperatures. This results in slightly higher energy consumption for the compressor. In addition, pumping efforts for the secondary refrigeration system should be mentioned. On the other hand, there will be less pressure losses in the suction valve at the direct system. In total, direct refrigeration will cause a slightly higher energy consumption in the size of 10%.

Concerning large integrated systems (like those in supermarkets), the entire contribution (CO_2 from electricity production and emission of refrigerant) to the greenhouse effect will be less for these systems (cf. calculation in enclosure 2) and other similar calculations (cf. enclosure 1). The reason for this is the large leakage and the large charge in e.g. supermarket systems.

When speaking about small and more compact systems (below 20 kW cooling capacity and approx. 10 kg. charge), the situation is different, as the energy consumption of indirect refrigeration still is somewhat higher (approx. 10%). However, the leakage rate of these systems is smaller than that of larger and more complicated systems. Consequently, it is not clear whether the use of natural refrigerants used with indirect refrigeration will be more environmentally friendly as these small commercial refrigeration systems are concerned.

A comparison between direct refrigeration systems using R404A and indirect refrigeration with propane/brine can be seen from enclosures 2 and 3. The comparison is based on a small compact refrigeration system (10 kW for refrigeration and 5 kg of charge).

According to Enclosure 2, a leakage rate of 10 % is preconditioned; however, the propane system presents the smallest contribution to the greenhouse effect.

According to enclosure 3, the leakage rate has changed to 5% per year, and the result is in favour of the HFC system.

It appears that the use of small compact refrigeration systems enables a minimisation of the leakage rates by 5 % p.a. In Denmark, the total emission from small compact HFC systems with a cooling capacity below 20 kW and a charge below 10 kg with direct refrigeration is estimated to be below the emission from a similar refrigeration system with indirect refrigeration.

Type of application[3]		Plug-in system		Split system	Chillers	Machinery
		Small	Large	-	-	-
	Supermarkets	V[1]	X	X	V	V
	Spec. shops	V	X	X (V)	V (X)	X (V)
	Kiosks / service stat.	V	X	X (V)	V (X)	
	Hotels	V	X	X	V	X
	Restaurants	V	X	X (V)	V (X)	-
	Agriculture	-	-	X	V (X)	X

Primary system types and primary applications

[1] *The table shows primary system types used in different types of application*
V: is solved; X: alternatives not found; -: no application
[2] *The applications for the different types of system are air-conditioning, refrigeration and freezing. air-conditioning is used in hotels and restaurants, increasingly in supermarkets and other detail trade.*
[3] *Various types of application for refrigeration systems*

References to Appendix B:

/1/ Ozone depleting substances and the green houses gasses HFC'er, PFCs and SF_6. Consumption and emission in Denmark 1999, COWI Consult 2001 (for the Danish Environmental Protection Agency).

/2/ Demonstration of natural refrigerants in supermarkets. Kim G. Christensen, Jesper Nyvad, Danish Technological Institute, Danish Energy Agency 2000 (J. Nr. 731327/99-0199)

