norden

Potent Greenhouse Gases

Ways of Reducing Consumption and Emission of HFCs, PFCs and SF6

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Nordic cooperation

Nordic cooperation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and three autonomous areas: the Faroe Islands, Greenland, and Åland.

Nordic cooperation has firm traditions in politics, the economy, and culture. It plays an important rol in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

Nordic cooperation seeks to safeguard Nordic and regional interests and principles in the global community. Common Nordic values help the region solidify its position as one of the world's most innovative and competitive.

Content

Preface

The Climate Change Policy Working Group of the Nordic Council of Ministers is a co-operation between energy and environmental division under the Nordic Council of Ministers. The most important task of the Nordic group for Climate Change Issues is to look into international climate change policy issues linked to the UN Framework Convention on Climate.

The Climate Change Policy Working Group has commissioned Danish Technological Institute to prepare this report *Ways of Reducing Consumption and Emission of Potent Greenhouse Gases (HFCs, PFCs and SF6)*. The report described the application and emission of the potent greenhouse gases in the five Nordic countries and at the same time how to reduce emissione and the use of alternative substances. It is an updated of the TemaNord 2001:594 report with the same title.

The Climate Change Policy Working Group does not necessarily share the views and conclusions of the report.

Oslo, June 2007

Jon D. Engebretsen
Chairman

Summary

The potent greenhouse gases (also called the “F-gases”, “fluorinated greenhouse gases” or the three “industrial gases”) are on the list of greenhouse gases, covered by the Kyoto Protocol.

In 1998, the report “Ways of Reducing Consumption and Emission of the Potent Greenhouse Gases (HFCs, PFCs and SF_6)” (Pedersen, 2000) was prepared. It was updated in 2001 and printed by the Nordic Council of Ministers (Pedersen, 2001). The report described the application and emission of the potent greenhouse gases in the five Nordic countries and at the same time described how to reduce emissions and the use of alternative substances. “Success stories” from the Nordic countries were included, in which alternative technology was introduced instead of technology based on the potent greenhouse gases.

The purpose of the new project is to update the report from 2001, to strengthen the Nordic co-operation in this area and to describe the possibilities of using alternative technology objectively. One advantage is that producers of these chemicals are not situated in the Nordic countries.

In addition, the purpose is to describe the national initiatives taking place in the Nordic countries to reduce the emission of potent greenhouse gases.

Finally, the purpose is to compile the latest results regarding the development of alternative technology. A rapid development is taking place in this area. Since 2001, new technology has among other things developed within insulation foam (polyurethane and XPS) and in the production of aluminium and magnesium and there is increasing focus on the use of hydrocarbons, ammonia and CO_2 as refrigerants.

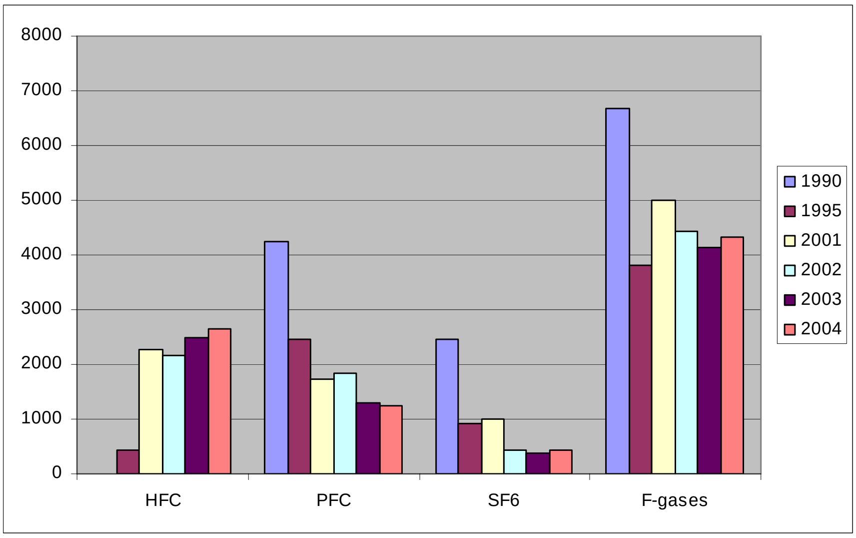
Table S1. Emission of greenhouse gases in the Nordic countries in 2004

	1000 Tonnes CO_2-eq.	
CO_2	224,576	80.9%
CH_4	21,523	7.8%
N_2O	27,216	9.8%
HFCs	2,661	1.0%
PFCs	1,235	0.4%
SF_6	421	0.2%
Total	277,632	100.0%

Note: Figures from 2003 were used for Iceland

It appears from the table above that the emission of potent greenhouse gases corresponds to 4.32 million tonnes of CO_2 equivalents on an annual basis. That corresponds to 1.55% of the emission of all greenhouse gases (in CO_2-eq.) from the Nordic countries.

Figure S1. Emission trends of HFCs, PFCs, SF_6 and total F-gases in the Nordic countries 1990 – 2004. Unit: 1000 tonnes of CO_2-eq.



In the Nordic countries, the total emission of F-gases decreased from 1990 to 1995 and since then it has stabilised at a level of about 4 million tonnes of CO_2-eq. per year.

The emission of PFCs and SF_6 has declined since 1990. That is mainly due to reduced emissions in the production of aluminium and magnesium caused by the introduction of new technology in the aluminium industry and because the production of raw magnesium has ceased.

The emission of HFCs has increased since 1990, and that is mainly because HFCs were introduced as substitutes for ozone depleting substances (CFCs and HCFCs). In the report it appears that a lot of development work is going on in the Nordic countries to develop and implement alternatives to HFC based products such as refrigeration systems and foam blowing. Also taxes and legislation have been introduced in some Nordic countries, and it might appear that the consumption and emission of HFCs will stabilize and perhaps decrease in the future.

The report describes how new refrigeration systems with natural refrigerants such as ammonia, hydrocarbons and CO_2 are installed in the Nordic countries. It is also described how HFC is phased out in much of the plastic foam production in the Nordic countries.

1. Introduction

1.1 The greenhouse effect and potent greenhouse gases

The potent greenhouse gases (also called the “F-gases”, “fluorinated greenhouse gases or the three “industrial gases”) are on the list of greenhouse gases, covered by the Kyoto Protocol. In 1997, the consumption of these substances (potential emission) constituted app. 3.5% of the total greenhouse gas emission in the Nordic countries and was increasing in some areas.

In 1998, the report “Ways of Reducing Consumption and Emission of the Potent Greenhouse Gases (HFCs, PFCs and SF_6)” (Pedersen, 2000) was prepared. It was updated in 2001 and printed by the Nordic Council of Ministers (Pedersen, 2001). The report described the application and emission of the potent greenhouse gases in the five Nordic countries and at the same time how to reduce emissione and the use of alternative substances. “Success stories” from the Nordic countries were included, in which alternative technology was introduced instead of technology based on the potent greenhouse gases.

Purpose

The purpose of the new project is to update the report from 2001, to strengthen the Nordic co-operation in this area and to describe the possibilities of using alternative technology objectively. One advantage is that producers of these chemicals are not situated in the Nordic countries.

The purpose is moreover to describe the national initiatives going on in the Nordic countries to reduce the emission of the potent greenhouse gases.

Finally, the purpose is to compile the latest results regarding the development of alternative technology. A rapid development is taking place in this area. Since 2001, new technology has among other things developed within insulation foam (polyurethane and XPS) and in the production of aluminium and magnesium, and there is increasing focus on the use of hydrocarbons, ammonia and CO_2 as refrigerant.

Contents

The project is partly based on the results of the previous Nordic reports as new research is carried out on consumption and consumption patterns in the Nordic countries. Moreover, a new examination of the different consumption/emission areas was carried out in order to describe the development level of alternative technology and its rate of implementation.

Summed up, the contents can be described as follows:

- Retrieval of data on the Nordic consumption/emission of potent greenhouse gases. The data has been retrieved from the national resports submitted to UNFCCC.
- New examination of technology for reducing consumption/emission of potent greenhouse gases. The rate of implementation of the new technology has been evaluated and for each consumption area a scenario has been laid down for when the most advanced part of the industry should have implemented the new technology (top 10%). In this connection, a new evaluation has been carried out on the relative additional costs of this new technology.
- A new analysis for commercial refrigeration systems has been made. The analysis has been made for Denmark, but is supposed to be representative for other countries as well.
- Description of the national initiatives for reducing emissions. A description of the politics and initiatives of each country is made. This is carried out in close contact with the national authorities represented in a reference group.
- Selection of areas where the Nordic countries are in a strong position with regard to alternatives (seen from an international point of view).
- Selection of areas where special efforts should be provided to promote the development of alternative technology.
- Description of the specific problems in some countries.

HFCs are used mainly as a refrigerant in:

- Commercial refrigeration systems (supermarkets, shops, refrigerated milk tanks etc.)
- Certain industrial refrigeration systems
- Mobile refrigeration systems (reefers, car air-conditioning etc.)
- Heat pumps
- Air-conditioning systems
- Cryogenic systems

HFCs are used for production of polyurethane foam in:

- Insulating foam
- Jointing foam (one component polyurethane foam)

HFCs are also used for:

- XPS-foam (extruded polystyrene foam)
- Extinguishants
- Propellant in aerosol cans (special products)

SF_6 is used mainly for the following purposes:

- Cover gases in light-alloy metal foundries
- Electric equipment
- Sound-insulating double-glazed windows
- Manufacturing microchips (semiconductors and optical chips)
- Other, including tracer gas

PFCs are used for the following purposes:

- Refrigerant in a special mixture
- Manufacturing microchips
- Other

PFCs are created as a by-product during the production of aluminium.

1.2 Measures to reduce emissions in the Nordic countries

National targets, political announcements:

Denmark

In Denmark, a tax was implemented in 2001 and a ban on certain uses was introduced in 2002.

A short description of the tax/refund scheme:

The main principle is that import of HFC/PFC/SF6 is taxed at DKK 100 (app. 13 Euro) per tonne of CO_2 equivalents.

In practice, the system is implemented by taxation of all gas in bulk and products that are imported into the country. The tax is administrated by the Danish Customs and Tax Administration, which is under the Danish Ministry of Taxation.

Information from the market indicates that the tax/refund scheme has led to more awareness from both owners and operators of the equipment. The tax has also increased attention paid to alternative substances (HC's, CO2, ammonia or other substances or techniques) and better housekeeping of reused gases.

Initial small problems have been solved with good cooperation between industry and ministries, and since then the administration of the system has worked satisfactory.

A short description of the ban:

In the Danish Statutory Order no. 552 on regulation of certain industrial greenhouse gases from 2002 there is a general ban on new products containing or using F-gases from 01.01.06.

There are some exemptions from this general ban. For instance, the ban on HFCs will come into force for cooling equipment with HFC charges > 10 kg from 01.01.07 and the use of HFC for service purposes is exempted from the Order.

Other examples of exemptions from the general ban are the use of SF6 in windows, car tyres and a tracer gas. All three were banned from 01.09.02 which is the case for the use of PFCs in general – except for a minor use in a refrigerant mixture which was banned from 01.01.06.

Other regulation

HFC used as refrigerants are classified as hazardous waste and must be recovered and disposed of properly. Since 1950, personnel handling HFC and PFC refrigerants have been required to be quilified for proper servicing practises.

Finland

HFCs used as refrigerants are classified as hazardous waste and must be recovered and disposed of properly (Ministry of Environment decree 1129/2001).

Personnel handling HFC and PFC refrigerants must be qualified to do so and they must have equipment for the proper servicing practices (Government decree 1187/2001).

Currently there is no legislation that restricts the use of F-gases or places regulations on inspection of F-gas-containing applications in Finland.

The emission reduction measures addressed in the upcoming EU F-gas regulation shall be applied in Finland.

Effect of legislation and other measures

In Finland, the certification system for personnel handling refrigerant agents has been in operation since 2001. This has led to more precise service of equipment and recovery of used gases. As refrigeration and air conditioning equipment are the main source of F-gas emissions in Finland the qualification system has led to lower emission rates in comparison to growing equipment capacity.

Together with qualified service personnel, the classification of F-gas containing refrigerants as hazardous waste has led to proper handling and destruction of these substances. Majority of used gases are recovered in service or at the end of equipment lifetime.

Finland has prepared greenhouse gas inventories since the 1990s to meet the obligations of the United Nations Framework Convention on Climate Change (UNFCCC). Data on the use of F-gas is collected from Finnish companies annually. Data reporting is voluntary but the surveys have had rather good coverage of Finnish F-gas users, importers and exporters. The response activity has also been at a good level. Although the F-gas data is collected for the UNFCCC inventories and not in the purpose of emission control, the inventory system simultaneously works as a follow up system of emission trends.

In some industrial sectors, the actors have voluntarily given up processes where F-gases are used. Additionally, producers have replaced high GWP gases with gases that have lower GWP. For instance in aerosol products, the share of HFC-134a is declining and share of HFC-152a is increasing.

In the latest survey (inventory year 2005), companies reported that many of the imported foam products did not include HFCs anymore. In most cases HFCs have been replaced with CO_2 and other low GWP alternatives.

The recent EU regulations have affected the F-gas emissions in advance. The use of F-gases in products that will be prohibited in Article 9 of the EC F-gas regulation is currently marginal. F-gases have mostly been replaced in Annex II products. Additionally, the EC directive regulating the use of F-gases in mobile air-conditioning systems will have a potent emission reducting effect with a few years delay from entering into force.

Norway

In Norway, a tax has been implemented.

The main principle is that import and production of HFC/PFC is taxed at NOK 190 (app. 23 Euro) per tonne of CO_2 equivalents and that the equivalent amount is paid in refund for (used) gas that is delivered for destruction. Thus, over time, this scheme is considered a proxy tax on emissions of HFC/PFC.

In practice, the system is implemented by taxation on all gas in bulk and on products that are imported into the country (Norway has no production of these substances). The tax is administrated by the Directorate of duties and taxes, which is under the Ministry of Finance.

The refund scheme is administrated by the Norwegian Pollution Control Authority (SFT). The refund is paid when a specific analysed and weighted amount of gas is delivered to an approved destruction facility. In practice, the system is rather simple, since there are very few actors up till now:

The collecting company (SRG) will collect (small) amounts of used gas from users, analyse the content and gather the gas in larger container tanks. The container tanks are sent to the Norcem Cement kiln for destruction and an application form describing the content of the tank, together with other documentation, is sent to SFT. The tank is stored at the destruction facility for two weeks, during which SFT can verify the content of the tank.

SFT processes the application and pays the appropriate refund to SRG.

After taking their expenses into consideration SRG pays a (smaller) refund to the users.

Up till now the system has appeared to be successful. There is an ongoing investigation on the impact of the introduction of the tax.

Information from the market indicates that the tax/refund scheme has lead to better maintenance of equipment, to increased attention paid to alternative substances (HCs, CO_2, ammonia), more recycling and better housekeeping of used gas, so in the longer term it is expected that emissions will be significantly reduced compared to the business-as-usual scenario.

Generally, the administration of the system has worked satisfactory. However, some technical problems have encountered regarding sampling and analysis of complex mixtures of gases.

Sweden

The use of ozone depleting and fluorinated greenhouse gases as refrigerants is controlled under the Swedish Refrigerants Order. This Order, originally issued in 1988 and amended several times is issued by the Environmental Protection Agency as mandated in the Ordinance 2002:187 on substances that deplete the ozone layer and Ordinance 1995:555 on HFCs. The Order is supplemented by regulations issued by the Board for Accreditation and Conformity Assessment (SWEDAC).

The Swedish Refrigeration Code and supplementary Fact Sheets are linked to the Refrigerants Order. These are issued by the Swedish Refrigeration Foundation (KYS) in consultation with the EPA.

The refrigerants order is applicable to all types of stationary and mobile refrigeration, air-conditioning and heat pump equipment containing CFCs, HCFCs and HFCs as refrigerants. The order specifies the obligations of the installation/servicing enterprises, the equipment owners and refrigerants suppliers. It also contains general directives on the choice of refrigerants and requirements on the design, service, maintenance, operation and dismantling of the equipment.

Regulations on recovery, recycling, repacking, destruction and export of recovered refrigerants are also included. Thus, importers and distributors of stationary and mobile system are required to receive recovered refrigerants for reclamation supplied by them. Nor charges may be levied for reclaimed amounts. The costs of the system are covered by a fee included in the sales prices for every sold kg of refrigerant. The system is completely run independently from government agencies by the companies involved.

Plants and equipment that are designed, installed, serviced and maintained in accordance with Swedish Refrigeration Code are deemed to fulfil the requirements of the Refrigerants Order. Furthermore, ODS and HFCs refrigerants may only be distributed to accredited enterprises, certain enterprises with certified personnel, equipment producers and some other minor categories.

EU

The EU has introduced a new “F-gas regulation” (Regulation (EC) No 842/2006). The regulation was adopted in May 2006 and restricts the use and emission of HFCs, PFCs and SF_6 in certain areas. The regulation specifies periodical checks for leakage for refrigeration systems and fire protection systems, ensures proper recovery of F-gases from refrigeration systems, solvents, fire protection systems and high voltage switchgears. The regulation also prohibits the use of SF_6 in magnesium die casting (exept for quantities below 850 kg p.a.) and SF_6 for filling vehicle tyres. References will be made to this regulation later on in this report.

The EU has also adopted a directive about emissions from mobile air-conditioning systems (MACs) (Directive 2006/40/EC). More about this in section 3.5.

1.3 Participants

The project is being carried out by Per Henrik Pedersen, M.Sc., Danish Technological Institute, Industry and Energy, in cooperation with the national authorities, which are gathered in a Climate Group under the Nordic Council of Ministers.

Section 3.3 (Commercial Refrigeration) has partly been written by Mr. Kim G. Christensen, DTI, Industry and Energy.

The project is being carried out in co-operation with a reference group with participants from each of the Nordic countries. The reference group is composed as follows:

- Maria Ujfalusi, Swedish Environmental Protection Agency
- Tuulia Toikka, Finnish Environmental Institute
- Frank Jensen, Danish Environmental Protection Agency
- Torgrim Asphjell, Norwegian Pollution Control Authority

Many other people and companies have contributed to the project: Liesbeth Melis, Huntsman Europe; Hans Haukås, Hans T. Haukås A/S; Alexander Pachai, York Refrigeration A/S; Halvor Kvande, Hydro Aluminium; Bjørn Vik; Gunnel Wisen, ABB; Roy Andersen, Jackon A/S; Chris Ungermand, Danish Plast Association PUR-section; Jesper Hansen, Vestfrost A/S; Sellan Haglund, Haglund Industri AB; Anders Sjøgaard, Gram Commercial A/S; Jan-Erik Nowacki, Svenska Värmepump Föreningen (SVEP); Paul Homsy, Nestlé; Salvatore Gabola, the Coca-Cola Company and Alan Gerrard, Unilever.

