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HCFC phase out in the Nordic countries

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Introduction

From January 2015, it is no longer allowed to refill HCFC refrigeration systems in the Nordic countries and the EU. This might cause problems for some owners and users of old HCFC refrigeration systems if they are not aware of this situation and if they have not been planning to install an alternative refrigeration system.

This report has been prepared by Danish Technological Institute (DTI) in cooperation with Hans Haukås, Norway, for the Nordic Ozone Group under the Nordic Council of Ministers in an effort to ease the final transformation from the use of HCFC to alternative refrigerants and to encourage the use of alternatives that do not harm the environment. The aim of this report is to develop information material which is to be used to guide the refrigeration industry and the owners and users of HCFC-refrigeration systems. The information material is also to provide examples of how to change to more environmental friendly refrigeration systems with natural refrigerants.

HCFC phase out in the Nordic countries

Nordic Ozone Group
Nordic Council of Ministers

January 2014

Per Henrik Pedersen
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1. Introduction

Objective of this report:

From January 2015, it is no longer allowed to refill HCFC refrigeration systems in the Nordic countries and the EU. This might cause problems for some owners and users of old HCFC refrigeration systems if they are not aware of this situation and if they have not been planning to install an alternative refrigeration system.

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This report starts with an overview of the legislation in the field.

In chapter 2, the use pattern of old HCFC refrigeration systems, based on information from Denmark, is described.

In chapter 3, the phase out strategies for HCFC are described. For very old refrigeration systems in poor condition, it would make sense to replace the systems with new refrigeration systems. It is recommended to install new systems with natural refrigerants, when possible.

Chapter 4 gives several examples of new HFC-free refrigeration systems developed and marketed in the Nordic countries.

Chapter 5 gives examples of refrigeration systems changed from HCFC to natural refrigerants.

Nordic Ozone Group

During the last two decades Denmark, Finland, Iceland, Norway and Sweden have been cooperating on issues related to ozone layer depletion, through participation in the so-called Nordic Ozone Group (NOG) under the Nordic Council of Ministers. The Nordic Ozone Group consists of:

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The Nordic Ozone Group contracted Danish Technological Institute (DTI) in September 2013 to write this report in dialog with the group. Per Henrik Pedersen, DTI, wrote the text of the report and Hans Haukås, Norway contributed with the case on the fishing vessel and the case on the fish processing plant as well as gave comments to the draft report.

Global phase out of ozone depleting substances

Gases that damage the ozone layer – ozone depleting substances (ODS) - have been used in a wide range of industrial and consumer applications. Mainly, they have been used in refrigerators, air conditioners and fire extinguishers and as aerosol propellants, solvents and blowing agents for insulation foams. To protect the ozone layer, the international community established the Montreal Protocol on substances that deplete the ozone layer in 1987.

The main ODS being phased out under the Montreal Protocol are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, carbon tetrachloride and methyl bromide. Most of these gases have been phased out completely. The remaining main group is the global phase out of HCFCs. All countries in the world have committed themselves to phase out the use of HCFCs.

EU regulation on ozone depleting substances

The European Union and its member states, including the EEA countries (Iceland, Norway and Liechtenstein) are at the forefront of ozone layer protection with a regulation that in several cases goes beyond the requirements of the Montreal Protocol.

The European Union has a strong commitment to protect the ozone layer and has put in place legislation that is among the strictest and most advanced in the world. Europe has not only implemented what has been agreed under the Montreal Protocol on protecting the ozone layer but has often phased out dangerous substances faster than required.

The EU has banned the use of the most harmful ozone depleting substances (like CFCs and halons) were banned in the 1990s. HCFC substances (such as HCFC-22) are less harmful to the ozone layer, and these were as refrigerant banned in new equipment in 2001; except for small air-condition systems where the date entered into force 2004.

The Regulation No EC/1005/2009 on substances that deplete the ozone layer is the present legal base for regulation in the EU. From January 2010, the use of virgin HCFC for servicing and maintaining existing refrigeration systems was banned. Only recycled or reclaimed HCFC may be used.

From 1 January 2015, the use of any HCFC to service refrigeration systems is going to be banned, which means that it is not allowed to use recycled or reclaimed HCFC.

The EU legislation can be found at this link: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009R1005:en:NOT>

F-gases and EU-regulation

Fluorinated greenhouse gases (F-gases) are a family of man-made gases used in a range of industrial applications. Because they do not damage the atmospheric ozone layer, they are often used as substitutes for ozone-depleting substances. However, F-gases are powerful greenhouse gases with a global warming effect up to 23,000 times greater than carbon dioxide (CO₂) and their emissions are soaring.

Hydrofluorocarbons (HFCs) are the most common group of F-gases. They are used in various sectors and applications, e.g. refrigerants in refrigeration, air-conditioning and heat pump equipment, as blowing agents for foams, as solvents, and in fire extinguishers and aerosols.

The European Union has taken action to control F-gases as part of its policy to combat climate change. [Legislation](#) was passed in 2006: EU No 842/2006 and supplementing regulations. In 2012, the European Commission made a [proposal](#) to strengthen this in order to cut F-gas emissions by two-thirds of today's levels by 2030.

All EU member states have implemented the EU F-gas regulation 842/2006 on certain fluorinated greenhouse gases, which regulated the use of HFCs and other F-gases.

A new stronger EU regulation on F-gases including HFCs was agreed in December 2013 and this includes a phase down scheme of the available amount of HFC refrigerants in the EU and EEA. Based on the quantity in 2015, the available amount will be phased down (in steps) to 21 % in 2030. Bans of new equipment using high GWP refrigerants will enter into force, including:

- Refrigerators and freezers for commercial use (hermetically sealed), GWP > 2500: 1. January 2020
- Refrigerators and freezers for commercial use (hermetically sealed), GWP > 150: 1. January 2022
- Stationary refrigeration equipment (> -50 °C), GWP > 2500: 1. January 2020
- Single split AC-systems, < 3 kg refrigerant, GWP > 750: 1. January 2025

National regulations on ozone depleting substances and F-gases

The national regulations in the Nordic countries are described briefly in the following (the countries are in alphabetical order):

Denmark

HCFCs

Installation of new refrigeration systems with HCFC was banned in January 2000. In January 2002, the use of new virgin HCFC for servicing purposes was banned, and only the use of recycled HCFC was allowed. From 1 January 2015, the use of any HCFC for servicing purposes is going to be banned.

HFCs

Denmark has additional legislation concerning the use of HFCs and other F-gases. Denmark also has a tax on HFCs. The taxation was implemented in 2001 and a ban on certain applications was introduced in 2002.

A short description of the ban on HFCs:

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 1 January 2006. There are some exemptions from this general ban. For instance, the use of HFCs in refrigeration systems is still allowed for cooling equipment with HFC charges between 0.15 kg to 10 kg and the use of HFC for service purposes is exempted from the Statutory Order. In 2002, it was necessary to introduce this “window” of exemptions, because it was estimated that it would take a long time to develop alternatives in this area.

A short description of the tax/refund scheme:

The main principle of the tax/refund scheme is that a tax of DKK 150 (approx. 20 Euro) per tonne of CO₂ equivalent is imposed on the importation of HFC/PFC/SF₆. This means that a tax amounting to DKK 195 (approx. 26 Euro) per kg is imposed on the most frequently used F-gas refrigerant (HFC-134a). The use of HFC for mobile air conditioning is exempted from the tax.