/3/ DEFU 1993

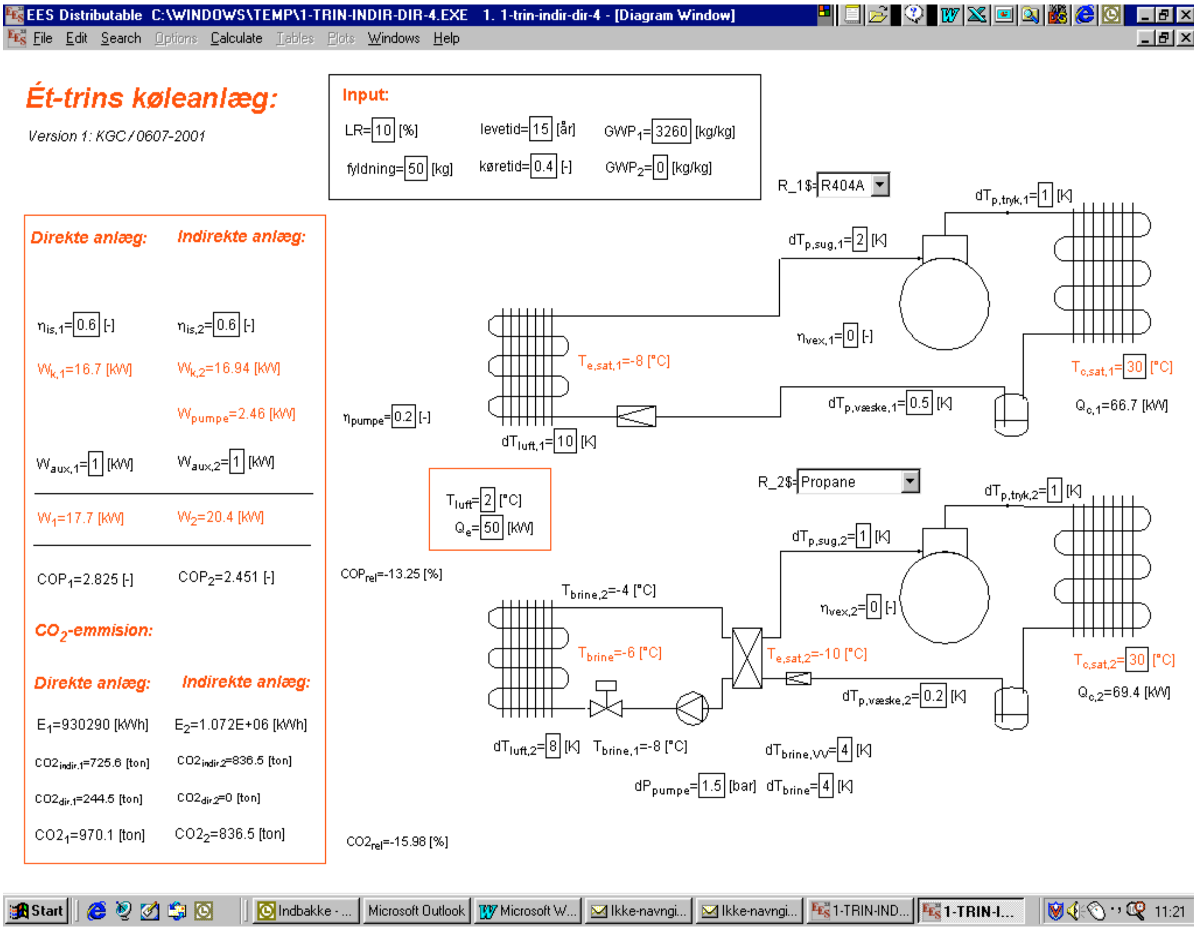
/4/ DEFU 1994

/5/ Børsen on-line database (www.borsen.dk)

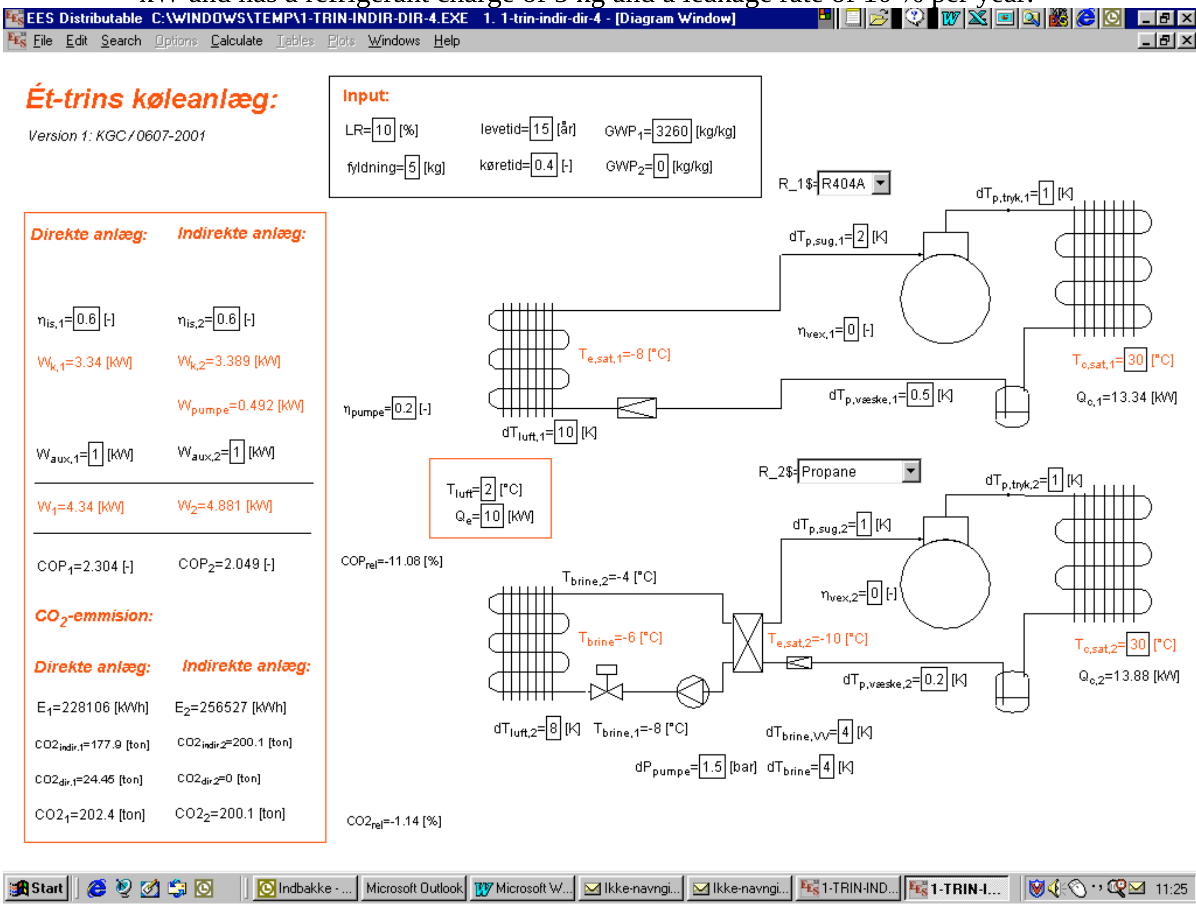
/6/ Implementation of ammonia in small refrigeration systems, Svenn Hansen, Søren Lund, Danish Technological Institute, December 1999.