DTI would like to thank the reference group, the Nordic Climate Group and representatives of industry, who have provided data for the report.

Work on the new report commenced in February 2006 and ended in September 2006. The project was completed within the budget, corresponding to 158 hours.

2. Consumption and emission of HFCs, PFCs and SF_6 in the Nordic countries

Data for consumption and emission has been found from the national reports sent to the UNFCCC. When this project started in February 2006, the newest national reports at the UNFCCC server contained figures from 2003. However, some countries have released figures for 2004. The data is reproduced in the following, with the countries listed in alphabetical order.

2.1 Denmark

Table 2.1: Trend in emissions in Denmark (NIR, 2006)

1000 Tonnes CO_2-e	1990	1995	2001	2002	2003	2004
CO_2	52,712	60,449	54,669	54,262	59,454	53,941
CH_4	5,692	6,025	6,026	5,985	5,966	5,765
N_2O	10,593	9,514	8,297	7,944	7,898	7,589
HFCs	0	218	647	672	695	749
PFCs	0	1	22	22	19	16
SF_6	44	107	30	25	31	33
Total	69,042	76,314	69,693	68,910	74,064	68,093

Table 2.2: Consumption of HFCs, PFC and SF_6 in Denmark (NIR, 2006)

Tonnes	1990	1995	2001	2002	2003	2004
HFC32 (RAC)	-	0.11	7.33	8.44	10.1	12.0
HFC125 (RAC)	-	2.58	45.1	48.5	54.9	59.9
HFC134a (RAC)	-	14.3	128	151	162	169
HFC134a (Foam)	-	136	132	122	98.8	110
HFC134a (MDI and Spray)	-	-	9.24	7.59	7.40	6.65
HFC143a (RAC)	-	2.43	40.1	43.2	49.0	52.8
HFC152a (RAC)	-	0	0.58	0.51	0.41	0.33
HFC152a (Foam)	-	43.4	12.8	12.5	1.63	5.81
PFC (C_3F_8) (RAC)	-	0.07	2.64	2.67	2.51	2.27
PFC (C_3F_8) (other processes)	-	-	0.52	0.50	0.25	-
SF_6 (magnesium)	1.30	1.50	0	0	0	0
SF_6 (electrical eq.)	0.06	0.16	0.53	0.37	0.40	0.43
SF_6 (other proc.)	0.50	2.83	0.75	0.68	0.91	0.96

2.2 Finland

Table 2.3: Emissions in Finland (NIR, 2006)

1000 Tonnes CO_2-eq.	1990	1995	2001	2002	2003	2004
CO_2	56,750	58,110	62,560	65,040	73,100	69,120
CH_4	6,340	6,110	5,300	5,100	4,890	4,700
N_2O	7,970	7,180	6,810	6,880	7,000	6,920
HFCs	0	30	660	460	650	700
PFCs	0	0	20	10	10	10
SF_6	90	70	60	50	40	20
Total	71,090	71,470	75,370	77,500	85,660	81,440

HFC emission started to rise rapidly following the phase-out of CFCs in the middle of the 1990s. Most of the HFC emission in Finland originates from refrigeration and air conditioning equipment.

Small quantities of PFCs have been used throughout the 1990s in semiconductor manufacturing. PFCs have also been adopted as a component in service refrigerant mixtures in refrigeration and air-conditioning applications.

The total bulk of refrigerants (HFCs and PFC-218) imported in 2003 was 732.7 tonnes. The total export of bulk refrigerants was 23.2 tonnes.

39.5 tonnes of HFCs was used in production of foam in 2003. Another 3.4 tonnes was imported in polyol.

2.3 Iceland

Table 2.4: Emission of potent greenhouse gases from Iceland (NIR, 2005)

1000 Tonnes CO_2-eq.	1990	1995	2001	2002	2003
CO_2	2,084	2,216	2,188	2,241	2,175
CH_4	413	466	490	473	472
N_2O	360	339	342	308	301
HFCs	-	25	54	36	68
PFCs	420	59	92	72	60
SF_6	5	5	5	5	5
Total	3,282	3,110	3,170	3,136	3,083

Note: The figures for HFCs are based on imported bulk and represent potential emissions.

2.4 Norway

Norway has a relatively large emission of PFCs due to considerable production of aluminium. The emission of PFCs has decreased due to improved production technology (see chapter 4.1).

Norway also had a big production of magnesium which accounted for most of the SF_6 emission. The emission of SF_6 has decreased considerably due to a stop of production of primary magnesium in Norway.

Table 2.5: Emission of greenhouse gases in Norway (NIR, 2006)

1000 Tonnes CO_2-eq.	1990	1995	2001	2002	2003	2004
CO_2	34,760	37,800	42,900	42,000	43,550	43,980
CH_4	4,760	5,084	4,958	4,792	4,820	4,820
N_2O	4,720	4,416	4,447	4,634	4,450	4,600
HFCs	0	26	306	356	378	401
PFCs	3,371	2,008	1,329	1,438	910	881
SF_6	2,200	617	805	250	230	280
Total	49,800	49,900	54,700	53,500	53,300	54,900

HFCs are used for refrigeration, air conditioning, extinguishants, and – in modest quantities (mixed with CO_2) – for blowing polyurethane foam.

Table 2.6: Emission of HFCs, PFCs and SF_6 in Norway (NIR, 2006)

Tonnes	1990	1995	2001	2002	2003	2004
HFC23	0.0	0.0	0.1	0.1	0.1	0.2
HFC32	0.0	0.0	1.5	2.0	2.0	2.2
HFC125	0.0	2.4	33.4	37.9	38.4	38.8
HFC134a	0.0	10.2	80.4	95.3	109.7	123.8
HFC152a	0.1	1.0	16.2	19.0	23.3	29.4
HFC143a	0.0	0.0	27.1	31.6	32.0	32.3
HFC227ea	0.0	0.0	0.3	0.3	0.3	0.3
CF_4	467.4	283.3	187.5	201.3	125.6	122.1
C_2F_6	36.2	18.1	11.9	14.0	10.1	9.4
C_3F_8	0.0	0.0	0.1	0.1	0.1	0.1
SF_6	92.0	25.4	33.1	10.0	9.8	11.5

2.5 Sweden

Table 2.7: The emission of greenhouse gases in Sweden (NIR, 2006)

1000 Tonnes CO_2-eq.	1990	1995	2001	2002	2003	2004
CO_2	56,601	58,206	54,245	55,401	56,469	55,360
CH_4	6,685	6,684	6,083	5,911	5,751	5,766
N_2O	8,694	8,497	7,937	7,888	7,812	7,806
HFCs	4	126	595	644	686	743
PFCs	440	389	268	296	292	268
SF_6	*107*	*127*	*111*	*104*	*69*	*83*
Total	72,532	74,029	69,239	70,244	71,078	70,026

Table 2.8: Emission in F-gases, divided into sources (1000 tonnes CO_2-eq.) (NIR, 2006)

Tonnes CO_2-eq.	1990	1995	2001	2002	2003	2004
Refrigeration and AC	2.5	120.0	458.0	512.0	561.0	603.0
Foam blowing	0	0	110.0	104.0	97.0	107.0
Fire exting.	0	0	5.1	5.6	5.8	6.1
Aerosol/MDI	1.3	6.7	23.0	23.0	24.0	30.0
Semicond.	-	11.0	11.0	14.0	10.0	4.2
Electrical eq.	81.0	95.0	43.0	26.0	23.0	30.0
Other	2.4	3.4	9.8	10.4	9.4	11.6

2.6 The Nordic countries combined

In this section, an attempt has been made to combine the figures for the Nordic counties.

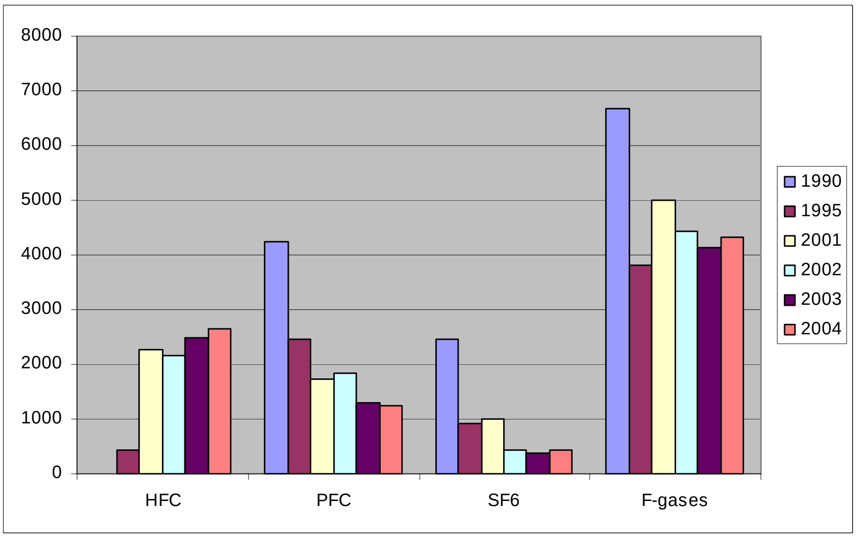
Table 2.9: Emissions of greenhouse gases in the Nordic countries in 2004

	1000 Tonnes CO_2-eq.	
CO_2	224,576	80.9%
CH_4	21,523	7.8%
N_2O	27,216	9.8%
HFCs	2,661	1.0%
PFCs	1,235	0.4%
SF_6	421	0.2%
Total	277,632	100.0%

Note: Figures from 2003 were used for Iceland

It appears from table 2.9 that the emission of potent greenhouse gases corresponds to app. 4.32 million tonnes of CO_2 equivalents on an annual basis. That corresponds to app. 1.55% of the emission of all greenhouse gases (in CO_2-eq.) from the Nordic countries.

Figure 2.1: Emission trends of HFCs, PFCs, SF_6 and total F-gases in the Nordic countries 1990 – 2004. Unit: 1000 tonnes of CO_2-eq.



The emission of PFCs and SF_6 has declined since 1990 (see table 2.10). The reasons are mainly due to reduced emissions in the production of aluminium and magnesium.

The emission of HFCs has increased since 1990, and that is mainly because HFCs were introduced as substitutes for ozone depleting substances (CFCs and HCFCs).

In the Nordic countries, the total emission of F-gases decreased from 1990 to 1995 and since then it has stabilised at a level of about 4 million tonnes of CO_2-eq. per year.

3. Use of HFCs, substitutes and other ways of reducing emissions

HFC (hydrofluorocarbon) is the name used for a number of substances produced by placing a number of fluoride atoms on hydrocarbons with some hydrogen atoms left in the molecule. The most common HFC substances are as follows:

Table 3.1: The most common HFCs

	Chemical formula	Normal boiling point (C)	GWP (100 yrs)	Atmospheric lifetime (yrs)
HFC-23	CHF_3	- 82.1	12,000	264
HFC-32	CH_2F_2	- 51.7	550	5.6
HFC-125	C_2HF_5	- 48.4	3,400	32.6
HFC-134a	CH_2FCF_3	- 26.5	1,300	14.6
HFC-143a	CF_3CH_3	- 47.5	4,300	48.3
HFC-152a	$C_2H_4F_2$	- 24.2	120	1.5
HFC-227ea	C_3HF_7	- 17.3	3,500	36.5

The commonly used “R” in the designations R-134a, R-125, etc. stands for Refrigerant. The designation HFA-134a is also used. It corresponds to HFC-134a.

HFC substances are often used in mixtures of refrigerants, which are assigned R-400 or the R-500 serial numbers. A list of refrigerants and refrigerant mixtures is given in Appendix A.

HFCs are not produced in the Nordic countries. All the gases are imported and made by international chemical groups such as DuPont, Archema, Solvay, Honeywell etc.

HFCs are used mainly as refrigerants in refrigerators and refrigeration systems, and as blowing agents for insulating foam. HFCs are also used for a number of other purposes, including propellant in special aerosol cans, for testing electronics and for special fire-extinguishing purposes.

This chapter is divided into 15 sections. The refrigeration industry is discussed in the first eight sections, and three sections follow these on polyurethane foam. The remaining four sections are used to discuss XPS-foam, extinguishants, aerosol cans and other uses.

Section 3.1 deals with domestic refrigerators and freezers and covers the use of HFCs both as refrigerants and for blowing insulating foam for these refrigerators and freezers. That is done because of the close relationship between these two applications.

3.1 Domestic refrigerators and freezers

A large quantity of domestic refrigerators and freezers are made in the Nordic countries. Electrolux, which has its headquarters in Stockholm, is one of the world's biggest manufacturers of these products. However, most of the production takes place outside the Nordic countries.

There is also a large production of components for refrigerators and freezers, including thermostats, pipe systems and compressor components. (Danfoss compressors are made in Flensborg in Germany and elsewhere.)

In Denmark, three manufacturers (Vestfrost, Frigor and Elcold) produce domestic refrigerators and freezers.

Ozone-depleting substances were once used when manufacturing refrigerators and freezers. CFC-11 was used for blowing polyurethane foam for insulating refrigerators and R12 (CFC-12) as the refrigerant in the refrigeration system. In a transitional period, different technologies were used instead of CFC, including HCFCs for blowing polyurethane foam. Companies have pursued different paths in their development work. All the manufacturers used R134a (HFC-134a) as a substitute for R12 in their refrigeration systems and are still using it in a large part of their production. R134a was also used by some manufacturers for blowing polyurethane foam.

In 1993, environmental organisations began questioning the environmental impact of HFCs because these substances (like CFCs and HCFCs) are potent greenhouse gases.

In Germany, Foron, together with environmental organisations, introduced refrigerators with hydrocarbons. Other manufacturers soon followed suit. In that connection, Electrolux at an early point of time introduced 35 models with isobutane as the refrigerant and cyclopentane in the insulating foam. Danfoss was out early with a complete compressor programme for domestic appliances with isobutane (R600a) as refrigerant.

Within just a few months, the entire German market was forced to use hydrocarbons. That also applied to foreign manufacturers who wanted to sell in that market.

Many people feared that explosions might occur in some of the refrigerators because there was some risk of an explosive mixture of hydrocarbons and air developing in the cabinet and of this mixture being ignited by a spark from the thermostat, door contact or other spark generator. That problem was solved by placing potential spark generators outside the cabinet and by preventing leakage of refrigerant inside the cabinet.

At present, several hundred million years of operating experience have been registered in Europe. According to available sources of information, no accident has been registered so far.

Furthermore, refrigerators and freezers with hydrocarbons are at least as efficient as HFC models, and refrigerators with hydrocarbons are less noisy than corresponding HFC models because of lower pressure in the refrigeration system.

Today, most of the European production is based on hydrocarbon technology, and the developing work for compressors and new energy efficient appliances are based on hydrocarbons. Recently, the Danish Electricity Saving Trust conducted a campaign where 1,000 DKK were given to customers buying “A++” refrigerators and freezers (the most energy efficient models in the European labelling specification). Among the 78 different appliances approved to be included in the campaign 100% were based on hydrocarbon technology (Walloe, 2006).

Hydrocarbon technology is also gaining momentum in Asia (Japan, China, India, Korea etc.), where most of the production now is based on R600a-refrigerant and cyclopentane is the most important blowing gas for the insulation foam.

However, in the US, R134a is standard and no signs indicate that this will change in the near furture. The blowing agent was until recently HCFC141b which has been replaced by HFC-245fa (IPCC, 2005).

Financial barriers

Hydrocarbon technology exists and has been fully implemented by the large European manufacturers, although parallel with this, many of them are using R134a as the refrigerant in part of their production. As investments took place in the 1990s, there are no additional costs for HFC-free technology.

The manufacturer of domestic refrigerators and freezers informs that in general no price difference exists between HFC and hydrocarbon based appliances.

Emission to the surroundings/accumulation in scrapped products

Only a small part of the HFCs used in the manufacture of refrigerators and freezers are emitted directly to the surroundings (estimated to be less than 5%). The remainder is accumulated in the product and is gradually released by diffusion from the insulating foam or leakage in the refrigeration system. At the time of scrapping, most of the HFCs still remain in the products.

Most of the refrigerators are exported outside the Nordic countries. A small proportion of the HFCs in refrigerators and freezers is presumably collected and incinerated in connection with collection schemes for old refrigerators. Nevertheless, it is assumed that some of the HFCs will be emitted to the atmosphere in the long run – through diffusion and leakage during the lifetime of the appliances and in connection with scrapping.

Situation with respect to alternative technology

HFC free technology has been developed and implemented in the Nordic countries.

3.2 Commercial refrigerators and freezers (plug-in)

A significant number of commercial refrigerators and freezers are manufactured and installed in the Nordic countries. It is estimated that close to 1 million units are installed in Scandinavia, although the specific figure is unknown. The three biggest groups of appliances within commercial refrigerators and freezers (plug-in) are bottle coolers, professional kitchen refrigerators and freezers and ice cream cabinets. The group also includes vending machines, water coolers, supermarket plug-in display cabinets, minibars, ice machines, wine coolers etc.

Bottle coolers

Glass door bottle coolers can be found in nearly every supermarket and kiosk in the Nordic countries. The most common type is the one door 400 litres type, but also bigger (2 or 3 glass doors) and smaller types are on the market. Glass door coolers are often installed by a soft drink company or a beer company and are labelled with the logo of the company.

It is estimated that about 70,000 bottle coolers are installed in Denmark where a significant production also takes place (Vestfrost, Derby/Caravell and Gram Commercial). In Finland, Norpe has a production of bottle coolers. In Norway, there used to be a production (Norcool) but it was moved to other Frigoglass facilities outside of Scandinavia.

Currently, R134a (HFC-134a) is standard as refrigerant in bottle coolers and almost all bottle coolers sold so far use this refrigerant.

There are also HFC free coolers on the market. Since 2000, Vestfrost has marketed a hydrocarbon version using R600a and has delivered several thousand units to the European marked.

Vestfrost markets the following bottle coolers that use R134a or R600a:

Table 3.2: Bottle coolers with hydrocarbon refrigerant

	Net volume (litres)	Capacity of 33 cl cans
FKG311	281	378
FKG372	351	476
FKG410	351	476
M200	379	504

The top model M200 is at present marketed with R134a. Models with R600a and CO_2 are currently undergoing field tests and will be marketed from January 2007 (Hansen, 2006).

Caravell markets an open bottle cooler with R290. It is an open top "Access-cooler" with 74 litres net volume (www.caravell.dk).