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

Faroe Islands

The Faroe Islands had no regulation of ozone depleting substances until December 2010 when a statutory order about ozone depleting substances: (kunngerð nr. 118 frá 16. desember um ozonoyðandi evni) came into force (<http://www.logir.fo/foldb/kunfo/2010/0000118.htm>). The statutory order only allows the use of reclaimed HCFC for service and refilling.

Like the EU regulation, it is not allowed to use HCFC for refill after January 2015. Refrigeration systems and other products using HCFC (used for business purposes) must not be used after 31 December 2016.

In the Faroe Islands, there is no legislation on HFCs.

Although the Faroe Islands is a part of the Danish kingdom, the islands are not a member of the EU.

Finland

The installation of new refrigeration systems with HCFC was banned in January 2000. In January 2010, the use of new virgin HCFC for servicing purposes was banned and only the use of recycled or regenerated HCFC was allowed. From 1 January 2015, the use of any HCFC for servicing purposes is going to be banned.

In addition to the restrictions concerning the use and placing of ODS on the market, maintenance of equipment containing ODS (e.g. cooling equipment) is regulated:

- Servicing personnel must be trained and certified
- Equipment owners must check their equipment for leakage at a regular basis

Currently, Finland does not have any national legislation concerning the use of HFCs that goes beyond the EU regulation on F-gases.

EU regulations 1005/2009 on ozone depleting substances and 842/2006 on fluorinated greenhouse gases apply.

Iceland

EU Regulation 1005/2009 (except for chapter IV which does not apply) came into force in the second half of 2013. Placing on the market and the use of HCFC for maintenance will be forbidden as from 1 January 2015. Until then, the use of HCFC for maintenance is restricted to equipment imported before 1996 and those which were issued an unlimited derogation.

Apart from this, the Icelandic legislation is slightly different. It is, however, only relevant until 1 January 2015. There is no distinction made on recycled and reclaimed HCFC in relevance of article

11.3 and 11.4 in Regulation 1005/2009 which is due to an error in the translation. This means that there is not a total prohibition on the import of reclaimed HCFC.

The exemptions are the same as in Regulation 1005/2009.

EU Regulation 842/2006 applies in Iceland. There are no restrictions on HFC besides this and there are no special taxes. More stringent restrictions were in place, e.g. concerning fire extinguishers, which were revoked on 1 January 2013.

There are no restrictions when changing a HCFC system to HFC.

Norway

Norway has implemented the EU Regulation 1005/2009 and it came into force 1 July 2013. The phase out schedule for HCFC is therefore the same as the phase out schedule in this regulation. This means that all import/export of HCFC to/from Norway is prohibited as from 2010 and only recycled/reclaimed HCFC can be used for refilling/servicing equipment. From 1 January 2015, HCFC can no longer be used to refill/service equipment.

HFCs

Norway has implemented the EU regulation 842/2006. In addition, Norway has a tax on HFCs. The main principle is that a tax of NOK 330 (approx. 42 Euro) per tonne of CO₂ equivalent is imposed on the importation of HFC and PFC.

Sweden

HCFCs

Sweden decided very early to phase out all uses of HCFC. The phase out in the refrigeration sector is carried out in three steps: 1) banning new production and installation 2) banning the refilling of existing equipment and 3) banning the use of HCFC in existing equipment (decommissioning). The bans came into force on the following dates:

1998	Production and installation of new refrigeration systems with HCFC
2002	Refilling of existing HCFC refrigeration systems (corresponding ban in the EU comes into force 1 January 2015)
2015	Use of HCFC as a refrigerant in existing equipment with exemption of equipment with a filling of 3 kg or less if they were in use before 1 July 2002 and has been in use since this date.

Moreover, there is an exemption for the Armed Forces; they are exempted from the use ban. However, the EU ban concerning refilling, which is effective from 1 January 2015, applies.

In 2008, the Swedish EPA tasked a consultant to carry out a study of the number of installed HCFC refrigeration systems and the amount of HCFC in that equipment. According to this analysis, there was a surprisingly large number of systems:

Less than 3 kg:	95,000 systems
Between 3 and 10 kg:	23,000 systems
More than 10 kg:	860 systems

The total amount of HCFC: 530 tons

Taking into account that the refill ban has been effective for many years, it is surprising to see that these large numbers of equipment are still in use. However, this analysis was made more than five years ago and today many of these systems are about 20 years old (at least 15 years old). It is expected that the current number is significantly smaller due to the replacement with newer refrigeration systems.

HFCs

Sweden has a national regulation in place to complement the EU F-gas regulation. The use of HFCs is regulated in the Swedish Regulation 842:2006 on fluorinated greenhouse gases and ozone depleting substances. In addition to EU requirements, Sweden has also in place requirements for the mobile sector and reporting. In general same rule applies for the mobile equipment as for stationary equipment with the following exemption; mobile equipment with a filling of 3 kg or less, only one person need to be certified in a company, others may work under a certified person's supervision.

2. Use of HCFC in the refrigeration industry in the Nordic countries

HCFC-22 (or R-22) was widely used in the refrigeration industry before the regulation came into force. It was the main refrigerant in several types of equipment, and in many of the Nordic countries there are still many old R-22 refrigeration systems in use. Most HCFC-22 systems will leak and stop working when the refrigerant charge has decreased to a certain level. Then, the system has to be refilled by reused HCFC-22. The frequency of the necessary refilling depends on several parameters, including the size of the refrigerant charge and the rate of the leakage. In some cases, it might last several years before a recharge is necessary and in other cases this has to be much more frequent.

An analysis has been made for Denmark in that Danish Technological Institute has collected detailed information about the use of HCFC-22 and the use pattern in 2011.

It has not been possible to receive similar detailed information for the other Nordic countries, but it might be assumed, that the use and the use pattern for Norway and Finland is similar to the Danish pattern. This might also be the case for Iceland. There is, however, a special situation for fishing ships (see later on in this chapter).

The situation in Sweden is probably different in that many HCFC refrigeration systems have disappeared after the ban on refill was introduced in 2002. However, a substantial number of systems were in operation in 2008 as stated above. It is reasonable to believe that many of the smaller HCFC-systems are still in operation.

Analysis from Denmark

There is a voluntary organization inside the Danish refrigeration trade: KMO (Kølebranchens MiljøOrganisation). This is a well-working organization which was supported economically by the Danish Environmental Protection Agency when it was established in the 1990s.

KMO organizes the registration of sold refrigerants and the collection of refrigerants for reuse or destruction. KMO also ensures that the refrigerants are only handled by educated technicians and that correct equipment exist in the more than 2000 companies which are members of KMO.

At KMO's website, www.kmo.dk, the following information can be found: The share of refilled HCFC-22 in the years before the ban in 2000 was about 45% of all used refrigerants. This share has decreased since the ban of new equipment in 2000 and was about 18% in 2011, which is 32 tons of HCFC-22. The share is expected to be about 15 % in 2013, which is about 27 tons.

Danish Technological Institute (DTI) is working closely with KMO, the Danish Environmental Protection Agency and the refrigeration trade. Therefore, DTI has some information about where the old HCFC-22 refrigeration systems are placed. There are many of such systems, at least 5.000, and they are used for many purposes. The general pattern is as follows:

1. Supermarkets and shops: The biggest usage is commercial refrigeration systems in supermarkets and smaller special shops like bakeries, butcher shops etc. A qualified guess is about 20 % of all HCFC-22-systems and about 30-35 % of the usage.
2. Food producers: HCFC-refrigeration systems are installed in small and medium sized companies for import and export of sea food, dairies, breweries, producers of cakes,

chocolate and salads, storage of fruit and vegetables etc. This count for about 15% of HCFC systems and about 25-30 % of the usage.