/7/ DS/EN-378-1: Basic requirements, definitions, classification and selection criteria.

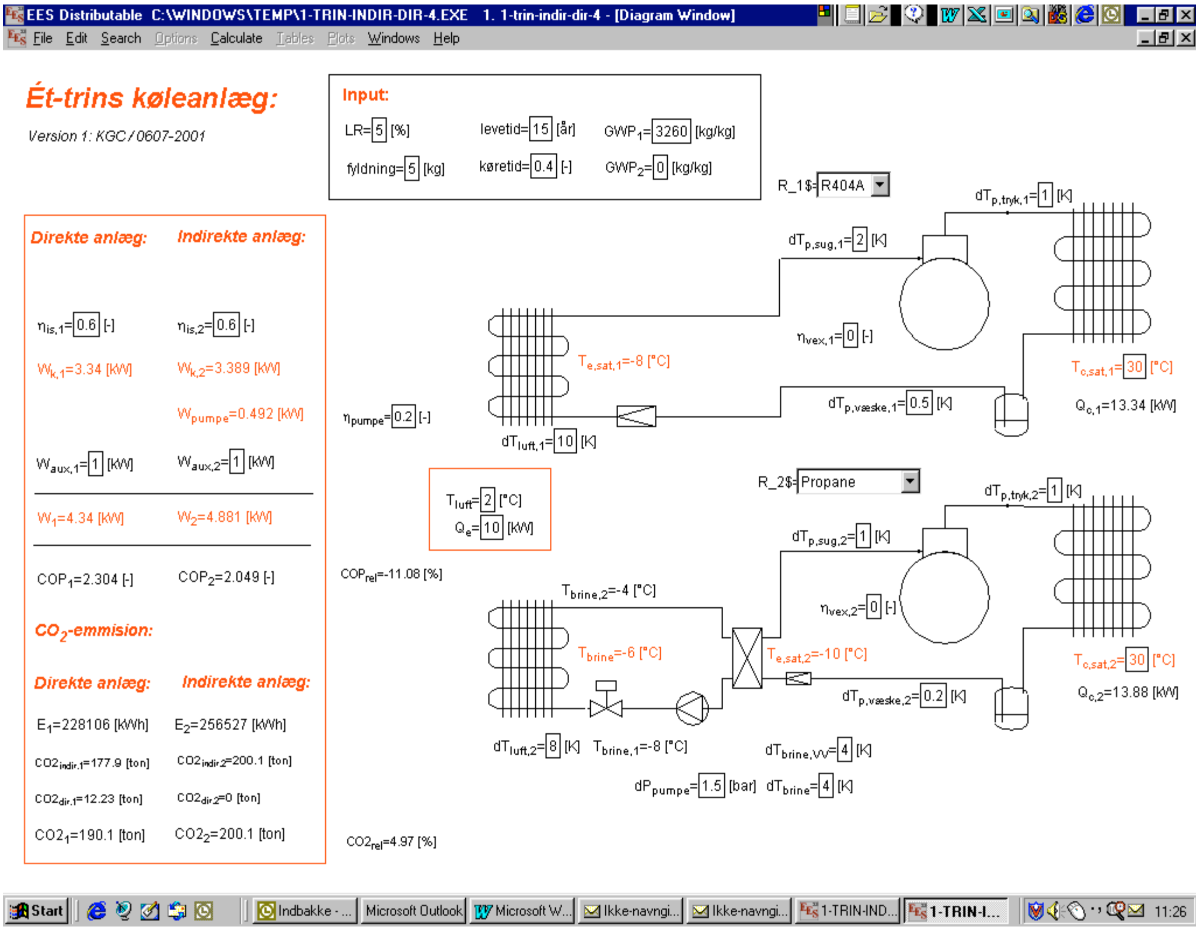
Enclosure 1: Comparison of indirect and direct refrigeration used in medium-sized refrigeration systems (50 kW). The simulation model shows a large integrated refrigeration system with relatively high charg and leakage rate (50 kg of R404A and 10% per year).