At the "Procool" event at Hannover in April 2006, Liebherr presented a new glass door bottle cooler with 50 gram R600a refrigerant. The net volume is 329 litres.

In 2000, *the Coca-Cola Company* (before the Sydney Olympics) declared that they would stop buying products with HFC. In 2004, the Coca-Cola Company also declared, that they would go for CO_2 as refrigerant (and not hydrocarbons).

The Coca-Cola Company has given the following status on the implementation of HFC free technology (Gabola, 2006):

> "We have conducted a three year research project looking at different alternative technologies and have concluded that CO_2 refrigeration is the most compelling system for our kind of equipment (coolers and vending machines, mostly of a capacity of 600W and above). CO_2 based equipment conforms to our performance requirements and has performed well in both lab and field tests. We have also decided that we will go for a modular system whereby the whole refrigeration deck will be contained in a plug-in/pull-out cassette.
>
> We currently have more than 2000 CO_2 coolers and vending machines in the marketplace, mostly in Europe, for pre-commercial testing. By the end of this year we plan to have almost doubled this amount in Europe and to be above 6000 units worldwide (with a strong push in Japan)."

Status of HFC free technology

HFC is standard, but HFC free technology has been available ever since HC coolers have been marketed. CO_2 based coolers will soon be available and a considerable number are present in field tests.

Danfoss Compressors has developed a CO_2 compressor for this purpose. So far, some hundred compressors have been produced and tested, and the compressor is expected to go into regular production in 2007.

Ice cream cabinets

Ice cream cabinets with glass lids can be found in almost every supermarket and kiosk in the Nordic countries. Most of them have been installed by substantial ice cream producers.

Many ice cream cabinets are produced in Denmark and the biggest producer is Caravell/ Derby (up to 200,000 units/year). Elcold is also a considerable producer and Vestfrost produces a smaller amount of cabinets.

HFC refrigerant is standard (R404A and R134a). However, hydrocarbon cabinets have been available since 2000 and it seems as if hydrocarbon technology now is gaining market share.

There are two major ice cream producers that purchase ice cream cabinets and they have different strategies:

Unilever has chosen hydrocarbons and is implementing hydrocarbon cabinets in Europe (Gerrard, 2006):

> "Unilever started the HC cabinet rollout in Europe (in Denmark) in 2003 (with 800 cabinets). In 2004, we introduced about 15,000 cabinets into 17 countries in the EU, followed by a further 40,000 in 2005. This year I estimate that we will have a further 45,000 in Europe. This means I am confident that we will have around 100,000 working in the EU this year.
>
> Outside of Europe, progress has been slower since we have been focussing our efforts on the largest region first (in terms of cabinet numbers). We will have HC cabinets in Mexico and Brazil this year in small numbers with the intention of getting larger numbers into the market by 2007. We always need to bring the supply chain with us, and this takes time to organise (e.g. only one compressor supplier makes 110V compressors used in some parts of Brazil and these are not available for all cabinet capacities). I expect other smaller markets (for Unilever ice cream) in Latin America to follow on from Brazil and Mexico.
>
> This year I hope to have a small number of HC cabinets on trial in China. Once again, bringing the supply chain with us is the difficulty, but I am confident those issues have now been resolved. I expect significant numbers of cabinets in China and other countries in Asia in 2007."

Nestlé is commited to search for HFC free commercial refrigeration that is safe, legally accepted, cost effective and commercially available (Homsy, 2006 and the Nestlé homepage):

> "Nestlé is extending its experience to smaller commercial refrigeration units and has started building and testing ice cream freezers with CO_2 refrigeration systems. This natural substance fulfils most requirements expected from a modern refrigerant, but unlike other currently available alternatives, it has a negligible impact on the environment and is inherently safe, even under extreme operating conditions.
>
> Nestlé is also working on other refrigeration technologies and is expected soon to announce a 'world first'."

Status on HFC free technology:

HFC free technology is available, marketed and implemented using hydrocarbon refrigerants. In 2006, Unilever will install ice cream cabinet no. 100,000 with this technology.

The other big ice cream producer – Nestlé – has chosen to go for HFC free refrigerants and this technology is still under development.

Professional kitchen refrigerators and freezers

It is estimated that about 200,000 professional kitchen refrigerators and freezers are installed in the Nordic countries (in Denmark about 50,000 units). Most of them are of the stainless steel upright type, but also counter types are present.

In Scandinavia, there are three manufacturers of professional kitchen refrigerators and freezers. HFC was standard until 2003/2004, but R290 (propane) is becoming standard in (some) Nordic countries.

Since 2003, Gram Commercial in Denmark has marketed appliances with R290, and this type is now standard for the company's products in Denmark and Sweden. It is becoming standard in Norway. A number of Norwegian technicians have been taught how to carry out service with hydrocarbons (Kulde 2/2006). Gram has about 50% of the market in Denmark.

Porkka in Finland uses R134a (in refrigerators) and R404A (in freezers). Porkka has a big market share in Finland and Sweden.

Haglund Industri in Sweden also produces professional kitchen refrigerators and freezers. HFC is standard, but Haglund now offers units with R290 (Haglund, 2006).

The energy consumption and the category of refrigerant and blowing agent for the insulation foam for energy efficient professional kitchen refrigerators and freezers sold in Denmark can be seen (also in English) on a web-site at the Danish Electricity Saving Trust: http://www.prof-hvidevarer.sparel.dk/ .

Wine Coolers

Wine coolers to some degree look like bottle coolers. Wine coolers have become popular for professional as well as domestic use. There is a great variety of wine coolers and they use different cooling technologies, including thermoelectric cooling for the smallest units. Other units use compression refrigeration.

Vestfrost is probably the only manufacturer in the Nordic countries. Vestfrost uses R600a as standard in production.

Minibars

Three different refrigeration technologies are present in minibars for hotel rooms. In the Nordic countries absorption minibars are most common. In Denmark, about 20,000 minibars are in use.

Absorption minibars do not have a compressor. They are quiet but have a high energy consumption and low cooling capacity. The refrigerant is ammonia and the refrigeration system consists of ammonia, water and hydrogen.

Thermoelectric minibars are now expanding. They are quiet but have high energy consumption. Thermoelectric cooling uses a “Peltiér element” which is a semiconductor.

Compressor minibars are energy efficient and have a high sound level, when the compressor is on. At least one type of compression minibar can be controlled, so the compressor runs during daytime and a small ice accumulator cools the contents during night-time.

Horesta (branch organisation for hotels in Denmark) and Danish Technological Institute have tested the 6 most used minibars in 2005.

One compression, one thermoelectric and 4 absorption minibars were tested and the compressor minibar was by far the most energy efficient.

This compressor minibar used R134a as refrigerant. A compressor for R600a is available and it is possible to use R600a for that purpose.

Table 3.3: Minibar test results. The tests are accredited according to EN153 and carried out at Danish Technological Institute.

Brand	Cooling principle	Energy consumption kWh/24h	Net. Vol. 1	Energy efficiency index	Energy label	Cooling performance /cooling time	Noise dB
IndelB K50	Compressor	0.45	31	65.7	B	5h 09min	39
Dometic Hipro 4000	Absorption	0.78	33	112.2	F	5h 35min	27
Dometic RH448	Absorption	1.03	30	148.4	G	6h 06min	30
IndelB CT40	Thermo-electric	1.13	36	162.7	G	5h 35min	33
Vibocold TM40	Absorption	1.19	30	172.2	G	6h 21min	29
IndelB A50	Absorption	1.47	32	212.2	G	10h 49 min	30

For more information about the test of minibars: www.horesta.dk

Vending machines

R134a is standard refrigerant in vending machines. Most soft drink vending machines are purchased by large suppliers of soft drinks. The refrigerant policy of the Coca-Cola Company has already been mentioned in the section about bottle coolers. The company is going for CO_2 as refrigerant and field tests are ongoing.

Water coolers

A great number of water coolers for both bottled water and tap water are installed in the Nordic countries. They are installed with a small compressor refrigeration system and so far HFC refrigerants have been standard.

The Danish company Kuvatek manufactures tap water coolers and beer coolers with hydrocarbon refrigeration system (R290).

Ice machines

A great number of ice machines are installed in restaurants and bars in the Nordic countries. So far HFC refrigerants are standard, and Danish Technological Institute has no information about marketed HFC free ice machines. However, one prototype ice machine with R290 was installed in the HFC free McDonald's restaurant in Vejle, Denmark, in 2003.

Supermarket display cabinets

The use of supermarket cabinets of the plug-in-type is increasing in Northern Europe. Many small- and medium-sized supermarkets install such units instead of the cabinets for remote cooling machinery.

The plug-in cabinets are cheaper and more flexible. With glass lids they are also economic in use.

The condenser heat is submitted into the supermarket sales area where the cabinets are placed, which might cause high room temperatures in summertime.

AHT from Austria is a major manufacturer of such cabinets. So far, HFC refrigerant is standard. The charge per unit is from 220 to 300 grams of R404A.

At the "Procool" event in Hannover in April 2006, AHT presented a R290 version of the "Paris" freezer cabinet (724 litres netto, 120 grams of R290). AHT informs that several hundred cabinets have been tested in field tests (some of them in Nordic countries) and the product is now in regular production. A similar cabinet with fresh food compartment is under way.

Vaccine coolers

WHO plays an important role in approving vaccine coolers for health stations. A large number of vaccine coolers (several hundred thousands) are installed in health stations around the world. Many of them are placed in rural areas in developing countries.

Vestfrost has a production of vaccine coolers in Denmark. Electrolux is another major manufacturer and their production takes place outside the Nordic countries.

R134a is the standard refrigerant, but WHO is at present drafting new standards, which also allow hydrocarbon as refrigerant. The technology for manufacturing hydrocarbon vaccine coolers is available including compressors. Some training of service technicians might be necessary in the countries installing such appliances.

DC coolers

There is some production of DC refrigerators (Direct Current, 12 V or 24 V) for trucks, small boats etc. and for vaccine chillers that are powered by solar cells (photovoltaic). Danfoss Compressors is a major manufacturer of compressors for this type of appliance, and so far R134a is the refrigerant that is used. Danfoss Compressors has developed and marketed new DC compressors for isobutane and propane. Up till now, this has been used in a limited number for solar powered vaccine coolers and solar powered ice cream cabinets.

Limited hydrocarbon charge

According to current CEN-standard (EN 378: 2000), limited amounts of HC can be used as refrigerant in refrigeation systems. However, HC is not allowed as refrigerant in direct systems for human comfort, i.e. air conditioning systems and heat pumps. In the draft for a revised standard (prEN378), it is opened up for the use of HC even in AC-systems and heat pumps (but with additional requirements). Another new rule of importance is that factory sealeds systems with up to 150 grams of HC can be used without restrictions for any purpose (Haukås, 2006).

3.3 Commercial refrigeration systems

The area of commercial refrigeration covers a wide range of refrigeration applications. Commercial refrigeration is the part of the cold chain comprising equipment used mainly in retail outlets for preparing, holding and displaying frozen and fresh food and beverages. However, equipment for commercial refrigeration can also be used by small producers of food products and smaller refrigerated warehouses for storage. In some cases there might be some overlap with the industrial segment for these latter applications.

For commercial systems, two levels of temperatures are typically used (medium temperature for preservation of fresh food and low temperature for frozen products). In the Nordic countries (and globally) commercial refrigeration is the refrigeration subsector with the largest refrigerant emissions calculated as CO_2 equivalents. These represent 40% of total annual refrigerant emissions (IPCC/TEAP, 2005). This is due to high charges of refrigerant (distributed systems) and high leakage rates. For commercial systems we typically see that the direct emissions of green house gasses amount to 40% of the total climate impact from the refrigeration system. In countries with a big share of hydropower and/or nuclear power this figure is even bigger. Taking these considerations into account it is very important to focus on this segment.

3.3.1 Conventional refrigerants and systems

In the Nordic countries, R404A is the preferred refrigerant for commercial refrigeration. R404A has a pretty low normal boiling point so it can be used both at low and medium temperature. R134a is also used, but mainly for medium temperatures. The CFC phase-out for new equipment and servicing in Europe ensured that no CFC systems are in operation today, but a large number of systems with HCFC-22 are still in operation (KMO, 2006).

Commercial refrigeration comprises three main types of equipment:

- stand-alone equipment (plug-in)
- condensing units
- centralised systems.

Stand-alone equipment (plug-in) is described in section 3.2 of this report.

Condensing units are used with small commercial equipment. They comprise one or two compressors, a condenser and a receiver which are normally located in the ambient. The evaporator is placed in display cases in the sales area and/or a small cold room for food storage.

Centralised systems consist of a compressor unit including valves and receivers placed in a machinery room. The unit is connected with distributed piping to evaporators placed in cabinets, cold stores etc. The condenser is typically placed in the ambient. The centralised systems tend to be more effective than the plug-in systems and condensing units. The centralised system can be sub-divided into 3 groups:

Direct systems, where the primary refrigerant (R404A) is circulated directly to the evaporators.

Indirect systems where the primary refrigerant and a heat transfer medium (a secondary refrigerant) exchange heat in a extra heat exchanger and the heat transfer medium is pumped to the cabinets and storage rooms (see appendix B). The heat transfer medium can be single phase brine, but also two-phase fluids such as volatile CO_2 or ice slurry can be used.

The last group is *hybrid systems* where 2 or more different primary refrigerants are combined e.g. in a cascade system, where the high temperature refrigerant is used in the medium temperature level (chilled food) and to cool the low temperature refrigerant in the cascade heat exchanger and the low temperature refrigerant is used at the low temperature level (frozen food). Some cascade systems (increasing in numbers) with CO_2 and a conventional refrigerant use CO_2 even for cooling demand at app. 0^0C.

Centralised systems are normally considered as “best available practice” in supermarkets when focusing on low energy consumption and low initial costs.

See appendix B for detailed system layouts for the different technical systems.

The table below shows availability of primary refrigeration technologies used in different applications.

Table 3.4: Primary system types and primary applications

	Stand-alone	Condensing	Centralised systems		
			Direct	Indirect	Hybrids
Supermarkets	- (V)	X	X (V)	V	V
Small retail	X (V)	X	X (V)	V	V
Kiosk/ service stations	V	X	X	V	-
Hotels/ restaurants	V	X	X	V	-

V: is solved with natural refrigerants; X: alternatives not found; -: no application

From the table above it can be concluded that a lot of work has been done so far regarding the development and implementation of refrigeration systems working with natural refrigerants, but still there are a lot of challenges before natural refrigerants can cover all applications in a commercial and efficient way. Hybrid systems are considered to be more complex systems with more than one type of refrigerant. In this report, the group of hybrid systems primary consists of different types of cascade systems.

3.3.2 Considerations regarding natural refrigerants, legislation and leakage rates

Natural refrigerants

Due to the global warming impact from HFC refrigerants there is great interest in introducing natural refrigerants especially in commercial refrigeration since the refrigerant charges and leakage rates are relatively high.

Natural refrigerants are substances that are already included in nature's own cycle, for instance ammonia, hydrocarbons, CO_2, water and air.

None of the refrigerants in the group of natural refrigerants are perfect, and they all have technical limitations. Ammonia is toxic, hydrocarbons are flammable, CO_2 operates at very high pressure and has a low critical point, water has very low volumetric refrigeration capacity and cannot be used below 0°C and air is only an interesting option at very low temperatures below -60°C.

Therefore, natural refrigerants have to be chosen with care and not only one fluid will cover all applications.

Legislation

In Sweden, indirect refrigeration is required for new refrigeration systems. Svensk Kylnorm (1994) (the Swedish Refrigeration Standards body) requires partially indirect refrigeration for charges of 10 to 30 kg. Normally indirect refrigeration is used for fresh food and direct refrigeration for freezing. With charges greater than 30 kg, the system must be completely indirect, i.e. indirect refrigeration is required for both refrigeration and freezing.

The introduction of HFC taxes in Denmark and Norway has indirectly established a situation, where direct cooling with HFC refrigerants is economically less favourable.

By 1st of January 2007 a total ban on the use of HFC refrigerants in Denmark in new system with charges exceeding 10 kg will come into force. This ban already has a huge impact on the systems implemented especially in supermarkets.

Furthermore, the new F-gas directive from EU gives shorter service intervals, sets stricter rules for the competences of refrigeration fitters and makes it necessary to use gas detectors (for systems with more than 300 kg refrigerant). The new rules will probably not change the current practices in the Nordic countries as most of the areas have already been dealt with here, however, it can be a way to push industry in the direction of natural refrigerants.

Leakage rates

The leakage of refrigerant from commercial refrigeration systems is rather high due to distributed piping. The leakage rates have earlier been estimated to be about 15 – 25% of the charge per year. However, a great deal has been done in the past years to reduce the leakage. Today all references indicate that the leakage rate is about 10–15% per year (Pedersen, 2001). A meeting organised by the Refrigeration Association in Denmark (Spring 2006) stated that the emission rate is about 10% (KMO, 2006). The registrated leakage rate for a Norwegian supermarked chain gave 14% p.a. and measured values for 1700 supermarkets in US and Europe are 18% (Haukaas, 2006).

Figures from Sweden indicate leakage rates between 8.6% and 12.5% in 2000 to 2003 at 450 supermarkets (Arias et al, 2004).

A lot of effort has been put into this area. The new F-gas regulation in EU introduces shorter service intervals, set stricter rules for the qualifications of refrigeration fitters and makes it necessary to use gas detectors (in systems with more that 300 kg refrigerant). The new rules will probably not change the current practices in the Nordic countries as most of the areas have already been dealt with here.

The leakage from more compact systems like stand-alone and condensing units is smaller. It is estimated to be about 5% per year.

Analysis of commercial refrigeration systems

A small TEWI analysis of commercial refrigeration systems appears in appendix B. The analysis was carried out on Danish commercial refrigeration systems, but the situation is assumed to be quite similar to the situation in other Nordic countries. The analysis evaluates if alternatives exists for given applications, evaluates the estimated additional costs for using systems without HFC, the possible additional energy use and the total contribution to global warming.

The conclusions are repeated here:

If systems for natural refrigerants using less energy than similar HFC systems are applicable, the matter is clear: Systems with natural refrigerants is the most environmentally benign solution, taking the greenhouse effect into consideration.

In places, where direct cooling with natural refrigerants or semi-direct cooling is possible, the energy consumption will in general not be higher than in similar HFC systems. Hence, these systems will be advantageous seen from an environmental point of view.

Indirect refrigeration with brine (e.g. a water/glycol mixture) will generate a loss because of the necessary heat exchange between the primary and the secondary refrigerant. By means of that the energy consumption will be a little higher because of the demand for lower evaporating temperatures. This results in a slightly higher energy demand 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 line of the direct system. In total, indirect refrigeration will cause a slightly higher energy demand in the size of 10%.