3. Cooling of industrial processes: Chillers for cooling of industrial processes such as plastic molding machines and in the pharmaceutical industry. The chillers produce cold water for cooling purposes. This counts for about 5% of the systems and about 10 % of the usage.
4. Air conditioning with chillers: The chillers produce cold water for cooling of buildings. This usage also counts for about 5% of the number of systems and about 10% of the usage.
5. Restaurants, professional kitchens, cafés and bars: There are many old HCFC-22 refrigeration systems which are cooling cabinets, drinks and walk-in cold rooms. These are mainly condensing units and they count for about 10% of the systems and about 5% of the usage.
6. Milk coolers at farms: There are still some old HCFC milk coolers at farms, and they count for (maybe) 10% of the systems and 5% of usage.
7. Heat pumps: many heat pumps with HCFC-22 were installed in private homes during the 1990s. It is likely that some of them are still working.
8. Other significant usages:
 - Hospitals: There are many HCFC-22 systems at hospitals. It must be supposed that they are for special cooling purposes. They count for about 2 % of systems and usage.
 - Universities: There are many HCFC-22 systems at universities. It must be supposed they are for special cooling purposes. They also count for about 2% of systems and usage.
 - Sport facilities, conference centers and other public institutions. HCFC-22 systems count for about 1 % of systems and usage.
 - Ferries and other ships: HCFC-22 systems count for about 1 % of systems and usage. NB: There might be other sources for supplying ships which are not accounted for in this analysis.
 - Museums: There are some HCFC-22 systems for special purposes in museums. They count for less than 1% of systems and usage.
 - Armed Forces: There is a very limited number of HCFC-22 systems with small usage in the Armed Forces.
9. Other systems: There might be other HCFC refrigeration systems which DTI is not aware of.

There is no official registration of the old HCFC refrigeration systems and the specific number is unknown. However, due to knowledge gained from cooperation with the refrigeration trade, DTI

estimates that at least 5.000 HCFC-22 systems are still being operated in Denmark. The number might be higher.

The use of HCFCs in fishing vessels in the Nordic countries

A Nordic project carried out in 2008-2010 by PlanMiljø ApS in cooperation with the Nordic Ozone Group investigated the use and leakage of HCFC-22 in fishing vessels in the Nordic countries (Poulsen, 2011).

Fishing vessels with HCFC-22 refrigeration systems were built before 2000 when a general ban on HCFCs for new systems was introduced. Fishing vessels have an expected lifetime of 20 – 30 years and there are still many vessels with HCFC-22 in operation.

The largest figures for the amount of HCFC-22 in fishing vessels belong to the following nations: Norway, the Faroe Islands and Iceland. In Denmark, Sweden and Finland there are no (or only marginal) presence of HCFC-22 systems in fishing vessels. Furthermore, the presence of HCFC-22 systems is mainly in smaller vessels < 25 m. The charge is mainly between 500 kg and 4 tons HCFC-22 per vessel, and the leakage rate is high because of rough conditions onboard the fishing vessels. An “acceptable” leakage rate is < 20% p.a.

The lower limit of refrigerant charge is for small and medium sized RSW-systems (Refrigerated Sea Water), and the upper limit is for ships with central systems for freezing and frozen storage.

The total amount of HCFC-22 on board fishing vessels in the Nordic countries was approx. 850 tons:

Norway: more than 400 tons (340 ships, consumption approx. 95 ton/yr)

Iceland: 200 tons (150 ships, consumption approx. 55 ton/yr)

Faroe Islands: 150 tons (130 ships, 40 ton/yr)

Denmark: less than 5 tons (5 to 10 ships)

Sweden and Finland: almost nothing

According to Poulsen, 2011, Greenland has about 10 ships with HCFC-22. No further figures are mentioned for Greenland.

The situation for fishing vessels today

It is assumed that the situation is different today. According to the authorities on the Faroe Islands (Umhvørvisstovan), the consumption of HCFC-22 (in total in the Faroe Islands) has decreased substantially in the period 2003 – 2009 to 2012. This might indicate that the fishing fleet has been replaced/converted to other refrigerants.

However, according to a representative for the fishing vessel owners, HCFC-22 is still used in many Norwegian fishing boats (Haukås, 2013).

3. Phasing out HCFC-22

This chapter describes the transformation from HCFC-22 to alternatives in refrigeration systems.

HCFCs (HydroChloroFluoroCarbons) are ozone depleting substances which are controlled by the Montreal Protocol. The most used HCFC (HCFC-22 or R-22) is less potent ozone depleting compared to the CFCs, which were banned in the 1990s. Appendix A provides tables with properties for different refrigerants and mixtures of refrigerants. From the first table it can be seen that HCFC-22 has an ozone depleting potential of about 5% compared to CFC-12, which (per definition) has the value ODP = 1.

HFCs and other fluorinated greenhouse gases

Some alternatives for HCFCs belong to the F-gases. These gases do not deplete the ozone layer. F-gases are fluorinated gases (HFCs, PFCs and SF₆) which are potent greenhouse gases. They are covered by the Kyoto Protocol.

The HFCs (HydroFluoroCarbons) are the most used group of F-gases, and they are most frequently used in the refrigeration industry as the working fluid in the refrigeration cycle. There are many different refrigerants based on HFCs. The most important ones are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407C. The most common refrigerants based on HFCs have Global Warming Potentials (GWP) from about 1300 to 4000. The baseline is CO₂, which has a value of 1. The GWP value of different refrigerants and mixtures can be found in appendix A.

One of the main objectives of this report is to advise owners of HCFC-22 refrigeration systems to avoid replacing HCFC-22 with HFCs as far as possible due to the high global warming potential of HFCs.

HFOs

The manufacturers of F-gases have developed low-GWP HFCs ("HFOs") such as HFC-1234yf with a GWP = 4 and HFC-1234ze with a GWP = 6. These new substances are expected to have a role in the refrigeration industry in the future. HFC-1234yf has been introduced in mobile air conditioning (AC) systems. There is, however, an ongoing discussion about flammability and other issues (see the section about mobile refrigeration). As mentioned above, the HFOs are expected to have a role in future refrigeration, but the situation is unclear. This alternative is not dealt with in more details in this report.

Natural refrigerants

Natural refrigerants are substances that can be found in nature's own cycle, e.g. ammonia, hydrocarbons, CO₂, water and air. Natural refrigerants do not deplete the ozone layer and has a very small (or no) GWP.

None of the natural refrigerants are perfect and they all have technical limitations; Ammonia is toxic in high concentrations, hydrocarbons are flammable when mixed with air, CO₂ operates at high pressure and has a low critical point, water 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 one fluid cannot cover all applications.

The industry in the Nordic countries has successfully implemented natural refrigerants for a wide range of applications; some of these appear from the examples in this report.

Strategy for phase out of HCFC-22

By 1 January 2015, the HCFC-22 refrigeration systems will be at least 15 years old and have been working most of their expected lifetime.

The expected lifetime for smaller equipment with air cooled condensers is up to 20 years, and the lifetime for bigger industrial systems with water cooled condensers can be up to 30 years.