Enclosure 2: Comparison between a direct system using R404A and an indirect system using propane. The refrigeration capacity of the system is 10 kW and has a refrigerant charge of 5 kg and a leakage rate of 10 % per year.



Enclosure 3: Comparison between a direct system using R404A and an indirect system using propane. The system is small and compact with a capacity of 10 kW, a refrigerant charge of 5 kg and a leakage rate of 5%.



Appendix C: The Danish refrigeration industry's plan of action

Below is the note of the four refrigeration associations on additional costs in connection with the implementation of the Danish Environmental Agency's plan of action on phase-out of potent greenhouse gases.

The purpose of the preparation of this note is to try to get an idea of the magnitude of the costs of a fully completed plan of action for the refrigeration industry.

The necessity of a co-operation between the authorities and all "refrigeration players" and the need for overall co-ordination and knowledge dissemination to the entire industry are – in the view of the associations – crucial to whether the industry succeeds in completing the approaching conversion process for application of refrigerants with ozone layer depleting substances or potent greenhouse gases (natural refrigerants) within the time frames suggested by the authorities. It is about handling the task jointly.

The present layout takes its starting point in headword and headings prepared as an introductory presentation for the refrigeration associations meeting with the Danish Environmental Protection Agency on 28 June 2001 concerning a plan of action for the refrigeration industry. Priority and selection have not been made, additions have not been made and subjects have not been removed.

So far it has been agreed that an application is prepared and sent to the Danish Environmental Protection Agency as a preliminary project which in details should make the outlined plan of action more specific and verify the associated costs.

Remarks and comments
The enclosed estimate is carried out in a very short time and should therefore be taken with some reservations.

Estimate
The economic estimates in the table are provisional:

	Total	Activity
	[tDKK]	[type]
Which refrigerants for which applications	600	Information
Basic analysis of who makes what in the Danish industry		
Preparation of common course with regard to the systems which have to be used for which refrigerants		
Authorisation/certification/competence	4,800	Courses, etc.
Updating of present authorisation scheme (certification scheme?)		
Securing of competence of companies and individuals		
Upgrading of all authorised companies for certificate 2 in time		
Education/basic and further education/courses	2,000	Courses, etc.
Development of basic and further education as well as courses		

covering all requirements		
Knowledge dissemination/internet/info centre/hotline/ consultancy/…	7,200	Information
Web based information service in the refrigeration industry		
Knowledge dissemination from institutes and educational establishments for implementing companies		
Components/development/import/wholesalers/…	25,000	Development
Development and/or import of components for future systems		
System experience/field test/system construction/ System design/dimensioning	46,000	Development
Knowledge dissemination from prototype and laboratory work		
Building up of operational experience with new system types		
Assistance for companies to gain experience with new types of system quickly		
Organisation/co-ordination/KKO/KMO/works committees/…	1,900	Information
Organisation of the preparation of a industry plan of action		
Codes of practice/guidelines/…	3,900	Information
Examination and adjustment of codes of practice		
Make the authority requirements operative		
Translation of standards from ”foreign languages” – including DS/EN 378		
New requirements for tightness and use of applicable components and assembly methods		
Consider whether small systems with small charges should be allowed to use HFC for some time to come		
Knowledge dissemination for project planners, consultants and implementers	3,100	Information
Knowledge dissemination for project planners, consultants, etc.?		
Køleteknisk Informationscenter, including web based knowledge base		
Economy	15,000	Development/ implementation
Compensation to customers for the additional expense of new systems – possibly in a transitional period		
Energy consumption/environmental impact/life economy	4,000	Inf./udv.
Ensure that all new installations are not of an inferior level than the existing		
Integration of relevant requirements in Kølebranchens Kvalitetssikringsordning (the Danish refrigeration industry's quality assurance scheme)		
In total	113,500	

NB! The estimates comprise all expected costs! It is not assessed to which extent the Danish Environmental Protection Agency and other authorities can and will subsidise the individual activities.