Concerning large built-in systems (e.g. like those in supermarkets), the entire contribution (e.g. CO_2 from the electricity production and emission of refrigerant) to the greenhouse effect will be less for systems using natural refrigerants, cf. calculation in enclosure 1 to the appendix. 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 app. 10 kg charge), the situation is different, as the energy demand of indirect cooling is still somewhat higher (app. 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 cooling will be more environmentally benign when these small commercial refrigeration systems are in question.

A comparison between direct refrigeration systems using R404A and indirect cooling with propane/brine has been made. The comparison is based on a small compact refrigeration system (10 kW for refrigeration and 5 kg of charge), but with 2 different leakage rates of 10% and 5%.

If the leakage rate is 10% p.a., the propane system presents the smallest contribution to the greenhouse effect.

If 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 cooling is estimated to be below the emission from a similar refrigeration system with indirect cooling.

3.3.3 Natural refrigerants for commercial refrigeration and alternative technologies

At present, centralised refrigeration systems are normally considered as the "best available practice" when focusing on low energy consumption and HFC refrigerants (R404A and R134a) are still mainly used in commercial refrigeration systems. However, CO_2, used directly or in hybrid systems (cascades) are becoming more and more commercially mature. Compared to ammonia (NH_3) and hydrocarbons (HC's, propane/ butane) CO_2 has the advantage of being neither toxic nor flammable, which makes the installation for CO_2 systems easier and cheaper. Ammonia has not been accepted in commercial refrigeration. The reasons are many, but the toxicity of the fluid and the unsuitability in relation to copper might be the main reasons. However, ammonia might be used as primary fluid in indirect systems in the future. The status is somewhat the same with HCs. In the case of HCs, it is mainly the flammability issue that matters and it seems that safety precautions are too expensive and complicated and therefore they form a barrier to this refrigerant. Nevertheless a lot of systems are installed at the moment, where HCs are used as primary refrigerant in indirect systems.

For the past year, a clearer picture has appeared regarding future technologies within commercial refrigeration. The trend is that natural refrigerants will "take over" from the HFCs within the next 3–5 years. Especially drivers such as taxes on refrigerants, restriction on charge size and bans have a major impact regarding solutions to be selected in the future. Already more than 150 systems with natural refrigerants have been installed in the Nordic countries and this tendency will continue. Now it is more a question about what kind of system will be preferred in the future.

Table 3.5: Refrigerants and type of systems

	Stand-alone	Condensing	Centralised systems		
			Direct	Indirect	Hybrids
HFC's	X	X	X	X	X
HCs	XX[1]				
CO_2 (transcritical)	XX[2]	XX[3]	XX[4]	XX[5]	
$CO_2/HC/NH_3$/R134a					XX[6]
HC/ NH_3				XX[7]	

Applications marked with XX are considered to be the most interesting applications operating with natural refrigerants.

Table 3.6: Description of systems working with natural fluids in the Nordic countries

Refrigerant	System	
	Numbers refer to numbers from table 3.5 above	No. unit
HC	[1] Hydrocarbon refrigerant is used in several plug-in-refrigerators and freezers with charges below 150 grams, according to section 3.2 in this report. This includes ice cream cabinets, bottle coolers and professional kitchen appliances.	Between 50,000 – 100,000
CO_2 Used as transcritical fluid	[2] Stand-lone: CO_2 is being examined as working fluid in bottle cooler, ice cream freezers etc. See section 3.2.	Prototype
	[3] Condensing unit: CO_2 is investigated and developed in Denmark. Units will be available from 2007.	Prototype
	[4] Direct: A few systems have been installed using CO_2 directly in supermarkets. Such systems have been installed in Norway, Sweden and Denmark.	~10
	[5] Indirect: The first systems entered the market early 2006. At least 4 manufacturers (2 in Sweden, 1 in Norway and 1 in Denmark) can deliver this kind of system.	~2
$CO_2/HC/NH_3$/ R134a	[6] Hybrids: Cascade systems are installed in all Nordic coutries. The systems work with CO_2 as low temperature refrigerant and propane, ammonia or R134a/ R404A as high temperature refrigerant. Different designs are available, but the basic technology is the same.	~120
HC/NH_3	[7] Indirect: Chillers with HC and ammonia are becoming more and more standardised. Many installers (~20) in the Nordic countries are capable of producing and installing chillers with these refrigerants. As heat transfer medium glycol or volatile CO_2 can be used.	~100

In Sweden, the company Bonus Energi (now a company in York Refrigeration) built around 400 refrigeration "chiller" systems with hydrocarbon refrigerants from 1996–2001. Most are used for air-conditioning, but several are installed in supermarkets. At the same time, a training scheme has been developed for refrigeration engineers to enable them to work with hydrocarbons in refrigeration systems. The production has now been moved to York Refrigeration in Denmark. The range of products has increased and the production has expanded. Products are sold in Denmark, Norway, Sweden, UK, Germany and New Zealand (Pachai, 2006).

In 2000, the first supermarket in Odense installed a hydrocarbon based refrigeration system with indirect cooling and another bigger system was soon after built with support from the Danish Environmental Protection Agency. Both were monitored and showed that the energy consumption is not bigger than for similar HFC systems. Other investigations show the same trends (Knudsen, 2005; Heerup, 2004).

3.3.4 Market penetration for natural refrigerants in supermarkets

In the Nordic countries there is an order of magnitude of 10,000 supermarkets, and most refrigeration takes place with centralised systems using direct, indirect or hybrid systems. In addition to this, there are approximately 10,000 very small supermarkets and their refrigeration utilises stand-alone or condensing units.

Previously, CFC or HCFC refrigerants such as R502, R22 and R12 were used. In recent years, systems have been converted for use of HFC based refrigerants like R134a or R404a. Systems built since the late 1990s are charged with HFC refrigerants. Since 1996, many systems in Denmark, Norway and Sweden have been designed to use natural refrigerants such as hydrocarbon or CO_2.

Hybrid systems with HC or HFC's have been investigated for many years. From 1995 to 2000 indirect systems and cascade system were investigated in Denmark (Christensen, 1999) and Sweden. CO_2 as a primary and secondary refrigerant at low and medium temperature was investigated in many projects. The systems in Denmark are the so-called cascade systems where CO_2 works at a relatively low pressure (40 bars). The CO_2 refrigerant is cooled and condensed in the condenser by a high-temperature refrigeration system working with ammonia, propane or a HFC refrigerant. These systems are now used as "state-of-the-art technology" in Denmark and are close to becoming commercially mature. In Sweden many indirect systems have been built with propane/ HFC as primary refrigerant and CO_2 as secondary volatile fluid. These systems are now considered to be commercially mature. However, in Norway no HC systems are installed in supermarkets (Haukaas, 2006).

Transcritical CO_2 refrigeration systems are also being implemented in supermarkets. Some of these systems are however still on prototype level.

In some supermarkets stand-alone/ plug-in units are used. Here the refrigeration system is integrated in the cabinet. The small stand-alone units are treated in section 3.2, and hydrocarbons or CO_2 might be used as substitute for HFC.

For bigger stand-alone units it might be more difficult to substitute HFC, if the charge of hydrocarbons is bigger than 150 grams. Some of the bigger plug-in units have about 2 kW in cooling capacity and the HFC refrigerant charge might be above 0.5 kg. Such systems are compact and hermetically sealed, and the leakage rate is small (less than 5% per year). Here CO_2 might be an alternative in the future.

3.3.5 Experiences with natural refrigerants in commercial refrigeration

Alternatives exist for bigger refrigeration systems such as supermarket refrigeration plants and other big refrigeration plants. Centralised cascade systems for bigger installations seem to be very efficient both energy-wise and economically. Experiences from Denmark show that the energy consumption for systems using natural refrigerants is at the same level as for optimised centralised systems using HFC refrigerants (direct use). Furthermore the investment is about 0–10% higher, but due to refrigerant taxes that is outbalanced in the lifetime of the system (Christensen, 2003).

However, things become more complicated when we talk about small commercial refrigeration systems for small shops, hotels and restaurants. The border between (for economical benefiticiallity and minimised energy consumption) is about 20 kW cooling capacity. It is assumed that smaller centralised systems will use transcritical CO_2 in the future. These systems are simpler than the cascade systems, but adjusting the energy consumption will be a challenge. Studies show 5–10% higher energy consumption compared to HFC systems, but in colder climates this can be improved (Girotto et al 2003). Investment is expected to be in the same level as best available technology of today.

Bigger stand-alone and condensing units for commercial refrigeration working with natural refrigerants are still not available to the market, but prototypes are investigated.

A TEWI analysis shows that the total contribution to global warming is bigger for HFC systems, even if the alternative system consumes 10% more energy (see appendix B). However, if the refrigeration system is a compact system with a small charge, the leakage rate is also small (about 5% p.a.) and if alternatives (hydrocarbons) can only be used by indirect refrigeration, the situation differs. In this case, the HFC system will have less impact to global warming.

The latter case will appear if:

- Indirect cooling is required for non-HFC cooling
- The refrigeration system is compact with small refrigerant charge and small leakage (5% or less).

This situation will appear mostly for small units with a cooling capacity less than 20 kW and a refrigerant charge less than 10 kg.

3.4 Air-conditioning

As mentioned in the previous section, there is not always a clear distinction between commercial refrigeration systems and air-conditioning systems.

In many office buildings and hospitals, chillers are installed for distributing cold water in the buildings. The air in the individual rooms is cooled in heat exchangers by means of the cold water. Various refrigeration systems are available for this purpose, and previously CFCs, HCFCs and HFCs were used. Many systems based on HFC refrigerants are still being sold. In the past few years, however, a large number of ammonia-based refrigeration systems have been installed for this purpose and recently a number of chillers with hydrocarbons and CO_2 have also been installed.

Ammonia

In the first Nordic report (Pedersen, 2000), hundreds of ammonia based chillers in the Nordic countries were listed. The list referred to includes systems installed in the period from 1990 to 1998.

Because of data confidentiality it was not possible to update the reference lists in the next Nordic report that was published in 2001, but according to the biggest installer in the Nordic countries (York Refrigeration) many new ammonia chillers have been installed in 1999 and 2000 (Pedersen, 2001). This trend in installation of ammonia chillers has continued after the second Nordic report, but there are slightly fewer new systems.

York Refrigeration, which is a major manufacturer of chillers offers a wide range of ammonia chillers (air and liquid cooled plants) in the range from 42 to 161 kW cooling capacity (Pachai, 2006).

Hydrocarbon

In the first Nordic report, a list of hydrocarbon chillers was compiled. The list includes systems installed from 1996 to 1998.

Because of data confidentiality it has not been possible to update the reference list, but York Refrigeration informed that between 400 and 500 hydrocarbon chillers were installed up to 2001. Most were installed in Sweden.

Since that an unknown number of hydrocarbon chillers have been installed in the Nordic Countries. The trend is that this has slown down a little (Pachai, 2006).

York Refrigeration offers a wide range of air and liquid cooled chillers in the range from 5 kW to 281 kW cooling capacity. The refrigerant is R1270 (Pachai, 2006).

Bundgaard Køleteknik offers liquid cooled chillers with R290 in the range from 50 kW to 440 kW cooling capacity and air cooled chillers with R290 in the range from 15 kW to 300 kW cooling capacity. Bundgaard has a reference list with 17 plants installed from 2002 to 2006 (15 in Denmark and 2 in Sweden) (Bundgaard, 2006).

Absorption

There are also a few systems that use absorption refrigeration (often lithium-bromide water absorption refrigeration systems). One example is the use of cooling water from an incineration plant in Tronheim, Norway. This “cooling water” is warm and is running a huge absorption refrigeration plant at the University Hospital in Tronheim.

Energy efficiency

The energy efficiency is a very important issue for chillers. Since the leakage rate is relatively small the energy use is the most important factor for the environmental impact. Danish Technological Institut has carried out a small analysis of the energy efficiency of chillers with different refrigerants (HFCs, HCs and ammonia).

A calculation tool “Coolpack”, developed at Danish Technical University has been used to analyse the energy efficiency. Coolpack is used by thousands of refrigeration engineers around the world and contains thermodynamic properties for different refrigerants and algorithms for calculation of refrigeration systems. The calculations have been carried out for two different situations:

a) Evaporation temperature -10 ^{0}C and condensation temperature +35 ^{0}C
b) Evaporation temperature +5 ^{0}C and condensation temperature +45 ^{0}C

For the compression cycle, the isentropic efficiency is set to 0.60 and heat loss from the compressor is set to zero.

Table 3.7: Comparison of the COP (Coefficient of Performance) for refrigeration systems with different refrigerants. COP expresses the energy efficiency of refrigeration systems, and the higher the value is the more energy efficient is the cooling system.

Refrigerant	COP, Situation a) T_0=-10^{0}C, T_C=+35^{0}C	COP; Situation b) T_0=+5^{0}C, T_C=+45^{0}C
R134a	2.78	3.30
R404A	2.53	2.94
R407C	2.71	3.15
R410A	2.65	3.05
R717 (ammonia)	2.82	3.41
R290 (propane)	2.74	3.25
R600a (isobutane)	2.80	3.36
R1270 (propylene)	2.73	3.21

Note: The refrigerants with mixtures (R404A, R407C and R410A) have temperature glides by evaporation. R407C has a significant glide, which make it difficult to make an explicit comparison with refrigerants without glide. No pressure drop in condenser and evaporator and no internal heat exchange.

Table 3.7 shows a varity in the energy efficiency of about 11% in situation a) and 15% in situation b). In both situations ammonia (R717) shows the best efficiency with isobutane in the second place. The distance to R134a is not substantial.

The comparison shows that R410A is inferior in terms of theoretical efficiency. Nevertheless, a great share of the marked is turning towards R410A in smaller AC applications. The main advantage of R410A is the volumetric efficiency that results in smaller components and better price competitiveness.

Financial barriers

The same considerations apply as in the comparison between ammonia or hydrocarbon based systems and HFC based systems.

Today, systems based on ammonia or hydrocarbons cost 10–40% more than HFC based systems. The difference is expected to decrease slightly when hydrocarbon based systems gain more ground.

Large ammonia based systems (>150 kW) are competitive compared to HFC-systems.

Emission to surrounding environment/accumulation in scrapped products

The systems in question are compact, factory-made systems with a relatively small charge and limited emission. The leakage rate of Norwegian chillers is 5 – 8% with a slightly declining trend (Haukaas, 2006).

With a lifetime of 15 to 20 years, there is some leakage of refrigerant. A large part of the refrigerant will remain in the system when it is scrapped. It is assumed that this refrigerant will be collected and reused in other systems. However, a small part of it will be emitted when the refrigeration system is opened during the scrapping process.

Situation with respect to alternative technology

Alternative technology with natural refrigerants already exists and has been adopted in some applications. In the Nordic countries, York (Bonus Energi AB) has been a key player in the development of HC technology. Today, there are several companies supplying AC systems with HC technology. Kylma in Sweden has a series of systems more or less identical to the York systems. Bundgaard in Denmark is also supplying the market with factory made systems.

Small air-conditioning systems

As far as we know, no production of small air-conditioning systems takes place in the Nordic countries. Although the climate in the Nordic countries does not necessitate air- conditioning, there is a growing tendency to set up small systems – in most cases, systems made in Asia. The refrigerant is normally HFC based.

The systems are often combined A/C and heat pump systems (air to air), where it is possible to switch mode. Many of the small air to air heat pumps sold in the Nordic countries can also be switched to A/C-mode.

There are hydrocarbon based systems on the market. De Longi in Italy is marketing small systems with propane as the refrigerant. In the UK market at least two split systems are available: PAC FX400eco (3.5 kW coling capacity) and PAC CS600eco (5 kW cooling capacity).

The refrigerant charge is probably greater than 150 grams.

There is no information about installation of such appliances in the Nordic Countries.

Dehumidifiers

A great number of small dehumidifiers for domestic use have been installed in the Nordic countries. Earlier, Vestfrost (Vesttherm) produced such appliances, but this has ceased now and the products are imported from Asia. The refrigerant used is R134a.

A production of professional dehumidifiers takes place at Danterm A/S. The refrigerant is of the HFC type, but CO_2 might be used in the future.

3.5 Industrial refrigeration systems

Normally, industrial refrigeration systems are very large systems. They are used for process refrigeration and cold storage within the food industry and in the chemical/ biochemical industry.

Ammonia

In the Nordic countries, traditional ammonia refrigeration systems are used for these purposes. To a great extent all dairies, slaughterhouses, breweries and fishery companies have ammonia refrigeration systems. There is a 100-year-old tradition for this in the Nordic countries.

However, many industrial refrigeration systems use HFC refrigerants. Many of them could just as well be ammonia-based refrigeration systems purchased for the purpose. (However, in most existing systems it is not possible to switch from e.g. HFC to ammonia).

The situation in the case of small industrial systems is slightly different. Here, extensive use is made of HFC based refrigerants in the same way as in commercial refrigeration systems and in connection with air-conditioning.

There is a growing trend towards the use of indirect refrigeration in order to reduce the refrigerant charge and avoid ammonia in work areas etc.

CO_2

The installation of industrial refrigeration plants with CO_2 for low temperature purposes in cascade system is growing rapidly. York Refrigeration has manufactured 74 plants with a total cooling capacity of 33.4 MW in 16 different countries. From this 20 plants have been installed in Sweden, 5 plants in Norway and 2 plants in Denmark. An indoor ski run with CO_2-system at -15 ^{0}C has been built in Holland. A process room has also been built in Holland with CO_2 at -2 ^{0}C. This indicates, that CO_2 can be used at many different temperature levels and still be competitive (Pachai, 2006).

Financial barriers

There are normally no financial barriers to using ammonia as refrigerant in large (>150 kW) industrial refrigeration systems. In the case of small systems, the situation corresponds to that for commercial refrigeration systems or air-conditioning systems.

Situation with respect to alternative technology

Alternative technology using natural refrigerants is available, it has been widely implemented and is nowadays standard for bigger industrial systems.

3.5 Mobile refrigeration systems

Mobile refrigeration systems should be understood to cover refrigeration systems installed in cars, trains, aircrafts, ships and containers.

Air-conditioning systems in cars

Previously, R12 was used for this purpose, but in recent years R134a has been used.

In the Nordic countries, cars are manufactured in Sweden and Finland. Until 5 years ago, most cars sold in the Nordic countries did not have an air-conditioning system. However, more and more cars are now being fitted with air conditioning, and air-conditioning has become standard.