Replacement

It would make sense to replace the older refrigeration systems and the systems in poor condition, since the end of their expected lifetime is near and a replacement must (in any case) be done in the near future. The systems can be replaced with systems with natural refrigerants or in some cases to systems with HFC refrigerants. It is up to the owner to decide.

One benefit of replacing the system is the ability to design a new and energy efficient system with the latest technology and components. Replacement is more expensive compared to conversion (in first costs), but as just mentioned earlier, it gives the possibility to acquire a more efficient system which will save energy and might be cheaper in the long turn. In Denmark and Norway, a replacement to a natural refrigerant will also save expenses for HFC tax.

Chapter 4 gives very good examples of refrigeration systems with natural refrigerants, which can replace old systems with HCFC-22 or HFC-refrigerants. The examples are mainly based on products developed and manufactured in the Nordic countries.

Conversion

In some cases it may be cost effective to convert a refrigeration system instead of replacing it. This might be the case if the system is in good shape and it still could be operated for several years. The term “conversion” includes:

- simple change to a “drop-in” refrigerant with similar properties as the ones of HCFC-22, with no or only minor technical modifications required
- system rebuilding, which may include the replacement of (major) components and possibly parts of the piping

System rebuilding to natural refrigerants

For refrigeration systems in good shape, it would in some cases make sense to rebuild them to ammonia or hydrocarbons. For a rebuilding to be of economic interest, a substantial part of the components and piping must be compatible with the properties of the new refrigerant.

Some examples are given in chapter 5.

Conversion to HFC refrigerants

For some newer refrigeration systems in good shape, it would also be possible to convert to an HFC refrigerant by replacing the existing refrigerant by a so called “drop-in” fluid. A drop-in refrigerant has similar refrigeration properties as the original fluid and can, in principle, be charged directly

after recovering the original refrigerant. Minor adjustments of system controls (expansion valve, pressure switches etc.) will normally be required. In some cases, the original refrigeration oil has to be changed to a lubricant which is more compatible with HFCs, e.g. a polyol ester. A variety of new HFC blends are marketed as drop-in replacements for HCFC-22.

The drop-in refrigerants are often mixtures of HFC substances with different boiling temperatures (zeotropic mixtures). This will introduce a temperature glide in the condenser and the evaporator, which will influence the cooling capacity and the efficiency of the system. The energy efficiency will often become poorer. The HFC mixtures in the R400 series are all zeotropic mixtures with a temperature glide. The R400 mixtures can be used in direct expansion refrigeration systems. However, the mixtures should not be used in refrigeration systems with flooded evaporator and pump circulation (which often is the case in bigger refrigeration systems) since the energy efficiency will suffer to a great extent in such systems. An exemption is HFC-404A, which has only a minor temperature glide.

A conversion (rebuild) can also be made with one-component HFC-substances (like R134a). However, this will require a shift of oil and other changes in the refrigeration system, such as a shift of expansion valve(s) in systems with direct expansion. In addition, in the case of R-134a, the compressor suction volume must be increased with about 60 % to keep the cooling capacity at its original level.

Finally, it might be possible to change to an azeotropic refrigerant mixture in the R500 series, e.g. R507A. The refrigerants in the R500 series behave like a pure substance and do not introduce a temperature glide. R507 is, however, a refrigerant with a very high GWP-value and it might be banned in the future in the EU and EØS. The same applies for R404A.

It should be underlined that conversion to a HFC refrigerant is far from ideal in that HFCs are potent greenhouse gases and subject to stronger EU-regulation in the future. This applies in particular to R-404A and R-507A which have by far the highest GWP-values. If possible, one should choose natural refrigerants instead.

Regulation of HFCs

Please note that:

- New stronger EU regulation on F-gases including HFCs was agreed in December 2013 and this includes a phase down scheme of the available amount of HFC refrigerants in the EU and EEA. Based on the quantity in 2015, the available amount will be phased down in steps to 21 % in 2030. Bans of new equipment using high GWP refrigerants will enter into force, including:
 - Refrigerators and freezers for commercial use (hermetically sealed), GWP > 2500: 1. January 2020
 - Refrigerators and freezers for commercial use (hermetically sealed), GWP > 150: 1. January 2022
 - Stationary refrigeration equipment (> -50 °C), GWP > 2500: 1. January 2020
 - Single split AC-systems, < 3 kg refrigerant, GWP > 750: 1. January 2025
- HFC refrigerants are quite expensive, especially in Norway and Denmark where a high tax adds to the price.

- In Denmark, it is not allowed to convert to HFC refrigerant when the refrigerant charge is > 10 kg.

Cost for conversion to ammonia and HFCs related to fishing vessels

In the examples regarding conversion of ammonia freezing systems in chapter 5, the rebuild was found to be 30% and 60% cheaper than new ammonia installations in connection with Case 1 and Case 2, respectively. In the case of fishing vessels, it is believed that the conversion of RSW-systems to ammonia, if applicable, will be less economic in most cases compared to the freezing system in Case 1, since both the evaporator and the condenser normally have to be replaced. The cost for conversion of RSW chillers from HCFC-22 to HFCs (HFC-507A and HFC-134a) was analyzed in a project carried out for the Nordic Ozone Group under the Nordic Council of Ministers in 2003. For new systems, conversion of RSW systems was found to be 50-70 % less costly compared with new HFC installations for a small RSW chiller (100 kW) and 35-50 % less costly for a bigger unit (500 kW). Specific cost analysis was not made for conversion of freezing systems (only HFC-507A applicable), but it was assumed that the cost savings would be of similar magnitude (in %) as for RSW systems. It is believed that these figures are fairly valid even today. A direct cost comparison between ammonia and HFCs as conversion fluids has not been made. From the information above, it can be concluded that ammonia competes better economically in terms of freezing systems than RSW chillers. It should be noted, that operation costs will be significantly lower with ammonia due to higher system efficiency (10 % or more), less leakage and a much cheaper refrigerant.

Taking the HFC tax into account, the competitiveness of ammonia improves strongly, especially for freezing systems with large charges of refrigerant. Thus, under Danish and Norwegian conditions, ammonia would most certainly be the most economical alternative, provided that a suitable room for the equipment is available.

When building new refrigeration systems onboard fishing vessels, it is recommended to use ammonia rather than R507A. The cost difference is minor (for systems over a certain size) and, as mentioned above, refrigeration systems with R507A will use at least 10 % more energy. Hence, the life cycle costs for the R507A system will be higher compared with the ammonia system.

In countries with a tax on F-gases, the tax will rule out R-507A as a refrigerant in freezing systems and also make RSW systems much less competitive versus ammonia.

RSW chillers with CO₂ as refrigerant have been developed and tested (see chapter 4). The first cost is currently higher compared with HFC units, but the difference is believed to decrease.

4. New refrigeration systems with natural refrigerants

In this chapter, all major refrigeration sectors are treated and a special view is taken on alternative technology using natural refrigerants like hydrocarbons, ammonia and CO₂. The examples are primarily based on technology developed in the Nordic countries.

The reason why all major refrigeration sectors are treated is due to the fact that this report presents alternatives to both HCFCs and HFCs.

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) was used 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. R134a was also used by some manufacturers for blowing polyurethane foam.

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

In Germany, the company Foron together with environmental organisations introduced refrigerators with hydrocarbons. Other manufacturers soon followed suit. Danfoss was quick off the mark 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. This also applied to foreign manufacturers who wanted to sell on that market. Many people feared that explosions might occur in some of the refrigerators because there was a risk of an explosive mixture of hydrocarbons and air developing in the cabinet. The mixture could be ignited by a spark from the thermostat, door contact or other spark generator. The 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 of appliances have been built and the technology has proven to be safe.