Termliste

Afkastluft:	discharge air
Afvikling:	phase-out
AKB:	Authorised Refrigeration Installers Association
Aluminiumsoxid:	aluminium oxide
Arbejdstilsynet:	Danish Working Environment Service
Behov:	requirement
Bekendtgørelse:	statutory order
Beredskabsstyrelsen:	Emergency Management Agency
Blokskum:	rigid block foam (rigid slap stock)
Blæsemiddel:	blowing agent
Brandbeskyttelse:	fire protection
Brandsikker:	fireproof
Blandslukning:	fire extinguishing
Brandslukningsmiddel:	fire extinguishant
Brandslukningsudstyr:	fire extinguishing equipment
Brom:	bromine
Brændbar:	flammable
Chlor:	chlorine
Chlorfluorcarboner:	chlorofluorocarbons
Chlorgas:	chlorine gas
Cyclopentan:	cyclopentane
Danske Køledage:	Danish Refrigeration Days
Dansk Industri:	Confederation of Danish Industries
Dansk Køleforening:	Danish Association of Refrigeration
DEFU:	Research Institute for Danish Electric Utilities
Den jydske Haandværkerskole:	the technical College of Jutland
Direkte køling:	direct refrigeration
Drivhusgas:	greenhouse gas
Drivmiddel:	propellant
Elektricitetsrådet:	Electricity Council
Elektrisk spænding:	electric voltage
Elsparefonden:	Danish Electricity Saving Trust
Energiklasse:	energy class
Energistyrelsen:	Danish Energy Agency
Erstatning:	substitution
Fluoratomer:	fluoride atoms
Fluorcarboner:	fluorocarbons
FN's klimakonferrence:	the UN Framwork Convention on Climate Change

Forbrugsområde:	area of application
Forbud:	ban
Fordelingsanlæg:	distribution system
Frysegondoler:	freezer display cabinets
Fuldt halogenerende:	fully halogenated
Gartneri:	market gardening
Hydrochlorfluorcarboner:	hydrochlorofluorocarbons
Hydrofluorcarboner:	hydrofluorocarbons
Implementeringsgrad:	implementing rate
Indirekte køling:	indirect refrigeration
Inerte gasser:	inert gases
Isoleringsevne:	insulating power
Isoleringsskum:	insulating foam
Kiosk:	kiosk
Klimagas:	gas with significant GWP
Kortlægning:	analysis
Købmandsbutik:	grocer's shop
Kølegondoler:	fresh food display cabinets
Kølemiddelfyldning:	refrigerant charge
Kølemøbler:	refrigeration cabinets
Køleydelse:	cooling performance
Landbrug:	agriculture
Lattergas:	nitrous oxide
Lydisolerende:	sound insulating
Lækage:	leakage
Mikroelektronik Centret:	Micro- and Nanotechnology Reserch Center
Miljø- og Energiministeriet:	Ministry of Environment and Energy
Miljøafgift:	environmental tax
Miljøstyrelsen:	Danish Environmental Protection Agency
Nedbrydning af ozonlag:	ozone depletion
Netstation:	distribution substation
Opblæsning:	as blowing agent of
Opskumningsmiddel:	foaming agent
Opskumningsproces:	foaming process
Optiske mikrochips:	optical microchips
Ozonlagsnedbrydende stoffer:	ozone depleting substances
Perflourede kulbrinter:	perfluorocarbons
Personkategori:	category
Polyurethanskum:	polyurethane foam

Projektudførende:	project implementer
Rensning:	cleansing
Skrotte:	scrap
Skumplast:	plastic foam
Slukkemedie:	arc-breaker
Specialbutik:	specialty shop
Sporgas:	tracer gas
Spraydåse:	aerosol can
Stofbalance:	metabolic balance
Storkøkkenapparater:	commercial kitchen appliances
Svovlhexafluorid:	sulphur hexafluoride
Trykbølge:	pressure wave
Tågehorn:	foghorn
Udfase:	phase out
Udfasning:	phase-out / phasing out
Vakuumafbryder:	vacuum switch
Varmeafgiver:	heat drain
Varmepumpefabrikantforeningen:	the Danish Heat Pump Association
Ventilator:	fan
Væskekøler:	liquid cooler