A number of projects are in progress in which CO_2 is being tested as a refrigerant for these systems. Demonstration systems have been fitted to all major brands of cars, including Toyota, Mercedes Benz, Ford, Renault, Volksvagen, Audi and BMW. SINTEF in Norway is involved in this work.

It should be mentioned that in some countries hydrocarbons are used (by DIY – do it youself) in car air-conditioning systems. This is for example the case in Australia and the US. The refrigerant is a mixture of propane and butane that can be used as drop-in substitute for R12 in existing systems.

The risk of fire and/or explosion in connection with the use of hydrocarbons in car air- conditioning systems has been debated. Hydrocarbons could be a natural choice since several kilos of hydrocarbons in the form of petrol, diesel oil or gas are already present in the car. However, it is important that the system is designed so an explosive mixture cannot occur inside the car.

The EU directive 2006/40/EF adopted in May 2006, put a ban on the use of refrigerants in MACs with a GWP higher that 150 and from 2011 there will be a ban on refrigerants with a GWP higher than 150 in car air-conditioning systems in new types of cars and from 2017 in all new cars.

Barriers: Natural refrigerants for air-conditioning in cars are on their way.

HFC consumption: There is no specific data on consumption for this application, but the typical refrigerant charge is 1 kg (0.7 – 1.2 kg) for a car, 1.5 kg for a truck and 5 kg for a bus. New European cars have a typical charge of 0.7 to 1.0 kg. (Oinenen, 2000).

Emission to the surroundings/accumulation in scrapped products: There is a relatively large leakage of refrigerant from mobile air conditioning systems – in the order of 20–30% of the charge per year. The leakage used to be even bigger. The leakage is due to seals and leaky hoses but has been reduced in recent years by means of tighter hoses. The leakage rate for new systems is now 10–20% per year.

The relatively large leakage amount means that almost all the refrigerant used will be emitted to the atmosphere during the lifetime of the vehicle. The remainder should be collected when the vehicle is scrapped.

Situation with respect to alternative technology: Alternative technology is being developed.

Integral reefer containers

The company Mærsk/Sealand Line is the world’s leading carrier of refrigerated goods and has more than 100,000 reefer containers in traffic on a global level. Previously, integral reefer containers were equipped with a R12 refrigeration system, and some old containers still use this equipment. Many new containers that were “born” with R12 have since then been converted for the use of R134a.

Since 1993, all new refrigeration systems have been installed with R134a as refrigerant. Mærsk Container Industry has a considerable production of integral reefer containers in Denmark and this production will cease ultimo 2006. CO_2 has been suggested as a refrigerant in reefer containers, and a development project is finalised with interesting results. But it is unsure what will happen.

Emission to the surroundings/accumulation in scrapped products: There is a relatively large leakage from integral reefer containers because of the violent actions these are subject to in ports and at sea. The leakage rate is of the same order of magnitude as from air-conditioning systems in cars – probably 20 – 30% of the charge per year. Therefore, most of the refrigerant used for this purpose will be emitted to the atmosphere. When a container is scrapped, the remaining refrigerant will be collected, cleaned and reused in another container.

Ships

HFC refrigerant is standard on ships today. There is a large leakage of refrigerant from these ships because of violent physical actions at sea. Experts estimate a substantial annual leakage rate for reefer ships.

Large, new or retrofitted ships use ammonia as refrigerant, but ammonia cannot be used in old ships.

In Iceland and Norway, about 20–30 fishing vessels have been built/rebuilt with an ammonia based refrigeration system.

In Norway, at least two large fishing vessels have CO_2/ammonia cascade systems (Haukaas, 2006).

Air-conditioning in aircrafts

For many years, cold-air refrigeration systems have been used to cool passenger cabins in ordinary airplanes. A simple joule process is used, in which air is compressed and cooled through heat exchange with the surroundings. Afterwards, the air is expanded in a turbine, whereby it becomes cold. The process is not particularly energy efficient but is used in aircrafts because of the lightness of the components.

Air-conditioning in trains

R134a is normally used as the refrigerant in air-conditioning systems in trains. In Germany, however, a cold-air refrigeration system has been developed for trains in which, as in aircrafts, air is used as refrigerant. The project has been successful and many units have been made for ICE trains. CO_2 systems might be interesting for this purpose.

3.7 Heat pumps

The function of heat pumps is similar to that of refrigeration systems, as heat is collected from a source (e.g. fresh air, soil, stable air, process water, etc.). At a higher temperature this heat is rejected to a heat carrier – for example, a hydronic heating system.

The following main types of heat pumps are used in the Nordic countries: domestic heat pumps, industrial heat pumps and large heat pumps for district heating systems. Domestic heat pumps are used for space heating and for heating of water for domestic use in single family homes or in apartment buildings.

Domestic heat pumps

Sweden has a large market for domestic heat pumps. Swedish manufacturers expect 100,000 heat pumps will be installed in 2006, and nearly all new houses will be equipped with heat pumps. A total of more than 500,000 heat pumps are installed in Sweden (Nowacki, 2006).

In Norway, 55,000 heat pumps were installed in 2003. Since then, the trend is a little lower (Haukaas, 2006).

In Denmark, 8,000 heat pumps were installed in 2005, and the total number is beyond 55,000 (Poulsen, 2006).

The figures from Finland and Iceland are unknown.

The domestic heat pumps can be separated into 5 catagories:

- Air to Air (Heat source: Outside air / Heat sink: inside air)
- Air to water (Heat source: Outside air/ Heat sink: hydronic system with water)
- Liquid to water (Heat surce: heat from ground, lake or bedrock/ Heat sink: hydronic system with water)
- Exhaust air heat pumps: (Heat source: exhaust air from the house/ Heat sink: hydronic system with water)
- Sanitary hot water heat pump: (Heat source: mostly exhaust air from house/ Heat sink: Tap water for local use in the building).

In Sweden there are 4 major manufacturers of heat pumps: Nibe AB, IVT AB, CTC AB and Termia AB. They produce about 90% of the heat pumps produced in Sweden. The major part is sold in Sweden, but a large scale export also takes place. Small air to air heat pumps are imported and installed in such a way, that some of them bypass the statistics collection (Nowacki, 2006).

The most important types are liquid to water and exhaust air heat pumps. Liquid to water heat pumps are mostly produced with R407C as refrigerant. A few units are produced with propane (R290). Danfoss Compressors offer propane compressors for small-sized heat pumps.

Exhaust air heat pumps are often produced with propane (R290) as refrigerant, though some have chosen R134a, many are installed in Sweden. The charge is about 400 grams of R290.

Most air to air heat pumps are imported from Asia. They use HFCs as refrigerant (preferably R410A). This type of heat pump can normally also be switched to A/C-mode.

In Denmark, Vestterm (Nilan) produces tap water heat pumps. So far, R134a has been used, but the company plans to change to CO_2 as refrigerant.

CO_2 refrigerant can be superior in heat pumps, because the high temperatures of the hot gas can be exploited in connection with heating for high temperature purposes like hot tap water.

Industrial heat pumps and large heat pumps for district heating systems in Sweden were often made by Siemens (former ABB) or Axima (former Sultzer). York and other companies e.g. use ammonia or propane as refrigerant. CO_2 is also interesting for large heat pumps and the company Advansor is offering large CO_2 heat pumps.

Financial barriers

It is possible to make domestic heat pumps for propane (liquid/water or air/water) without major additional costs. Experience indicates that compact heat pumps have to be equipped with a fan for extraction of air from an enclosure to the surroundings. However connection boxes are sometimes filled with epoxy in order to avoid sparks. The other components are the same as for heat pumps for synthetic refrigerants. When the necessary infrastructure and service is in place, the additional cost of propane heat pumps is expected to be modest.

As mentioned, CO_2 is very interesting for heat pumps, and some manufacturers are going for offering heat pumps with this refrigerant. The current price for CO_2 heat pumps in the small and medium sized range is significantly higher than for HFC systems. This is due to a lack of mass produced components (compressors) for the time being. However, Danfoss Compressors plans to offer mass produced compressors for transcritical CO_2 from 2007 and also Dorin plans to deliver semihermetic CO_2 compressors in the future. In the long term, it should be possible to deliver CO_2 heat pumps with minimal additional costs.

HFC consumption

There is a consumption of HFC for this application. A typical liquid/water heat pump is charged with 2.5 kg HFC, a tap water heat pump with 0.8 kg HFC. The systems are hermetic and the leakage rate is small. The actual consumption is however not known.

Emission to surrounding environment/accumulation in scrapped products

The leakage from heat pumps has become quite small, a few percent per year, due to hermetic systems, compact refrigeration systems and good quality. When a heat pump is scrapped, the remaining refrigerant should be collected and reused or incinerated.

Situation with respect to alternative technology

Heat pumps that use natural refrigerants have been developed, but a lack of compressors and other components approved by the manufacturer for hydrocarbons have practically limited it to the use of hydrocarbons in exhaust air heat pumps.

Many manufacturers of heat pumps are going for CO_2 as refrigerant, because it is not inflammable, and some manufacturers have experienced problems with the oil in propane heat pumps.

3.8 Cryogenic systems

Cryogenic systems have a relatively small area of application. They are used to cool laboratory specimens and other small specimens to low temperatures.

The equipment normally consists of a cascade system; the high temperature stage can be a R507 system. During the high temperature stage of the process, temperatures down to approximately -50 ^{0}C are reached. During the low temperature stage, hydrocarbons are used as refrigerants – either ethane (R170) down to approximately -80 to -90 ^{0}C or ethene (R1150) down to approximately -100 to -120 ^{0}C.

Some foreign manufacturers use R23 or R508 in the low temperature stage. These refrigerants have very high GWP values.

York Refrigeration has supplied cascade systems with R1270 on the high temperature stage and R170 on the low temperature stage for cooling blood plasma at -70 ^{0}C (Pachai, 2006).

There is a production of small plug-in units with one-stage coling systems, cooling down to -80 ^{0}C. The refrigerant is a mixture of at least three different substances, of which one or more are potent greenhouse gases. The refrigerant mixture is delivered by the customer of the products. Danish Technological Institute has information about prototypes with refrigerant mixtures of hydrocarbons used for the same purpose.

3.9 Polyurethane insulating foam

Until the beginning of the 1990s, large amounts of CFC-11 were used as blowing agent for rigid and flexible polyurethane foams. Special features of CFC-11 includes good cooling capacity to to reduce the foam exotherm and a low thermal conductivity, hence rigid polyurethane foam containing CFC-11 in the closed cells has a excellent heat insulating capacity – twice as effective as mineral wool.

Refrigerators and freezers

CFCs have been banned for this application and alternative technologies have been developed. As will be seen from section 3.1, the insulation in most refrigerators and freezers in Europe are being blown with cyclopentane – often in combination with other hydrocarbons (HCs). Although not as efficient as CFC, HCs provide good insulating capacity.

For further information concerning refrigerators and freezers, readers are referred to section 3.1.

District heating pipes

A large fraction of the world's district heating pipes are manufactured in Denmark by Logstor AS (Former Løgstør Rør and I C Møller) and Dansk Rørfabrik AS (Star Pipes).

App. 820 tonnes of CFC-11 were used for this application (1986). During a period, HCFC-141b and HCFC-142b/HCFC-22 and HFC-134a were used, but today manufacturers exclusively use cyclopentane for this purpose. No ozone-depleting substances or any potent greenhouse gases are used for district heating pipes.

In Sweden, district heating pipes are produced by Power Pipe and Logstor using cyclopentane as the blowing agent.

In Finland, district heating pipes are made by KWH Tech Ab (Vaasa), Logstor (Saarijärvi) and ArvoPutki Oy (Mynämäki). All are using hydrocarbons as blowing agents (Ungermand, 2006).

In Iceland, district heating pipes are made by Set h.f. (Selfoss), using hydrocarbons as the blowing agent in the production and CO_2 for in-situ joint connection of the pipes.

Insulating panels

In all five Nordic countries, insulating sandwich panels are made for cold stores and other applications. The panels are sandwich structures that can be assembled to form complete buildings. The sandwich structure consists of polyurethane foam core with metal facings.

CFC-11 was used for this purpose. In Denmark, HCFCs have been used extensively for a period to blow the polyurethane foam. This was banned at the end of 2001. There is also a small production of CO_2 blown panels. The annual consumption of CFC-11 for insulating panels in Denmark used to be app. 140 tonnes. The manufacturers have now changed to hydrocarbons and/or CO_2.

In Sweden, the use of HCFC blown panels is prohibited and CO_2 is used instead. According to Kindbom, Eugensson and Persson (2001), HFC is not used for any production of polyurethane foam in Sweden, except for a small usage for jointing foam (see section 3.10).

In Finland, Huurre Group Oy (Ylöjärvi) and Henkel Makroflex Oy (Oitti) have produced sandwich panels with hydrocarbons since 1994. HFC is still used by one company that makes insulating panels and boards for ordinary homes. These panels are covered with flexible and permeable foil on both sides (Toikka, 2006).

Some small Finnish producers used HCFC until January 2000, when it was banned. Since then, some smaller producers exit the business, others mainly used HFCs as substitutes until recent years whereupon they have mostly replaced HFCs with CO_2 (Toikka, 2006).

Norway has a production of insulating panels, including a special variant with plasterboard (multi-elements). In Norway, HCFC was used as the blowing agent, but Norwegian producers have converted to hydrocarbons (Vig, 2006).

Barriers to the introduction of alternative technology: CO_2 blown panels have a poorer insulating capacity than CFC/HCFC/HFC blown panels. This difference increases with time because of diffusion of CO_2 out of the foam, and it is replaced by air. To prevent long-term shrinkage, CO_2 blown foam are produced with a minimum density of 45 kg/m^3, which is up to 30% above other foam types. This causes additional costs for raw material (Ungermand, 2006).

Hydrocarbons are being used, but that calls for investments in handling of flammable liquids and training of personnel. Once that investment has been made, the production costs will be approximately the same as before.

Situation with respect to alternative technology: Alternative technology has been developed and alternative technology with hydrocarbons has been partially implemented.

Integral reefer containers

There is a production of integral reefer containers in Denmark. HCFC was used for blowing the polyurethane foam insulation. The production has now changed to hydrocarbons (Ungermand, 2006).

Rigid block foam (rigid slab stock)

Many small users of foam insulation buy rigid block foam, which they then cut to the size required for their specific purpose. The foam is usually only a small part of a complex machine.

Norway has one manufacturer of rigid block foam, which has switched to pentane as blowing agent (Ungermand, 2006).

Denmark has two manufacturers of rigid block foam and they have switched to n-pentane and isopentane as blowing agents.

Other insulating foam

Some companies use a small quantity of polyurethane foam for insulating purposes. Many of these use CO_2 blown foam or rigid block foam purchased pre-blown. Others use foam blown with HFC-134a blowing agents.

CO_2 results in a slightly poorer insulating capacity, in many cases this can be accepted. If good insulating capacity is essential, polyurethane foam with hydrocarbons can be used instead. That will necessitate investment in fire-protection measures and training of personnel. When those investments have been made, the price of the material will be approximately as before.

If CO_2 is used, the foam density must be increased by up to 30%, which will cause additional expenses for raw materials.

3.10 Jointing foam (one component PU-foam)

Jointing foam is used when fitting doors and windows in houses because the foam insulates. In the Nordic countries, jointing foam is made in Finland.

One component foam is used by professional craftsmen and to a smaller extent by DIY enthusiasts in order to mount doors and windows and to fill and insulate different kinds of open joints and crevices. One single standardised 750 ml can contains between 180 and 240 ml (130–180 g) propellant gas. Unlike other rigid PU foam products the propellant does not serve as an insulation agent, but as a blowing agent, viscosity reducer, processing aid and expels the foam from the can.

The propellants are either blends of HFCs (i.e. HFC-134a, HFC-152a) and flammable gases (i.e. propane, n-butane, iso-butane and dimethylether) or flammable gases without HFCs (Melis, 2006).

Nordic producers were out early with an alternative solution to CFC, HCFC and HFCs, in which propane and butane were used as propellants. This system has been used in the Nordic countries since 1987, and practically only systems operating on hydrocarbons have been used in this market. Recently, HFC blown foam has been used for special purposes for use in small rooms.

Henkel Makroflex Oy in Finland makes one component jointing foam, using propane/ butane as propellant. Also HFC based foam is produced.

Barriers

The HFC content per can has steadily decreased and more than halved within 10 years. There are two main reasons. Firstly, the higher cost pressure that favours halogen-free i.e. flammable propellants despite of relatively high one-time investment for explosions protection of filling equipment as well as of storage tanks. Secondly, it has been proved that the safety concerns have been exaggerated. They were expressed by the voluntary rule to limit the content of inflammable gases to max. 50 g/750 ml standard can. This rule was not only a constant controversial subject among most of the European fillers. The rule was being broken repeatedly so that it was changed into a 100 g rule and at a later stage it was even completely abandoned (Melis, 2006).

At the beginning of 2006, the Council of Ministers and the EU Parliament reached an agreement at the first conciliation meeting on the two new EU laws to curb releases of the fluorinated gases covered by the Kyoto protocol.

The first piece of legislation is the regulation that introduces containment and handling rules, labelling provisions and a ban of HFCs in One Component Foam applications, except when required to meet national safety standards (Melis, 2006).

Accidents with hydrocarbon based cans have occurred in cases in which safety precautions have not been observed and cases in which the cans have been used in small rooms and a match or a lighter has been lit and has ignited a fire. However, this danger also exists for cans with HFC propellants, as they also are flammable due to the content of hydrocarbon and HFC-152a.

Accidents are more likely to occur when using hydrocarbons instead of HFC-152a due to the much lower explosion limits of propane/butane.

There are app. 50 manufacturers worldwide, and competition is tough. One Nordic manufacturer can therefore not decide the technological trend on its own, but may make cans with HFC propellants for other countries than the Nordic countries.

Cans with pure hydrocarbon propellants are considerably cheaper than cans with HFC substances. The propellants have different properties so a comparison based solely on price is not possible. The properties of the jointing foam differ with the propellant.

HFC consumption

The consumption at the Finnish manufacturer is known, but confidential.

Emission to the surroundings/accumulation in scrapped products

The propellant escapes from the foam upon application, except for small residues that remain for max. one year in the hardened foam (Melis, 2006).

Situation with respect to alternative technology

Alternative technology has been implemented in the Nordic countries. In special cases (when used in small rooms) HFC foam might be used. Another reason for using HFC is that it can be applied at lower temperatures compared to products based on hydrocarbons.

3.11 Flexible polyurethane foam

Flexible polyurethane foam is used for furniture, mattresses and automotive applications. The material is manufactured in all of the Nordic countries except for Iceland.