Furthermore, refrigerators and freezers with hydrocarbons have proved to be more efficient than 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 development work for compressors and new energy efficient appliances is based on hydrocarbons.

Hydrocarbon technology is also gaining momentum in most countries in Asia, Africa and Latin America and it is expected to be introduced on the US market.

Commercial refrigerators and freezers (plug-in)

A significant number of commercial refrigerators and freezers is manufactured and installed in the Nordic countries. It is estimated that there are about one million units installed, although the specific figure is unknown. The three largest groups of appliances within commercial refrigerators and freezers (plug-in) are bottle coolers, professional kitchen refrigerators & freezers and ice cream

cabinets. Commercial refrigerators and freezers also include 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, gas station and kiosk. 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 they are labelled with the logo of the company.

It is estimated that about 350,000 bottle coolers are installed in the Nordic Countries where a significant production also takes place (Norpe (FIN), Vestfrost Solutions (DK) and Gram Commercial (DK)).

Previously, R-134a and R-404a were the standard refrigerants in bottle coolers and almost all bottle coolers sold until 2010 use F-gases.

However, this has changed rapidly during the last couple of years. Already in 2000, Vestfrost Solutions marketed a hydrocarbon version using R600a and has delivered several thousand units to the European market. Later on, Gram Commercial also started a production with R600a.

In 2006 – 2007, a field test was conducted in a cooperation between Carlsberg, Vestfrost and Danish Technological Institute. Nine coolers were operated with CO₂, five with R134a and four with R600a. In 2006, they were placed in supermarkets for three months and during this time field tests were carried out.

The hydrocarbon coolers as well as the CO₂ coolers showed good performance; the hydrocarbon coolers showed 27.7% reduced energy consumption compared to the R134a coolers and the CO₂ coolers showed 11.7% reduced energy consumption compared to the R134a coolers. (Pedersen, 2008).

On the basis of these results and other investigations, Carlsberg has decided to go for hydrocarbon coolers where possible and where educated technicians can service the appliances. Hydrocarbon coolers have proved reliable and Carlsberg is installing bottle coolers in the Nordic countries and has started installation in Germany and Switzerland. Soon, they will be installed in other countries as well (Andersen, 2011).

Photo 1: Vestfrost bottle cooler during field test in a supermarket in Copenhagen, Denmark..

Norpe (FIN) provides at least four different bottle coolers with propane (R290) as refrigerant (670 l, 921 l, 1310 l and 1855 l).

Photo 2: Two-door bottle cooler from Norpe (FIN) using R290 refrigerant (from [www. norpe.com](http://www.norpe.com))

Status of HFC free technology

HFC free technology with hydrocarbon refrigerant is very rapidly being introduced to the EU market.

CO₂ based coolers are also a possibility, but so far these have only been produced in limited numbers.

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 sizeable ice cream producers.

Many ice cream cabinets were earlier produced in Denmark. However, most of this production has been moved to low income countries, and Elcold and Vestfrost are now the only producers, and the production is small.

HFC refrigerants were standard use (R404A and R134a). However, hydrocarbon cabinets have been available for many years and it seems as if hydrocarbon technology now is the standard within the EU. Unilever has chosen hydrocarbons for their ice cream cabinets and they are implementing hydrocarbon cabinets worldwide.

Unilever started the HC cabinet rollout in Europe (in Denmark) in 2003 (with 800 cabinets). In 2004, Unilever introduced about 15,000 cabinets into 17 countries in the EU followed by an additional 40,000 cabinets in 2005. In 2010, the company installed approx. 100,000 cabinets with hydrocarbons and Unilever has now installed more than a million units worldwide. This figure is going to increase to 1.3 million in 2015 (<http://www.refrigerantsnaturally.com>, 2013).

Status of HFC free technology

HFC free technology is available and it is marketed and implemented. Moreover, it is a standard technology using hydrocarbon refrigerant.

Professional kitchen refrigerators & freezers

It is estimated that about 250,000 professional kitchen refrigerators and freezers are installed in the Nordic countries. Most of them are of the stainless steel upright type, but also counter types are present. Three manufacturers are present in the Nordic Countries.

Since 2002, Gram Commercial in Denmark has marketed appliances with R290, and this type is now standard for the company's products in Denmark and other European countries. Gram has about 50% of the market in Denmark and 85% of the production is exported to mainly UK, Germany, Austria, Holland, Belgium, Sweden and Norway.

*Photo 3: Professional kitchen refrigerator (food service cabinet) from Gram.
The refrigerant system uses R290 (propane).*

Porkka (FIN) offers professional kitchen appliances with propane R290.

*Photo 4: Porkka (FIN) professional kitchen refrigerator with R290 refrigerant
(from www.porkka.fi)*

Haglund (Sweden) is producing professional kitchen appliances with R290.

*Photo 5: Haglund (S) professional kitchen refrigerator with R290 refrigerant
(from www.haglundindustri.se)*

Wine Coolers

To some degree wine coolers look like bottle coolers and they 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 (as far as DTI knows) the only manufacturer in the Nordic countries. Vestfrost produces energy efficient coolers and uses compressor cooling technology, which uses R600a as the standard refrigerant in their production.

Photo 6: Vestfrost wine cooler using R600a (isobutane).

Walk-in cold rooms

Small cold rooms (WICR, Walk-in cold rooms) less than 10 m³ are now available with R290 (propane) refrigerant.

Porkka (FIN) has developed and marketed these new products. The refrigerant charge is less than 150 grams and the price is 2 – 5 % higher compared to HFC-systems (Kahrola, 2013). The new WICR are marketed in the Nordic countries and the EU.

Photo 7: Walk-in cold room using R290 (propane) refrigerant (from www.porkka.fi)

Minibars

Three different refrigeration technologies are available for use in hotel minibars. Absorption minibars have so far been the most common type.

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

Thermoelectric minibars are also available in smaller numbers. They are quiet but have high energy consumption and a long pull down time. Thermoelectric cooling uses a “Peltier element” which is a semi-conductor.

Compressor minibars are much more energy efficient but they have a slightly higher sound level, when the compressor is working. The use of compressor minibars is now expanding very quickly in Europe and they represent at least 50 % of the market. This figure is increasing. The driving force is energy efficiency. Compressors for R600a of relevant sizes are available from SECOP (former Danfoss Compressors) and others and they are becoming the standard. (J. Christensen, 2013).

Vending machines

R134a is the 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 focuses on CO₂ as refrigerant and the objective is to be HFC-free in the near future.

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 HFC refrigerants were earlier the standard use. Coolers using hydrocarbon (R600a) are available on the market.

Ice machines

A great number of ice machines are installed in restaurants and bars. So far, HFC refrigerants have been the standard. The Japanese company Hoshizaki with production in the UK has developed and marketed ice machines with hydrocarbon technology (R290) and the first units are available on the European market. Scotsman also provides units with R290 and other ice machines prepared for CO₂ refrigerants delivered from external (remote) refrigeration systems.

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 cabinets for remote cooling machinery.

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

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

AHT from Austria is a major manufacturer of such cabinets. Since 2007, hydrocarbon cabinets using R290 have been standard.

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 and many of them are placed in rural areas in developing countries.