CFC-11 and later HCFCs have been the traditional propellants, particularly for soft, lightweight qualities for the furniture industry.

The heavy qualities are traditionally blown with CO_2.

The only country were HFCs have been used for this purpose is Denmark. A mixture of HFC-134a and HFC-152a was used for this purpose (Solkane XG87). The use of HFCs stopped ultimo 2004 and CO_2 is now being used exclusively (Ungermand, 2006).

In Norway and Sweden CO_2 is used.

In Finland, Espe Oy (Kouvola) and Suomen Superlon Oy (Rauma) make flexible polyurethane foam. They have been using CO_2 for this purpose since 1989 (Pullola, 1998).

In some countries (also within the EU) methylenchloride has been used for production of the material. That would be inconceivable in the Nordic countries because of health and safety reasons.

Slabstock foamers in Sweden and Finland have made a volunteer agreement, not to produce and market foams below 23 kg/m^3. This initiative eliminated most of the need for a physical blowing agent (Ungermand, 2006).

Situation with respect to alternative technology

Alternative technology has been implemented.

3.12 XPS-foam

XPS-foam (Extruded Polystyrene Foam) is produced in Sweden, Norway and Finland. XPS-foam has a number of applications: thermal insulation in buildings, thermal insulation under buildings and roads and in sandwich constructions like cold storage transport.

XPS-foam is a relatively expensive type of insulation and is used where it is needed.

In the 1980s, XPS-foam was blown with CFC12 and in the 1990s HCFC was used.

In Norway Jackon A/S is using HFCs for blowing the foam. Due to the high tax on HFCs, Jackon is in a process of stopping the use of HFC and changing to a mixture of hydrocarbons and CO_2 (Andersen, 2006)

In Sweden, Nordic Foam A/S uses HFCs for blowing the foam. Nordic Foam is owned by Jackon, Norway and the blowing agents will be changed to hydrocarbon and CO2 like at the Norwegian production facility (Andersen, 2006). The other production facility in Sweden is Dow, which is using CO_2.

In Finland, Finnfoam is carrying out production with CO_2. The company also has the ability to produce with HFC and used some quantity of HFC in 2004 (Toikka, 2006).

Barriers

The insulation properties of CO_2 blown foam is poorer compared to HFC or HCFC foam.

BASF (which is only producing with CO_2 and some etanol) argues that the difference is small ("…the thermal conductivity is only insignificantly higher than those of HFC foamed XPS") for normal types of insulation panels (thickness smaller than 80 mm) (Boy, 2001).

The technical properties of both types of foam are identical, except for thermal conductivity.

HFC consumption

No figures are available (due to confidentiality) at present.

Emission to the surroundings

Some HFC will escape to the surroundings during production.
HFC will slowly diffuse out of the foam. Half life of HFC-134a is about 19 years for a 50 mm XPS board (Boy, 2001).

Situation with respect to alternative technology

Alternative technology has been developed and partially implemented in the Nordic countries.

3.13 Extinguishants

In connection with the global phase-out of Halon, a number of chemical substitutes have appeared, including one that is based on HFC-227 (e.g. Great Lakes FM-200). These substances are marketed rather intensively in many countries round the world.

In the Nordic countries, some use is made of HFC-227 ("FM-200") as well as a mixture of HFC-134a, HFC-125 and CO_2 ("Halotron").

In Denmark, however, the use of halogenated hydrocarbons for fire-fighting on land is banned.

Enterprises have developed impressive alternative technologies for fire-fighting – Inergen, for example, which has been developed by Dansk FireEater. Inergen consists of inert gases (which do not react chemically), i.e. argon, nitrogen and some CO_2. Inergen can be used for total flooding systems in computer rooms, control rooms, power stations, engine rooms, etc.

Ginge-Kerr, Danmark A/S has a similar technology called Argonite, which consists of argon and nitrogen. This firm has also developed a water mist technology.

The technology of using inert gases for fire-extinguishing purposes has become a remarkable success – also internationally. Foreign multinationals, such as Wormald, are marketing Inergen.

There are also other alternatives for chemical extinguishants – CO_2 or foam extinguishers in machine-rooms in ships, better detectors combined with manual extinguishers, etc. It is beyond the scope of this report to go into every detail. This entire area has been described in detail in a report published by the Danish Environmental Protection Agency in 1995: Environmental Report No. 312: Going towards Natural Extinguishants, Experience from Danish Industry.

Barriers

There are no general financial barriers to using alternative technologies. According to Haukås et al., the price is the same as for HFC technology. There can be some applications for which there are no alternatives to chemical extinguishants – for example on board aircrafts and for military purposes, for which Halon is still used.

HFC consumption

HFC consumption for fire-extinguishing purposes in the Nordic countries is as follows:
Finland: app. 1.5 tonnes (2004).
At present no figures from other countries are available.

Emission to the surroundings/accumulation in scrapped products

Initially, HFCs remain in the gas cylinders. Some will, however, be emitted to the atmosphere through leakage and accidental activation and in connection with fires. Emission from Halon systems is estimated to be around 15% of the charge per year. Suppliers of HFC based systems claim that there is less emission in connection with new modern equipment (5 – 10% per year) and possibly even smaller emission rates can be reached in the future.

Situation with respect to alternative technology

Alternative technology has been developed and partially implemented in the Nordic countries.

3.14 Aerosol cans

In some of the Nordic countries (including Denmark and Iceland), the use of HFCs in aerosol cans is banned, except in the case of medical applications (MDI).

Medical sprays

CFC-11 and CFC-12 have been used as propellants in medical sprays and especially in asthma sprays.

Alternative products have been available for many years, for instance self-inhaled asthma powder. Astra in Sweden has developed such a product, called “turbohaler”. This and similar products have a very large share of the market in Sweden and presumably also in Denmark. However, not all asthma patients are able to inhale them themselves.

Asthma sprays with HFC substances as propellant have been developed and are now standard in MDI (Metered Dose Inhalers).

Barriers to use of alternative technology: There can be barriers of a medical nature, such as weak lungs. The powder product is more expensive than the HFC based metered dose inhalers.

HFC consumption: As far as is known, there is no production of asthma sprays in the Nordic countries, but consumption exists.

Emission to the surroundings/accumulation in scrapped products: All HFC is emitted to the surroundings during the use of asthma sprays.

Situation with respect to alternative technology: Alternative products such as powder preparations are on the market and are used by a large number of patients. But this product cannot be used by all patients. At present there is no alternative propellant for MDIs.

Foghorns

Foghorns with HFC-134a as propellant are available. The horn is an aerosol can with a plastic horn that emits a loud noise.

It is believed that foghorns are mainly used by spectators at football matches, but they are also used on leisure crafts to warn other boats.

Non-HFC alternatives are available. Several different types are available. In one type, isobutane is used as the propellant. Another type uses compressed air and can be recharged at petrol stations or by means of a hand pump. Foghorns operated by means of an electric compressor are also available. Finally, manually operated foghorns that are blown by mouth or activated by means of a rubber ball are also available.

Foghorns with HFC are banned in Denmark.

Barriers to use of alternative technology: Foghorns with hydrocarbons can be used if there is no naked flame nearby. They should not be used in closed rooms or where there may otherwise be a risk of fire. Hydrocarbons are deemed to be cheaper than HFC based foghorns. Alternatives using compressed air can be used anywhere.

HFC consumption: Presumably there is no production in the Nordic countries. Import figures are not available.

Emission to the surroundings/accumulation in scrapped products: All HFC is emitted to the surroundings during use of foghorns.

Situation with respect to alternative technology: Alternative products are available in the Nordic countries.

Tear Gas

It is reported that some emission of HFCs from aerosol cans with tear gas takes place in Finland (Toikka, 2006).

3.15 Other applications

Detecting faults in electronic products

HFCs are used to a small extent for detecting faults in electronic products. HFC is stored under pressure in an aerosol can and cools down when sprayed on an electronic component. This is used to find faults in electronic products such as television sets. Products of this type are made in Finland. The consumption of HFC for this purpose is confidential.

Experience shows that it might be difficult to find alternatives for fault detection purposes because of fire risk in applications using hydrocarbons.

CO_2 might be an alternative in some fault detection applications. AGA A/S in Sweden and Denmark has produced a brochure about it, but it is uncertain whether or not the product is sold in the Nordic countries.

There are also HFC containing aerosols that are used for cleaning lenses and other equipment. For that purpose non-flammability may be a requirement (Oinonen, 2001).

Cleansing

According to Haukaas (2001), HFC has been offered for sale in Norway for cleansing. No further information is available.

HFC-134a is in Denmark used for cleaning electrical equipment with high voltage, like control boards. The use is about 1 tonne per year (Jensen, 2006).

Micro etching

A small amount of HFC-23 is used for etching microchips. See more about this in chapter 5.

4. PFCs

The use and production of PFCs in the Nordic region are described in this chapter, together with possibilities for reducing the emission of these substances.

PFCs are perfluorocarbons, i.e. substances formed on the basis of simple hydrocarbons in which all hydrogen atoms have been replaced by fluorine atoms. As these substances are very stable, they have a very long atmospheric lifetime. At the same time, they are very potent greenhouse gases with a high Global Warming Potential (GWP), see Table 4.1.

Table 4.1 The principal PFCs

Chemical formula	R-number/ chemical formula	Normal boiling point (C)	GWP (100 yrs)	Atmospheric Lifetime (yrs)
CF4	R-14/Perfluoro-metane	- 127.9	5,700	50,000
C2F6	R116/Perfluoro-etane	- 78.2	11,900	10,000
C3F8	R218/perfluoro-propane	- 36.8	8,600	2,600
C4F10	Perfluorobutane		8,600	2,600
C4F8	Perfluorocyclo-butane		10,000	3,200
C5F12	Perfluoropentane		8,900	4,100
C6F14	Perfluorohexane	+ 58	9,000	3,200

4.1 PFC emission during production of aluminium

Several Nordic countries have a large production of hydroelectricity (and in the case of Iceland also geothermal energy). Aluminium is produced by means of an electrolytic process in which large quantities of electricity are used. It is therefore attractive to locate aluminium smelters in countries with an ample supply of electricity.

Aluminium is produced in Norway, Iceland and Sweden. Aluminium is made from bauxite, which is used to produce pure aluminium oxide – also called alumina. Metallic aluminium is made in large pots (cells) by means of an electrolytic process with carbon electrodes. The carbon block lining in the pots (cells) acts as the cathode, and one or more carbon anodes are inserted in the electrolyte from the top of the cell (Kvande, 2006).

During the production process, alumina (Al_2O_3) is dissolved in a fluoride melt consisting mainly of cryolite (Na_3AlF_6). PFCs are formed through a phenomenon called the *anode effect (AE)* when the concentration of alumina in the electrolyte is low. The total cell voltage is thereby increased from 4 – 5 Volt to 20 – 50 Volt. PFC gases then form in the electrolytic process in a reaction between fluorides and carbon, with the carbon being used as anode/reduction material. It is assumed that PFC gases form only during the anode effect.

The PFC emission increases with the frequency and duration of the anode effect. The anode effect typically occurs between 0.05 and 2 times per day per cell and usually lasts for 2 to 4 minutes (Kvande, 2006 and Karstensen, 2001).

There are several different kinds of aluminium cells. The production process and therefore the emission of PFCs differ considerably with the type of cell technology. The IPCC Guidelines refer to a study from 1995, in which the global emission of PFC from production of aluminium is estimated to be app. 1.4 kg CF_4 and 0.2 kg C_2F_6 per tonne produced aluminium.

Emission data for different cell technologies in aluminium production are reproduced in Table 4.2. It will be seen that there is a large variation in the emission of PFCs. The emission varies by a factor of 40 between the technology with the smallest emission to the technology with the biggest emission.

The "modern prebaked" technology has a much smaller emission rate than the other (older) technologies – app. 0.05 kg PFC/tonne Al, compared with 1.0 – 2.0 kg PFC/ tonne Al for all the other types.

Table 4.2: Estimated PFC emission from aluminium smelting works with different cell technology. Source: Tabereaux, 1995, reported in UNEP, 1996.

Cell technology	Share of global production (%)	Emission in kg/tonne Al
Modern prebaked	20	0.05
HS Søderberg	11	1.0
Older prebaked	40	1.75
VS Søderberg	29	2.0
Weighted global production	100	1.40

Norsk Hydro states that the distribution in the western world is: app. 21% Søderberg (6% HSS and 15% VSS) and app. 79% prebake (50% PFPB and 29% SWPB or CWPB).

The UNEP manual (1996) also reports measurements from Norway (Norsk Hydro, 1996) and Canada (1994). The manual gives measured values for the emission of CF_4 and C_2F_6 in kg/tonne aluminium. These data are reproduced in Table 4.3.

Table 4.3: Measured emissions of PFCs from aluminium production in Norway and Canada. Values are given for different cell technologies. Same source as Table 4.2.

	Norsk Hydro 1996	Norsk Hydro 1996	Canada, Shiff 1 994	Canada, Shiff 1994
	CF_4 (kg/tonne Al)	C_2F_6 (kg/tonne Al)	CF_4 (kg/tonne Al)	C_2F_4 (kg/tonne Al)
Side Worked Prebaked	-	-	1.19	0.067
Horizontal Stud Søderberg	-	-	0.82	0.14
Vertical Stud Søderberg	0.15 – 0.9	0.006 – 0.04	0.4	-
Centre Worked Prebaked	0.02 – 0.18	0.001 – 0.008	0.045 – 0.53	0.007 – 0.032

Norway

Norway is the largest producer of aluminium in the Nordic countries and one of the world's largest producers. There are seven smelters, four of which belong to Norsk Hydro.

Table 4.4: Emission of PFCs (in tonnes) from Norwegian producers. The trend is clearly downwards. Source: Natianal Inventory Report 2005.

	1990	1995	1998	1999	2000	2001	2002	2003
CF_4	479	229	185	164	131	152	163	102
C_2F_6	20	8	7	6	5	6	7	4

It can be seen from table 4.4 that emissions of PFCs from Norwegian producers of aluminium declined by about 79% from 1990 to 2003. That is attributed to improved technology and process control.

In June 1997, the Norwegian Ministry of Environment entered into an agreement with the Norwegian aluminium industry represented by Elkem Aluminium ANS, Hydro Aluminium AS and Sør-Norge Aluminium AS. Under this agreement, the industry undertakes to reduce the total specific emission of climate gases (emission of climate gases per tonne aluminium) by 50% and 55% by the year 2000 and 2005, respectively, in relation to the 1990 emission. Most of the reduction will be in the form of a reduction in the emissions of PFCs (Weidemann, 1998). It can be seen from table 4.4. that this has been (more than) fulfiled.

Iceland

Iceland also has a production of aluminium at two smelters, while a third will be in operation in 2007. In 1990, the PFC emission was estimated to be app. 45 tonnes. The emission was reduced to app. 8 tonnes in 1995 and to app. 4 tonnes in 1996 through the introduction of new technology in the form of new control technology. However, new production capacity started up and the emission increased to 8 tonnes in 1997, 12 tonnes in 1998 and 19 tonnes in 1999. In 2003, the emission was about 10 tonnes (NIR, 2005).

Sweden

Sweden has one aluminium smelter. The emission of PFCs was 42 tonnes in 2003 (NIR, 2005).

4.2 PFCs in refrigerant mixtures

In recent years, PFCs have been used in special refrigerant mixtures, which are used as “drop-in” substitutes for CFC refrigerants.

A growing consumption of these refrigerants was registered in several of the Nordic countries, but it seems like this usage is declining now.

The main “drop-in” refrigerant is R413A, which is also sold under the trade name “Isceon 49”. It consists of 9% C_3F_8, 88% HFC-134a and 3% isobutane.

There are also other refrigerant mixtures with PFCs, including R403A, R403B, R412A, R508A, R408B and R509. Haukås states that R508A probably has been sold for certain low-temperature freezers and R403B for freezing systems for road transport in Norway (Haukås, 2001).

The refrigeration industry is generally cautious about using refrigerant mixtures because of uncertainty about the concentration of the remaining mixture after leakage and because it is generally not desirable to transport several types of refrigerants in service vehicles.

The refrigerant R413A contains C_3F_8. Consumption of the pure substance in Denmark amounted to 6.4 tonnes in 1999 (Poulsen, 2000).

KMO in Denmark informs to the Danish Environmental Protection Agency that more than 1000 small refrigeration systems have been charged with R-413A in 2000 (Jensen, 2001).

The use of PFCs for refrigeration purposes has been banned in Denmark from January 2006 (Jensen, 2006).

Consumption in Norway in 1996 amounted to “some hundreds of kilograms” (SFT 2001).

The usage of C_3F_8 for refrigeration purposes in Finland has been reduced from 3.6 tonnes in 2000 to 0.5 tonnes in 2004 (Toikka, 2006).

According to the suppliers, this refrigerant is used for charging old R12 refrigeration systems and can therefore be used to prolong the lifetime of systems that have been fully depreciated. That can be financially advantageous.

Reasonably new CFC-12 systems can be converted for use of an HFC refrigerant.

4.3 Other PFC applications

Electronic industry

Some amounts of PFCs are used in the electronics industry, in plastma etching and vapour phase soldering. Some amount is used in the air craft industry.

In microchip manufacturing a small amount of PFCs are used. This is treated in detail in chapter 5.

Laboratory use

Small quantities are presumably used for laboratory applications. In Denmark, perfluorohexane (C_6F_{14}) is marketed, but sale of the product, which is intended for use as an inactive liquid in the electronics industry, has not been reported.

Fire extinguishers

It should be mentioned that an attempt has been made to sell PFCs as an extinguishant – a substitute for Halon. However, there are no reports of this application in the Nordic countries.

Use of PFC in fire protection systems and fire extinguisers will be prohibited from July 2007 onwards under the EU F-gas regulation.

5. Use of SF_6

This chapter describes the use of sulphur-hexafluoride (SF_6) in the Nordic countries, together with the possibility of using other substances and of reducing the emission of SF_6. SF_6 has a very long atmospheric lifetime and is the gas with the biggest greenhouse effect per unit of weight.

Table 5.1: Principal data for SF_6

Chemical formula	R-number	Normal boiling point (C)	GWP (100 yrs)	Atmospheric lifetime (yrs)
SF_6	R-7146	-63.8	22,200	3,200

The global consumption of SF_6 is app. 7,500 tonnes per year and is still increasing. Most of it – approximately 6,000 tonnes per year – is used as the insulating medium in heavy-current installations in connection with the rapid expansion of electricity supply systems in new growth areas, including Asia. In the "old" industrialised countries this expansion took place some years ago, and there the consumption of SF_6 is relatively low due to reuse of the substance.

The second-largest source of consumption on a global scale is magnesium production (approximately 500 tonnes per year). Other global fields of consumption include degassing of aluminium and cleaning of electronic components.

5.1 Cover gas in light-alloy metal foundries

SF_6 is used in a low concentration in connection with the production of light-alloy metal. It is used to prevent liquid magnesium from bursting into flames when the metal is cast into bars and machine components. Liquid magnesium is highly flammable and without cover gas it would burst into flames on contact with oxygen. SF_6 has been used for this purpose since the end of the 1970s.

When SF_6 is used for this purpose, the gas is emitted to the atmosphere. There is very little or no chemical decomposition during the process.

Norsk Hydro is the world's largest producer of magnesium, with a total production of 85,000 tonnes per year and a recycling volume of 35,000 tonnes. Norsk Hydro had production facilities in Porsgrunn, Norway, and has production in Canada and China.

The production of primary magnesium in Norway has stopped.

Norsk Hydro also advises that it is working to find and test a substitute for SF_6 and is also assisting customers who want to switch to another cover gas. Norsk Hydro has reintroduced SO_2 and developed a mixture of SO_2 mixed with dry air. Hydro is also involved in other solutions (Hydro Magnesium homepage, 2006). SINTEF is involved in this work.

The main customers for magnesium are the aluminium industry (in which it is used as a component in alloys) and the automobile industry, where there is a growing demand for light-alloy components made with magnesium.

SF_6 consumption

Consumption of SF_6 for the production of magnesium in Norway amounted to app. 18 tonnes in 1997 (SFT, 2000). In 2001, Hydro stopped the production of raw magnesium in Norway, and recently (2006) they also stopped remelting Magnesium in Norway. The emission in 2005 is 10 tonnes (Asphjell, 2006)

Consumption of SF_6 for magnesium casting in Sweden was about 1.3 tonnes in 1999 (Kindbom, Eugensson and Persson, 2001). The figure from 2003 was not available when the 2005 NIR was made.

The use of SF_6 in magnesium die casting in Finland was reduced and was stopped in 2004 for the time being. It is possible that small amounts of SF_6 will be used in processes in the future. The annually used quantities will not exceed the restrictions stated in the EU F-gas regulation. Article 8 of this regulation prohibits the use of SF_6 in magnesium die casting from January 2008 unless the annually used quantities are below 850 kg (Toikka, 2006).

Consumption of SF_6 for magnesium casting in Denmark amounted to app. 0.7 tonne in 1999, but has now stopped due to a ban from 2002.

Emission to surrounding environment/accumulation in scrapped products

All the SF_6 used in the production process is emitted to the surroundings. None of it accumulates in the products.

Situation with respect to alternative technology

Norsk Hydro advises that it is working on reduction in emission and the development of alternatives. The result is quite clear; the emission of SF_6 has been reduced. Also alternative (non-SF_6) technology has been implemented to some degree.

5.2 Insulating gas in power switches

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

- as arc-breaker in power switches
- as insulator in compact distribution systems.

There is a large quantity of SF_6 in electrical installations in the Nordic countries. The emission is relatively small because the gas is in sealed equipment. When repairs are carried out, the gas is collected and reused. Emission therefore occurs by accident or through unforeseen leakages. Emissions do also occur as intentional releases. Recovery practices are not yet perfect.

Production of switches

According to Wisen (2001), ABB Switchgear AB produces both high and medium-voltage switches with SF_6. ABB Switchgear is one of the world's biggest manufacturers, with about 20% of the global production. ABB in Sweden used app. 38 tonnes SF_6 in switches in 1999, with most of the production going for export. ABB also makes switches with SF_6 in Norway and Finland.

Several years ago, ABB became aware that SF_6 was a very potent greenhouse gas. It has therefore developed new routines for reducing leakage to the atmosphere. Leakage during the production process is less than 4% in 1999, and with even better equipment being set up in the production there will be further improvements in the future. All products undergo tightness testing before delivery and have an integral indicator that shows if there is a leakage.

Use in switches

According to Weldingh (1998), an electric arc forms when power is switched off and temperatures may reach extreme values (10,000–100,000 K). A substance is needed for breaking the electric arc by rapid and efficient cooling so that power cut-off is completed by the time the current reaches the zero point of the AC sine wave. There are several possibilities:

- blasting the electric arc away with heavily compressed air from a cylinder; this technology is old and is still used in some systems but has the disadvantage that the release of the compressed air makes a loud noise resembling an explosion;

- breaking the contact in oil, whereby hydrogen is formed; this technology involves some risk of explosion and has been abandoned;
- switching off the current in a closed vessel containing SF_6; this method works satisfactorily;
- switching off the current in a vacuum chamber; this technology also works satisfactorily in the range up to 20 kV.

Power switches are made by large companies such as ABB, Siemens, Group Schneider, Alstrom and Ormazabal (Jensen, 2001).

Transformer stations in the 10–20 kV range can be equipped with either SF_6 or vacuum switches.

The prices are similar and competition is tough. Therefore, non-SF_6 power switches for 10–20 kV transformer stations are available. However, space problems may arise when changing to this type and the entire station may have to be rebuilt.

In the Nordic countries, there are also about 200,000 10 kV/400 V substations. For substations in this range the equipment can be based on SF_6 both as switching and insulating medium, but non-SF_6 solutions are also available. Because of the large number of substations, such parameters as reliability, maintenance and small physical size play a decisive role.

There are no alternatives to SF_6 in the high-voltage range from 60 kV and upwards.

The other application in the heavy-current field is as insulating gas in compact transmission cables. As an example, high-voltage cables of 400 kV from the generator and out of the power plant are carried in pipes (for example, 20 m length), filled with SF_6. This prevents flashover to the pipe material and thus also short-circuiting of the power cables. Alternatively, the distance between the cables can be increased, allowing atmospheric air to become the insulating medium.

SF_6 emission

The emission from production of Gas-insulated switchgear (GIS) in Sweden has been reduced from 1.7 tonnes in 1999 to 0.3 tonnes in 2003.
The installed amount in the electricity distribution system was 79.9 tonnes in 1999 and 85.3 tonnes in 2003. The emission from the installations was 0.48 tonnes in 1999 and 0.43 tonnes in 2003 (NIR, 2005).

The emission from this sector in Finland has been reduced from 1.46 tonnes in 1999 to 0.40 tonnes in 2004. The total installed amount of SF_6 is 62 tonnes (Toikka, 2006).

In 1999, emissions in Norway amounted to 6.8 tonnes and this was reduced to 2.5 tonnes in 2003 (NIR, 2005).

Emissions in Denmark from GIS amounted to 0.43 tonnes in 2003 (NIR, 2005).

Emissions in Iceland are assumed to be constant during time and amount to app. 0.23 tonnes per year (NIR, 2005).

Emission to surrounding environment/accumulation in scrapped products

After production, the SF_6 accumulates in the products. Most of the substance is still in the products when they are scrapped and should be collected and reused or incinerated.

In Denmark, a study is made for Danish EPA. The study is conducted by Cowi Consult, and it shows, that a total of 56 tonnes of SF_6 is installed in the Danish electricity distribution system. In the study, a system for increased collection and cleansing of SF_6 during repair of switches is developed (Poulsen, 2001).

Situation with respect to alternative technology

As far as we know, there is no alternative technology for high-voltage switches. Alternative technology – vacuum technology – is being marketed for medium-voltage switches and it is a competitive and mature technology.

5.3 Sound-insulating windows

SF_6 is gaseous at normal temperatures and atmospheric pressures. SF_6 was used in some sound-insulating thermal glazing. It was used in a mixture with argon, among other gases, to fill the space between the panes of glass. The purpose of this is to damp acoustic pressure waves and thus protect against noise from outside.

There is a considerable production of sound-insulating windows in the Nordic countries and therefore there was a large consumption of SF_6. According to Poulsen (2000), consumption (in Denmark) amounted to 13.5 tonnes in 1995 but fell to 7.2 tonnes in 1999. This use has now been banned. It is assumed that the use of SF_6 for this purpose has also ceased in other Nordic countries.

The use of SF_6 for sound insulating windows will be prohibited in the EU due to the F-gas regulation (from July 2007 for domestic use and July 2008 for professional use).

Initially, SF_6 is accumulated in the windows, but if the windows puncture, the substance leaks out into the atmosphere.

As there are no schemes for collection or recovery arrangements (which would be difficult to establish), all the SF_6 will probably end up in the atmosphere. As this type of window has been produced for some years (20 – 25 years), some emission from old windows with SF_6 must be expected in connection with puncture or scrapping of the windows.

It is assumed that all the SF_6 will be emitted to the atmosphere.

5.4 Other applications

SF_6 has a number of minor applications.

Microchips (semiconductors and other chips)

SF_6 and several PFCs are used for producing electrical and optical microchips. They are used for plasma etching and for cleaning the chips and the production chambers.

The PFCs used are CF_4, C_2F_6, C_3F_8 and C_4F_8. Some amount of NF_3 and HFC-23 is also used.

In 2001, 4 companies in Denmark consumed less than 1 tonne for that purpose. At present (2006), consumption is smaller (if any production at all).

The consumption of PFC and SF_6 in Sweden was 1.0 tonne in 1999 (0.1 tonnes of PFC-14, 0.7 tonnes of PFC-116 and 0.2 tonnes of SF_6) (Kindbom, Eugensson and Persson, 2001).

The emission of gases amounted to 12 Gg CO_2-eq in 1999, and the similar figure was 21 Gg CO_2-eq. in 2003 (NIR, 2005).

The amount of gases in semiconductor production has decreased in Finland at the beginning of the 2000s due to recent transfer of production to other countries. The decreasing trend might, however, be temporary (Toikka, 2006).

At the moment, no alternatives for use of PFCs in semiconductor manufacturing processes exist.

Tracer gas

DMU (the National Environmental Research Institute) used a small amount of SF_6 as a tracer gas for testing dispersal in the atmosphere. SF_6 was used as a tracer gas because it has a number of special properties that are not found in other gases.

Approximately five laboratories (including Danish Technological Institute, which used approximately 2 kg per year) performed ventilation tests. Small amounts of SF_6 were used as tracer gas for indoor tests.

This usage has now been banned in Denmark.

There might also have been similar use in the other Nordic countries, but so far no information has been available.

Medical applications

In Finland, a small quantity of SF_6 has been used in eye operations.

Car tyres

There have been reports that large quantities of SF_6 have been used in Germany for inflating car tyres. Consumption has been in the order of magnitude of 100 tonnes per year. This usage stopped years ago.

Due to the EU F-gas regulation this use will be prohibited from July 2007.

Shoe soles

SF_6 was used in the soles of Nike sports shoes. This was stopped January 2004. There is a temporary use of PFC for this purpose and this has stopped (Jensen, 2006).

Due to the EU F-gas regulation, the use of fluorinated gases for footwear is prohibited from July 2006.

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Sammendrag

De kraftige drivhusgasser (også kaldet ”F-gasser” eller ”de tre industrielle gasser”) er på listen over drivhusgasser, som er reguleret af Kyotoprotokollen.

I 1998 påbegyndtes arbejdet med at skrive rapporten ”Ways of Reducing Consumption and Emission of the Potent Greenhouse Gases (HFCs, PFCs and SF_6)” (Pedersen, 2000). Denne rapport blev opdateret i 2001 og udgivet af Nordisk Ministerråd (Pedersen, 2001). Rapporten beskriver anvendelse af – og emission af de kraftige drivhusgasser i de 5 nordiske lande. Samtidig beskriver rapporten muligheder og bestræbelser for at begrænse anvendelsen af disse stoffer og benytte alternativer. I rapporten blev beskrevet ”succeshistorier”, hvor alternativer med held var blevet indført i produktionen i de nordiske lande.

Formålet med det nye projekt er at opdatere rapporten fra 2001. Formålet er endvidere at styrke det nordiske samarbejde omkring begrænsning af emissionen af kraftige drivhusgasser samt at beskrive mulighederne for at benytte alternativ teknologi. I den forbindelse er det en fordel, at der ikke er producenter af F-gasser i de nordiske lande.

Det har endvidere været formålet at beskrive de nationale tiltag for at reducere emissionen af kraftige drivhusgasser.

Endelig har formålet været at beskrive de nyeste resultater i forbindelse med udvikling af teknologi, som eliminerer brug af, – eller begrænser brug af HFC, PFC eller SF_6. Siden 2001 er der bl.a. udviklet ny teknologi indenfor produktion af isoleringsskum (polyurethanskum og XPS-skum), i produktion af aluminium og magnesium, og der er stigende fokus på at benytte hydrokarboner, ammoniak og CO_2 som kølemiddel.

Tabel: Emission af drivhusgasser i de nordiske lande i 2004:

	1000 Tonnes CO_2-eq.	
CO_2	224.576	80,9%
CH_4	21.523	7,8%
N_2O	27.216	9,8%
HFCs	2.661	1,0%
PFCs	1.235	0,4%
SF_6	421	0,2%
Total	277.632	100,0%

Note: For Island benyttes tal fra 2003.

Det fremgår af ovenstående tabel, at emissionen af F-gasser svarer til ca. 4,32 millioner tons CO_2-ekvivalenter per år. Dette svarer til ca. 1,55% af al emission af drivhusgasser i de nordiske lande.

Appendix A: Refrigerants and refrigerant mixtures

The following table shows the most common refrigerants consisting of single substances. GWP figures for HFCs and PFCs are from UNEP, 2004 (Third assessment report).

Substance	**R-number**	**Chemical formula**	**ODP value**	**GWP value (100 yrs)**
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	12,000
HFC-32	R-32	CH_2F_2	0	550
HFC-125	R-125	C_2HF_5	0	3,400
HFC-134a	R-134a	CH_2FCF_3	0	1,300
HFC-143a	R-143a	CF_3CH_3	0	4,300
HFC-152a	R-152a	$C_2H_4F_2$	0	120
HFC-227ea	R-227ea	C_3HF_7	0	3,500
HFC-236fa	R-236fa	$C_3H_2F_6$	0	9,400
HFC-245ca	R-245ca	$C_3H_3F_5$	0	640
PFC-14	R-14	CF_4	0	5,700
PFC-116	R-116	C_2F_6	0	11,900
PFC-218	R-218	C_3F_8	0	8,600
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	C2H6	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 following table shows refrigerant mixtures in the 400 series (zeotropic mixtures). The ODP and GWP values can be calculated on the basis of the values in the table for single substances, weighting on the basis of the mix ratio between the individual substances.

R-number	Substances	GWP (100 yr.)	Concentration in weight – %
R-401A	HCFC-22/HFC-152a/HCFC-124	1080	53/13/34
R-402A	HCFC-22/HFC-125/HC-290	2686	38/60/2
R-403A	HCFC-22/PFC-218/HC-290	2995	75/20/5
R-403B	HCFC-22/PFC-218/HC-290	4306	56/39/5
R-404A	HFC-143a/HFC-125/HFC-134a	3784	52/44/4
R-406A	HCFC-22/HC-600a/HCFC-142b	1755	55/4/41
R-407C	HFC-32/HFC-125/HFC-134a	1653	23/25/52
R-408A	HCFC-22/HFC-143a/HFC-125	3015	47/46/7
R-409A	HCFC-22/HCFC-142b/HCFC-124	1440	60/15/25
R-410A	HFC-32/HFC-125	1975	50/50
R-412A	HCFC-22/HCFC-142b/PFC-218	2120	70/25/5
R-413A	HFC-134a/PFC-218/HC-600a	1918	88/9/3
R-414A	HCFC-22/HCFC-124/HCFC-142b/HC-600a	1334	51/28.5/16.5/4
R-415A	HCFC-22/HFC-23/HFC-152a	1978	80/5/15

The following table shows refrigeration mixtures in the 500 series (azeotropic mixtures).

R-number	Substances	GWP (100 yr.)	Concentration in weight – %
R-502	CFC-115/HCFC-22	5576	51/49
R-507	HFC-143a/HFC-125	3850	50/50
R-508A	HFC-23/PFC-116	11939	39/61
R-508B	HFC-23/PFC-116	11946	46/54
R-509A	HCFC-22/PFC-218	5564	44/56

Appendix B: Commercial refrigeration systems

This appendix is an updated version of the appendix from the 2001 report. The appendix has been changed and shortened compared to the 2001 report.

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.

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 made up of purchased standard components. In some commercial refrigeration systems (i.e. supermarkets), long piping is involved and the leakage rate has previously been very high (in the order of 20–25% of the refrigerant charge per year). In recent years, the trade association AKB (Authorised Refrigeration Installers Association) and the two refrigeration associations have done much to reduce leaks and in that way reduce emissions. This implies that the emission of new supermarket centralised refrigeration systems is reduced to app. 10% per year.

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

This appendix is divided into two and the first section deals with various types of systems that are divided into 4 categories: Stand-alone units, condensing units, direct systems/ indirect systems and hybrid systems. The second section deals with a total evaluation of the impact on global warming in the commercial area of refrigeration.

B.1 Types of systems

Stand-alone units

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

Stand-alone units can be divided into large and small systems. The small plug-in units can use hydrocarbons, while the larger are problematic because the charges with hydrocarbons will exceed 200–300 grams. The large stand-alone units (above app. 2 kW in cooling capacity) are used in many different places in various respects. Many supermarkets use many large stand-alone 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 petrol stations as well as in the hotel and restaurant industry. The large stand-alone cabinets are often inexpensive, prefabricated units, which are easy to set up and inexpensive to service. Moreover, these cabinets have the advantage compared to centralised refrigeration cabinets that they can easily be moved to other locations in the shop. In some shops such flexibility is given high priority. The disadvantages are that heat and noise are emitted into the shop area.

In addition to the systems mentioned, a number of single-purpose machines exist, i.e multicoolers for soft drinks and beer in bars and restaurants, ice machines e.g. in fish mongers and other types, in which capacities and charges are so large that the use of hydrocarbons as refrigerant cannot immediately be justified.

Transcritical CO_2 systems might be a solution. Alternatively, it might be necessary to use indirect refrigeration in many of the applications where plug-in equipment has been used previously.

Condensing units

The condensing units cover a wide range of applications. The units consist of two units. The first unit: the evaporator is placed in the cold store or in the room where air conditioning is desired. The second unit: the compressor and condenser part (in total called the condensation unit) is often placed outdoor or in basements. This part emits heat to the surroundings. The condensing 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) and Danfoss. The condensing units are used widely within the retail trade and hotel and restaurant industry. They are used for cold storages, air conditioning and remote refrigeration cabinets. Condensing units are advantageous compared to the plug-in/stand-alone units as the condenser heat and noise is not emitted to the room itself and noise problems are avoided.