Vestfrost Solutions has a production of vaccine coolers in Denmark.

R134a has been the standard refrigerant, but WHO has drafted new standards, which also allow hydrocarbon as refrigerant. Vestfrost now offers vaccine coolers ("ice liner") with R600a.

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 which are powered by solar cells (photovoltaic). SECOP (former Danfoss Compressors) is a major manufacturer of compressors for this type of appliances, and so far, R134a is used as refrigerant. SECOP has developed and marketed new DC compressors for isobutane and propane. Up till now, DC compressors have been used in a limited number of solar powered vaccine coolers and solar powered ice cream cabinets.

SolarChill vaccine coolers

Vestfrost Solutions was first on the global market with a SolarChill vaccine cooler, approved by WHO. This SolarChill vaccine cooler is powered directly by photovoltaic panels. It uses hydrocarbon refrigerant and has an ice storage which can keep the vaccine cool for up to 5 days

without any power. At least 2,000 SolarChill vaccine coolers are now installed at health centres in areas without grid electricity. The SolarChill technology is developed in a partnership between the organizations: WHO, UNICEF, UNEP, PATH, GIZ, Greenpeace International and Danish Technological Institute.

Photo 8: Photo of the SolarChill vaccine refrigerator, produced by Vestfrost. The refrigerant is R600a (isobutane). Ice storage ensures cooling during night time.

Commercial Refrigeration

This section includes centralized systems in supermarkets and condensing units for special shops, restaurants, professional kitchens, bars, café's etc.

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, storing and displaying of frozen and fresh food as well as 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). Commercial refrigeration is the refrigeration subsector with the largest refrigerant emissions calculated as CO₂ equivalents. These represent about 40% of the total annual global refrigerant emissions (IPCC/TEAP, 2005). This is due to high charges of refrigerant (distributed systems) and high leakage rates. For commercial systems, it is typically seen that the direct emissions of greenhouse gases 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.

Furthermore, HCFC-22 was widely used before the ban of this substance in new refrigeration systems. HCFC-22 was widely used in both centralised systems in supermarkets and in condensing units in small shops, small walk-in cold rooms etc. HCFC-22 systems have been installed up to 2000, and it has been possible to service those systems since then, except in Sweden where a ban on servicing came into force in 2002. This is the reason why there still are many HCFC-22 systems in most of the Nordic countries.

After the ban of installation of HCFC systems came into force, R-404A has been the preferred refrigerant for commercial refrigeration. R-404A has a quite low normal boiling point so it can be used at both low and medium temperatures. R-134a has also been used, but mainly for medium temperatures.

Commercial refrigeration comprises of three main types of equipment:

1. Stand-alone equipment (plug-in)
2. Condensing units
3. Centralised systems.

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

Condensing units are used with small commercial equipment and they comprise of 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 supermarket systems

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 subdivided into three groups:

Direct systems; where the primary refrigerant (R404A and now: CO₂) is circulated directly to the evaporators.

Indirect systems; where the primary refrigerant and a heat transfer medium (a secondary refrigerant) exchange heat in an extra heat exchanger and the heat transfer medium is pumped to the cabinets and storage rooms. The heat transfer medium can be single-phase brine, but also two-phase fluids such as volatile CO₂ or ice slurry can be used.

The last group is *hybrid systems*; where two 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) as well as to cool the low temperature refrigerant in the cascade heat exchanger. The low temperature refrigerant is used at the low temperature level (frozen food). Some cascade systems (increasing in numbers) with CO₂ and a conventional refrigerant use CO₂ even for cooling demand at approx. 0 °C.

So far, a lot of work has been carried out regarding the development and implementation of refrigeration systems working on natural refrigerants.

Legislation

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

Since 1 of January 2007, a total ban on the use of HFC refrigerants in Denmark in new systems with charges exceeding 10 kg has been in force. This ban has had a huge impact on the systems implemented especially in supermarkets, as practically all new supermarkets are built with transcritical CO₂ systems.

Leakage rates

The leakage of HCFC and HFC refrigerant from commercial refrigeration systems is rather high due to distributed piping. The leakage rates have earlier been estimated to be about 15% and even more of the charge per year. However, a great deal has been done in the past to reduce the leakage. Today, all references indicate that the leakage rate is about 10% per year (including accidents, e.g. breaking pipes).

The leakage from more compact systems such as stand-alone and condensing units is smaller. It is estimated to be about 1 - 5% (stand-alone) and 5% (condensing units) per year.

Experience with alternative systems

During the past decade, many different concepts of supermarket refrigeration systems have been designed, built and tested.

These alternative systems can be divided into three main groups:

- Indirect systems with brine. The refrigerant in the primary system can be R134a, R404A, propane or ammonia.
- Cascade systems with propane, ammonia, R134a or R404A in the primary system and CO₂ as low temperature refrigerant. Different designs have been tested.
- CO₂ used as transcritical fluid. Different designs have been developed and transcritical CO₂ systems are now the standard concept for supermarket refrigeration systems in the most of the Nordic countries.

Transcritical CO₂ systems

A "transcritical refrigeration system" is using a thermodynamic process, where the refrigerant is passing the critical point of the refrigerant (which is CO₂). The critical point is the condition above which condensation of gas to a liquid is no more possible.

The idea of using CO₂ in a transcritical system is not new. For the past 20 years, research and development has been carried out on smaller systems especially for heat pumps and air-conditioning units (eg. at SINTEF and NTNU in Norway). However, the know-how required to build an economic transcritical CO₂ system for the supermarket area was limited. A few test installations were made in Sweden, Denmark and Norway up to about 2005. Later on, an increasing amount of components became available and increasing experience was achieved. Moreover, large installers and supermarket chains chose this technology to be the standard.

Figure 1: Refrigeration system for supermarket using transcritical CO₂ as refrigerant. This piping diagram shows the first transcritical CO₂ installations in Denmark.

*Figure 2: Principal piping diagram for supermarket transcritical CO₂ booster system.
Today, this is the most frequently used system.*

The system operates under transcritical conditions during higher ambient temperatures (e.g. 25°C). A transcritical CO₂ system is an attractive option for supermarkets because they are much more simple than cascade systems. The system comprises of a high-pressure compressor that compresses the CO₂ to 120 bar. The compressed gas then enters a gas cooler where it is cooled to a temperature close to the ambient. Subsequently, the cooled, high-pressure gas 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 (under the critical point). The liquid is circulated towards the low and high temperature refrigeration cabinets where after the liquid is 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 mixed with the gas from the high-temperature cabinets after compression. The mixture is then led to the high-pressure compressor and the closed cycle starts again.

Status of supermarket refrigeration systems, 2013

Transcritical CO₂ systems need high pressure components and the availability was very limited until about 2005, where the first mass-produced commercially available compressors and regulation valves were launched on the market.

When this happened, it became clear to a number of people and companies that this technology poses a great potential. The technology has become competitive and superior because of the following issues:

- Only one refrigerant is necessary in supermarkets (CO₂)
- No need for additional heat exchangers (and the related loss caused by temperature differences in the exchangers)
- Environmental properties are very fine
- Properties for working environment are fine
- Good thermo physical properties for the refrigerant
- Good energy efficiency at normal ambient temperatures.

In Denmark and Norway, the conditions for a quick implementation of this technology became relevant, because of the high taxes on HFC refrigerants and (in Denmark) the introduction of the ban on building new systems with more than 10 kg HFC.