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

Direct/indirect refrigeration

Direct refrigeration is the simplest form of cooling. A refrigerant is circulated and expanded into the evaporators. The refrigerant vapour is sucked back to the compressor. Unfortunately, neither ammonia nor HCs can be used in direct refrigeration due to toxicity and flammability issues. Therefore, one has to look into the use of indirect refrigeration.

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 or ammonia can therefore 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 available on the market today. A lot of bigger ammonia chillers are available on the market. Prefabricated chillers for capacities below 20 kW cooling capacity are not yet available with natural refrigerants.

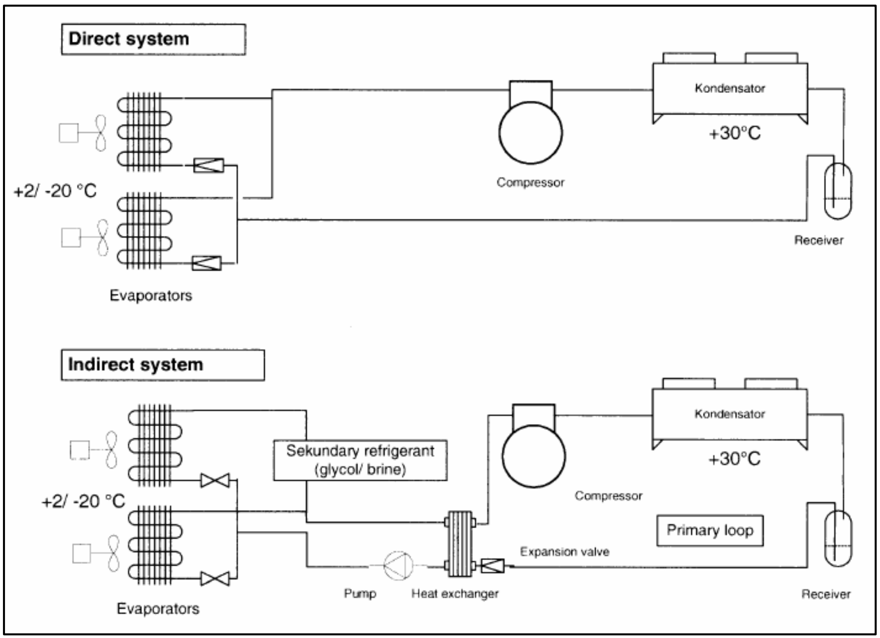


Figure B.1: Outline of direct and indirect refrigeration system

Hybrid systems

Hybrid systems are used widely in medium-sized and large supermarkets. The systems are characterised by a number of remote cabinets/evaporators coupled in parallel on the evaporator side, while the condenser also is remote coupled. The hybrid 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, many hybrid systems have been built. In 1999–2001, the first 2 systems were built using propane at the high temperature level and brine (propylene glycol) at medium temperatures and CO_2 with direct expansion at low temperature level.

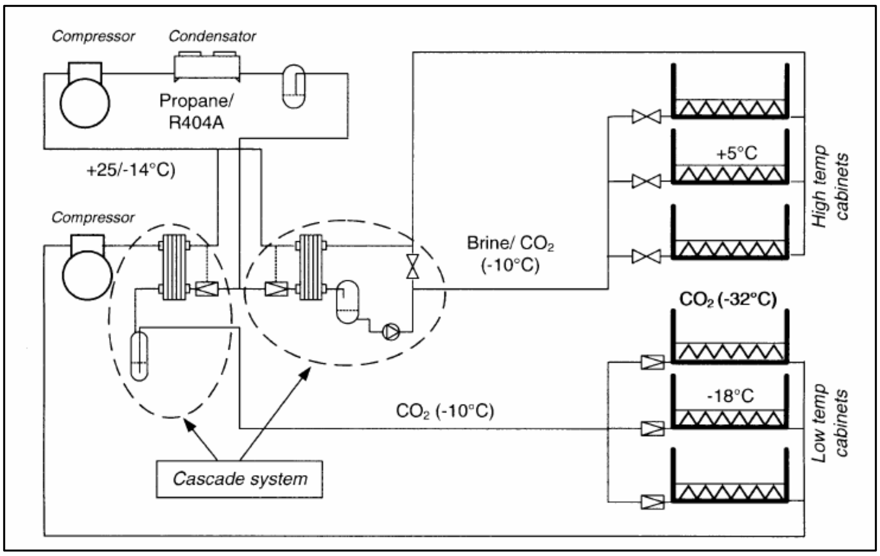


Figure B.2: Hybrid system built in Denmark (propane/ glycol and CO_2)

In Sweden, many indirect systems with volatile CO_2 as secondary fluid have been built. The experience from these systems was used in combination with the system outlined above and a new generation of systems were built using CO_2 as volatile secondary refrigerant (see figure below).

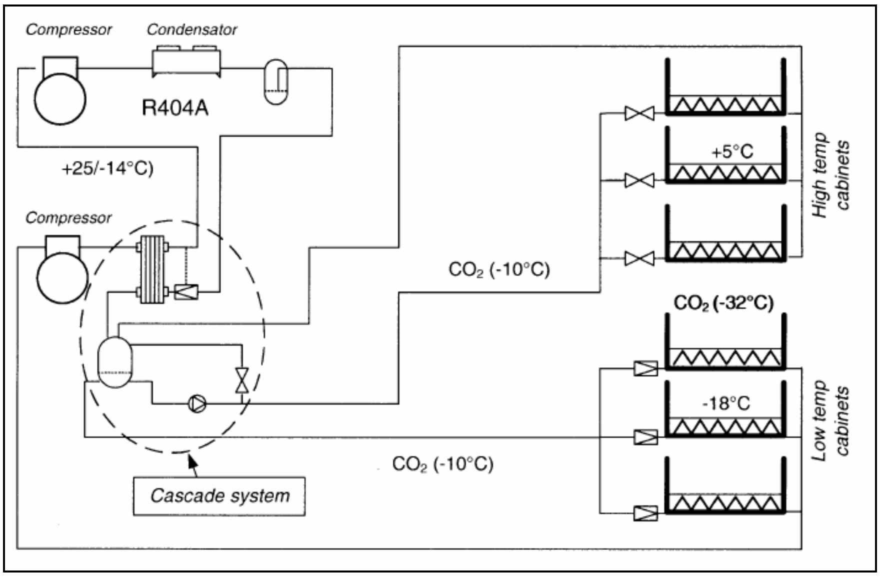


Figure B.3: Hybrid (cascade) system using propane (or HFC) and CO_2

In Sweden, many indirect systems with volatile CO_2 as secondary fluid have been built. The experience from these systems was used in combination with the system outlined above and a new generation of systems were built using CO_2 as volatile secondary refrigerant (see figure below).

The cascade systems showed above have almost become “industrial standard” and more than 50 of these systems are known to be installed in Denmark.

To keep the cabinets at medium temperatures a pump is used to circulate the volatile CO_2 to the cabinets. These pumps are rather expensive and difficult to operate (operation is very dependent on correct design of the system). Therefore, various companies look into new types of methods for circulating CO_2 in these systems. Systems with 2 vessels operating with liquid are used, but also “high pressure cascade systems” are used.

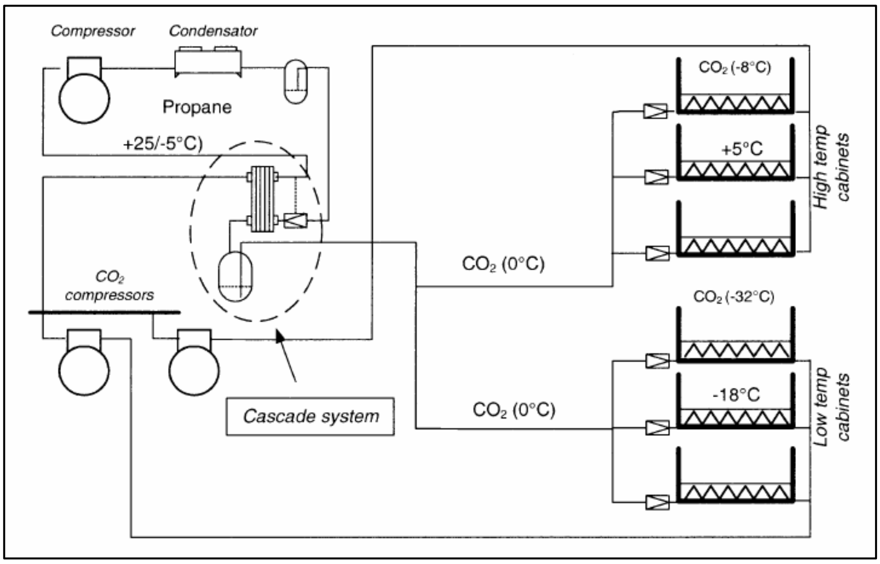


Figure B.4: “High pressure cascade system” where the pressure in the receiver at the cascade heat exchanger is around 50 bar. In this case, the cabinets at the medium temperature level can be operated with direct expansion.

Unfortunately, cascade systems are more complicated in design and construction and use two different refrigerants (CO_2 and another one). That makes them more expensive to service. Therefore, the cascade systems will probably not be profitable when used in small-scale supermarkets (total cooling capacity below 30 kW). The use of transcritical CO_2 will bring different advantages: One refrigerant only (CO_2) and a simpler layout of the system.

The idea of using CO_2 in a transcritical system is not new. For the past 15 years, research and development has been carried out on smaller systems especially for heat pumps and air conditioning units. However, the know-how required to build an economic transcritical CO_2 system for the supermarket area is still very limited. A few test installations have been made in Sweden, Denmark and Norway.

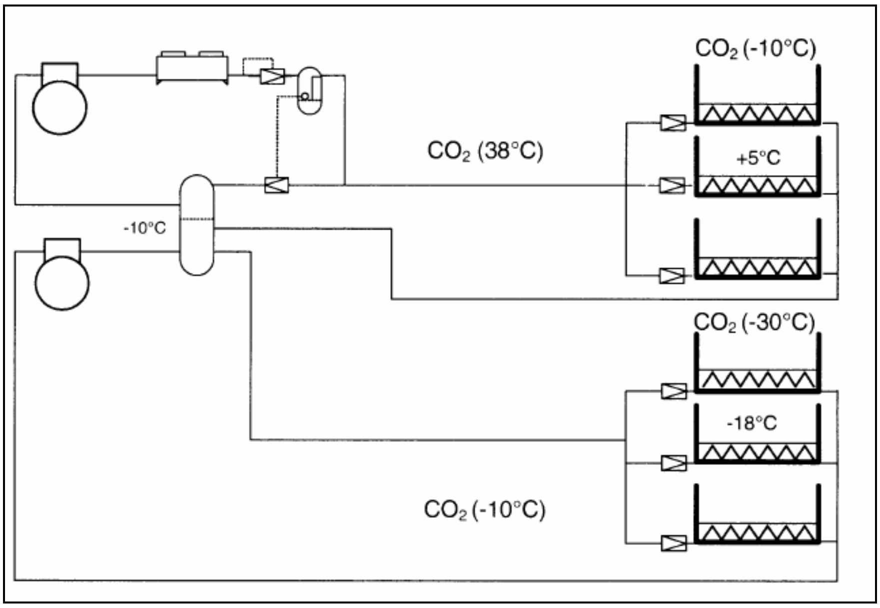


Figure B.5: Refigeration system for supermarket using transcritical CO_2 as refrigerant

The system operates under transcritical conditions during higher ambient temperature (e.g. 25°C). A transcritical CO_2 system is an attractive option for smaller supermarkets because they are much simpler than the cascade systems. The system comprise a high-pressure compressor that compresses the CO_2 to 120 bar. The compressed gas then enters a gas cooler and is cooled to a temperature close to ambient. The cooled, high-pressure gas then passes through a high-pressure valve, which allows the gas to expand and reduces pressure to a level below the critical point where saturated liquid can exist. The liquid is circulated towards the low- and high-temperature refrigeration cabinets.

The liquid is then allowed to expand to 25 bar in the high-temperature cabinets and to 15 bar in the low-temperature cabinets by the expansion valves. The liquid evaporates in the cabinets and the resulting gas from the low-temperature cabinets is removed by the low-pressure compressor and, after compression, mixed with the gas from the high-temperature cabinets. The mixture is then lead to the high-pressure compressor and the closed cycle starts again.

B.2 Impact on global warming

As far as the small systems are concerned (the stand-alone units and condensing units), the main problems are concentrated on replacement of HFCs. In connection with small AC systems in buildings with public entrance, the use of hydrocarbons and ammonia is hardly possible. Use of carbon dioxide is possible, but due to high pressures and a troublesome thermodynamic circuit process (in the relevant temperature area), further development work for introduction of this refrigerant is required. A tremendous effort is made to develop new systems and the first transcritical AC-system has now been marketed (Sanyo).

Energy consumption, refrigerant leakage and greenhouse effect

A refrigeration system using HFC refrigerants contributes to the greenhouse 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 app. 0.78 kg CO2 each kWh (today this value might be considered lower app. 0.65 kg/ kWh in Denmark and even lower in the other Nordic countries due to a higher rate of hydro power and nuclear power). 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. Due to different preconditions, *much of the calculation material presents contradicting results.*

If systems for natural refrigerants using less energy than similar HFC systems are applicable, the matter is clear: Systems with natural refrigerants is the most environmentally benign solution, taking the greenhouse effect into consideration.

In places, where direct cooling with natural refrigerants or semi-direct cooling is possible, the energy consumption will in general not be higher than in similar HFC systems. Hence, these systems will be advantageous seen from an environmental point of view.

Indirect refrigeration with brine (e.g. a water/glycol mixture) will generate a loss because of the necessary heat exchange between the primary and the secondary refrigerant. By means of that the energy consumption will be a little higher because of the demand for lower evaporating temperatures. This results in a slightly higher energy demand 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 line of the direct system. In total, indirect refrigeration will cause a slightly higher energy demand in the size of 10%.

Concerning large built-in systems (e.g. like those in supermarkets), the entire contribution (e.g. CO_2 from the electricity production and emission of refrigerant) to the greenhouse effect will be less for systems using natural refrigerants, cf. calculation in enclosure 1 to the appendix. 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 app. 10 kg. charge), the situation is different, as the energy demand of indirect cooling is still somewhat higher (app. 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 cooling will be more environmentally benign when these small commercial refrigeration systems are in question (enclosure 2).

A comparison between direct refrigeration systems using R404A and indirect cooling with propane/brine appears from enclosure 2 and 3. The comparison is based on a small compact refrigeration system (10 kW for refrigeration and 5 kg of charge), but with 2 different leakage rates of 10% and 5%.

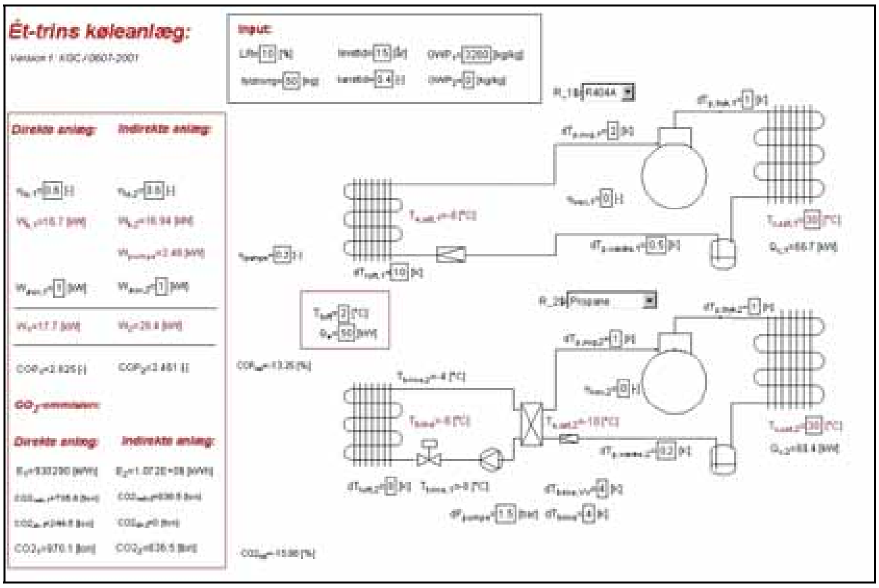
According to Enclosure 2, a leakage rate of 10% is preconditioned; however, the propane system presents the smallest contribution to the greenhouse effect.

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 cooling is estimated to be below the emission from a similar refrigeration system with indirect cooling.

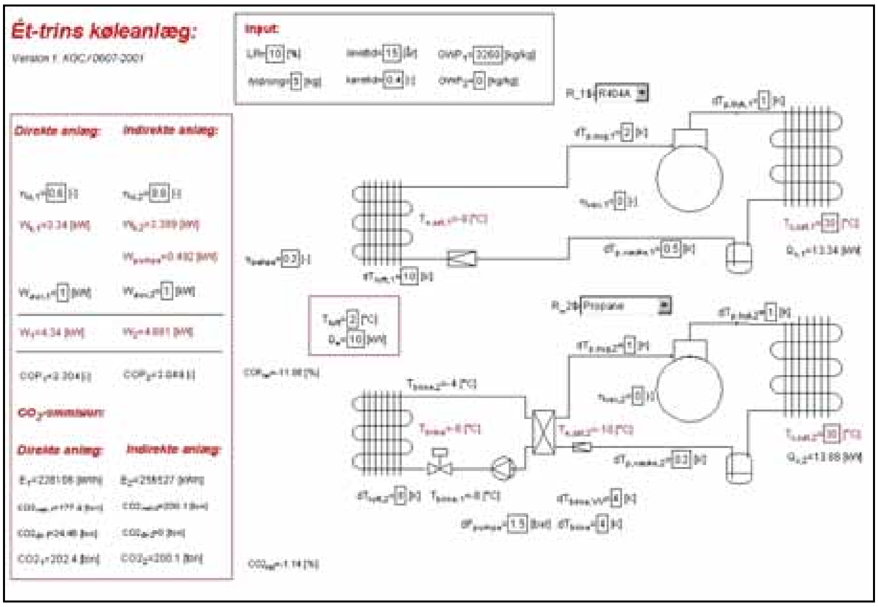
Enclosure 1

Comparison of indirect and direct refrigeration used in middle-sized refrigeration systems (50 kW). The simulation model shows a large integrated refrigeration system, relatively heavily charged with 50 kg of R404A and a leakage rate of 10% p.a.



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.



Ét-trins køleanlæg:

Input:

Direkte anlæg: **Indirekte anlæg:**

CO_2-emmission:

Direkte anlæg: **Indirekte anlæg:**

R_1$ R404A

R_2$ Propane

Enclosure 3

Comparison between direct systems using R404A and indirect systems 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%.