In the years from 2005 to 2009, a total of about 150 systems were installed in Denmark and a similar number in the rest of Europe. In 2010, about 200 systems were installed in Denmark and the total figure for Europe was more than 400 units.

In 2013, more than 1000 systems were installed in Europe. In the first part of 2014, the total amount of transcritical CO₂ systems in supermarkets is going to pass 3000 systems in Europe, approx. 700 of these systems will be installed in Denmark (K. G. Christensen, 2013).

Photo 9: Photo from the production of “remote refrigeration packs” for CO₂ at the Advansor Company in Aarhus, Denmark.

Supplier of transcritical CO₂ components and systems

The fast development of this technology has resulted in new business areas.

Danfoss has developed a full programme for valves and controls for transcritical (and subcritical) CO₂ systems. Danfoss offers these components worldwide and the business is increasing.

Photo 10: Valves for CO₂ refrigeration systems (Danfoss).

There are a number of suppliers of compressors, including Bitzer, Bock, Copeland, Dorin and Frascold as well as several manufacturers of heat exchangers, covering evaporators and gas coolers as well as plate heat exchangers for heat recovery and special applications.

New qualities of pipes (Wieland K65) have been available and can manage the high pressure in the systems as well as the inline components from different manufacturers.

In Denmark, at least three companies are building transcritical CO₂ systems:

- Knudsen Køling A/S is building as well as installing such refrigeration systems in Danish supermarkets.
- Carrier (formerly Birton) is also building and installing the system in Danish supermarkets.
- Advansor A/S.

The company Advansor was founded in 2006 by former employees at Danish Technological Institute and has achieved great success with developing a “remote refrigeration pack” for transcritical CO₂ refrigeration systems for supermarkets.

The packs are mass-produced at their factory in Aarhus, Denmark, and they are sold to large installers throughout Europe. The packs are sized in modules, and Advansor has a full programme for all supermarket sites. In 2011, about 300 supermarket refrigeration systems was built and about 80% were be exported (K. G. Christensen, 2013).

In the late 2011, Advansor was acquired by Hillphoenix, a Large US based manufacturer of refrigeration equipment for mainly supermarkets. Now Advansor is expanding their activities in Europe as well as globally. In Europe, Advansor is going to establish new production facilities outside Denmark to ensure a larger volume at even more effective conditions. By the end of 2014, Advansor’s production capacity is going to exceed 1000 systems per year.

Advansor is the world’s biggest producer of transcritical CO₂ systems for supermarkets. Since the beginning in 2006, new generations of systems have been developed and produced. This work ensures continuously better energy efficiency as well as lower investment and running cost.

The largest installer in Denmark is Superkøl, which covers 35-40% of the market. Superkøl has installed more than 200 transcritical CO₂ packs from Advansor and it is monitoring about 2,000 supermarket refrigeration systems. The transcritical CO₂ systems use approx. 10% less energy compared to similar HFC systems and the technology has proved to be reliable.

Sweden

In Sweden, the company Green and Cool has developed similar remote refrigeration packs. Green and Cool has produced transcritical refrigeration packs since 2007, and the refrigeration packs have been installed all over Europe. The company has been acquired by United Technologies, and the production takes place in France. The development work takes place in Luleå, Sweden. Green and Cool expected to produce about 200 systems in 2013 (Kyla, 2013).

Photo 11: Mistral 345 LT CO₂ transcritical refrigeration system from Green and Cool (Sweden) (www.greenandcoolco2.com).

At least two companies are producing supermarket refrigeration and freezer cabinets for CO₂ refrigerant. Norpe (Finland) is producing a variety of cabinets and Knudsen Køling (Denmark) is producing cabinets for CO₂.

Photo 12: Supermarket cabinets from Norpe, Finland (www.norpe.com)

Economy and energy efficiency

The new generation systems use about 10% less energy in Northern Europe compared to direct DX HFC systems (R404A).

In Central Europe, the figure is around 5% less energy.

In Southern Europe, the systems have to be tailor-made due to higher ambient temperatures and in some cases, cascade systems with subcritical CO₂ systems have to be used. New developments for warmer climate are now available in the market. These systems use more advanced technologies, e.g. parallel compressors or subcooling features, and actually improve energy efficiency for warmer climates. These new developments are going to move CO₂ into southern Europe as well.

In 2011, the price was 4 to 5% higher (for the total refrigeration system) compared to similar HFC systems and the payback time was 1 to 2 years in Denmark and Norway (because of the HFC taxes) and 3 to 5 years in other countries (K. G. Christensen, 2011). In 2013 these numbers are even lower. In countries with taxes on HFC, the prices are more or less even, whereas prices in countries with no taxes are currently (2013) only 3-6% higher which reduces the payback time to 2-3 years at the most (K. G. Christensen, 2013).

Condensing units

Condensing units with CO₂ are quite new products. In the Nordic countries there are two producers: Advansor (DK) and Green and Cool (S). Their products are quite new and supposed to replace the “old” condensing units with R-22 and HFCs.

It is in fact not correct to name them “Condensing units”, because during transcritical duty there is no condensing taken place due to the special nature of CO₂. “Gas cooler units” might be a more correct term, but this would not be understood by most users. Thus, they are called “Condensing units” in this report.

Photo 13: Condensing unit from Green and Cool (Sweden) (www.greenandcoolco2.com)

Photo 14: Condensing unit from Advansor (DK) (www.advansor.dk)

The new condensing units are much more expensive compared to cheap HFC-units. According to Advansor, the new products are optimized according to energy efficiency and this might be the driving force for this new technology. So far (October 2013), about 40 units have been installed (K. G. Christensen, 2013).

Chillers for Air Conditioning and industrial processes

In many office buildings and hospitals, chillers are installed for distribution of cold water in the buildings. The air in the individual rooms is cooled in heat exchangers by means of the cold water. Moreover, many industrial processes are cooled by cold water generated by chillers, e.g. cooling of plastic moulding machines and fermentation processes in the pharmaceutical industry. Various refrigeration systems are available for this purpose and CFCs and HCFCs were used previously. At present, HFC is the standard in Europe. In the past years, however, a large number of ammonia-based and hydrocarbon based refrigeration systems have been installed for this purpose.

Ammonia

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

Because of data confidentiality, it has not been possible to update the reference lists in later reports, but according to the largest installer in the Nordic countries (Johnson Control International, former Sabroe), many new ammonia chillers have been installed since then to cool large office buildings, hospitals, airports and other big buildings.

Sabroe Factory by Johnson Controls International, which is a major manufacturer of chillers, offers a wide range of ammonia chillers, heat pumps and tailor made industrial refrigeration systems (cascade, air and liquid cooled plants) in the range from 300 to 6.500 kW cooling capacity (Pachai, 2013). The factory is located in Aarhus, Denmark.

Photo 15: Assembly of ammonia chiller at Sabroe Factory (Johnson Control International and formerly York Refrigeration).

Photo 16: The shopping mall “Fields” in Copenhagen, Denmark, is cooled by ammonia chillers.

The price of ammonia chillers is higher than HFC chillers. The difference depends on the size of the chiller. Ammonia chillers are often competitive with other chillers because of the higher energy efficiency.

Ammonia reversible chillers are the primary source for both heating and cooling at Oslo International Airport (OSL). The airport opened in 1998 and since then a ground water based

reversible chiller has been in operation (6 MW cooling capacity and 8 MW heating capacity). The airport has recently been enlarged and an additional reversible ammonia chiller has been installed to cover the increased need for cooling and heating. The capacity of the new unit is 4 MW cooling capacity and 5 MW heating capacity (Eggen, 2013).

Photo 17: Reversible ammonia chiller (JCI, 4 MW cooling capacity and 5 MW heating capacity) recently installed at Oslo International Airport (OSL).

Hydrocarbon

The two Danish companies Bundgaard Kølleteknik and Johnson Control International have started a production of hydrocarbon chillers in the medium to large range (50-400 kW). Annually, the two competing companies produce about 150 units and most of the produced units are installed in Denmark and some are exported to e.g. Norway, UK and Germany.

The energy efficiency is better than in HFC systems (about 10%), but the price is about 20% higher compared to HFC systems. The payback time for countries without taxes will typically be 1 to 2 years (Pachai, 2013).

Hydrocarbon chillers cool the new University Hospital in Aarhus (Skejby), Denmark.

*Photo 18: Hydrocarbon chiller produced by Bundgaard Køleteknik (DK).
The refrigerant is R290 (Propane).*

Absorption

There are 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 Trondheim, Norway. This “cooling water” is warm and runs a huge absorption refrigeration plant at the University Hospital in Trondheim.

Recently, an absorption refrigeration system was installed in central Copenhagen. In combination with huge ammonia chillers, it is going to distribute cold water for district cooling of buildings in central Copenhagen.

Water vapour compression

Chillers using water vapour compression is currently being developed and a pilot plant is being developed in cooperation between JCI, DTI, Lego and a Japanese company. This work is economically supported by the Danish Energy Agency.

Energy efficiency

Energy efficiency is a very important issue for chillers. As the leakage rate is relatively small, the energy use is the most important factor for the environmental impact. Danish Technological Institute has carried out a small analysis in the Nordic report from 2007 (Pedersen, 2007). The Analysis compared 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 as well as algorithms for calculation of refrigeration systems. The calculations have been made for two different situations:

- a) Evaporation temperature - 10°C and condensation temperature + 35°C
- b) Evaporation temperature + 5°C and condensation temperature + 45°C

The evaporation temperature refers to the temperature to which the liquid is cooled and the condensing temperature refers to the ambient temperature. A small temperature difference will always occur between the heat exchangers.

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

Refrigerant	COP, Situation a) $T_0 = -10^\circ\text{C}$, $T_C = +35^\circ\text{C}$	COP, Situation b) $T_0 = +5^\circ\text{C}$, $T_C = +45^\circ\text{C}$
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, making an explicit comparison with refrigerants without glide difficult. No pressure drop in condenser and evaporator and no internal heat exchange.

Table 1: Comparison of COP (Coefficient of Performance) for refrigeration systems with different refrigerants. COP expresses the energy efficiency of refrigeration systems. The higher the value, the more energy efficient cooling system.

Table 1 shows a variety 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 comparison shows that R410A is inferior in terms of theoretical efficiency. Nevertheless, a great share of the market has been turned towards R410A in smaller AC applications. The main advantage of R410A is the volumetric efficiency that results in smaller components and better price competitiveness.

Emissions to surrounding environment/accumulation in scrapped products

The systems in question are compact, factory-made systems with a relatively small charge and limited emissions. The leakage rate is estimated to be 4 – 5% per annum.

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.

A few small, very inexpensive HFC chillers are expected to have a shorter lifetime.

Situation with respect to alternative technology

Alternative technology with natural refrigerants already exists.

District cooling

In Finland and Sweden, huge district cooling systems have been built and taken into use. A few systems are in use in Norway. They consist of pre-insulated pipes dug in the ground in a given city. The pipes distribute cold water for the cooling of buildings (and potentially also cooling of industrial processes). The cold water is generated by huge chillers. This technology can replace many smaller refrigeration systems.

Small air-conditioning systems

No production of small air-conditioning systems takes place in the Nordic countries. Although the climate does not necessitate air-conditioning, there is a growing tendency to set up small split systems – in almost each case, the systems are made in Asia. The refrigerant is R410A.

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

Hydrocarbon-based systems are being developed in Asia with refrigerant charges of 250-300 g. So far, there is no experience with these systems in the Nordic countries, maybe because nobody has tried to install them.

Moreover, De Longi in Italy offers a small local air conditioner with propane. So far, Danish Technological Institute has not heard about the installation of such an air conditioner in the Nordic countries.

Industrial refrigeration systems

Normally, industrial refrigeration systems are very large systems used for process refrigeration and cold storage within the food industry and the chemical/biochemical industry. Industrial refrigeration systems are built on site, using components suited for ammonia refrigeration systems.

Ammonia

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

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

CO₂

The installation of industrial refrigeration plants with CO₂ for low temperature purposes in cascade system is growing rapidly. Ammonia is used in the high temperature stage and CO₂ in the low temperature stage. Johnson Control International has built many such systems including warm climates (Pachai, 2013).

Financial barriers

There are normally no financial barriers related to the use of ammonia as refrigerant in large industrial refrigeration systems. In the case of small systems, the situation corresponds to the situation 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 today, it is the standard for industrial systems.

Mobile refrigeration systems

Mobile refrigeration systems is to be understood as the refrigeration systems installed in cars, trains, aircrafts, ships and containers.

Air-conditioning systems in cars

Since the mid-1990s, R134a has been used for mobile air conditioners (MAC).

Great efforts have been made by car manufacturers and sub-suppliers to develop MAC for CO₂. This technology is almost mature.

In the meantime, new low GWP HFCs have been introduced onto the market, and for a couple of years, car manufacturers have been working to implement the new low GWP substances which include HFC-1234yf. It would be easy to change to this substance as the existing refrigeration system can be used with no (or very simple) changes. However, the fluid is more expensive.

Some German manufacturers have declared that HFC-1234yf is dangerous to use and have stopped the development. They now declare that they will continue to develop CO₂-based air conditioning systems. Other manufacturers want to continue with HFC-1234yf, but the situation is unclear.

There is car production in Sweden.

It should be mentioned that in some countries hydrocarbons are used (by DIY – do it yourself enthusiasts) in car air-conditioning systems. This is for instance the case in Australia and USA. The refrigerant is a mixture of propane and butane which can be used as drop-in substitute for CFC-12 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 as 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 correctly 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 than 150. From 2011, there was a ban on refrigerants with a GWP higher than 150 in car air-conditioning systems in new types of cars and from 2017, the ban is effective in connection with all new cars.

The typical refrigerant charges in new vehicles are (Öko-Recherche, 2011):

- Cars and light trucks: 400 – 800 grams
- Heavy trucks: 0.7 – 1.5 kg

- Busses: 6 – 14 kg
- Double decker and articulated busses: up to 18 kg and more.

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 it 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.

Air conditioning in trains, trams and metro vehicles

The stock of HFC in Trains, trams and metro vehicles in the EU is about 160,000 vehicles of which about 75.000 are equipped with air conditioning systems. 75% of these are charged with HFC-134a and 25 % with R-407C. HCFCs are no more in use (Öko-Recherche, 2011).

The leakage rate is lower compared to MACs; about 7 % p.a. for rail vehicles.

The refrigerant charge is between 5 and 30 kg. For a double decker: up to 50 kg.

The European manufacturers have been working with two different alternatives: air cycle and CO₂.

About 500 individual cars of German ICE-3 high speed trains have been installed with air cycle systems (using the Joule process). They are light systems compared to normal HFC-systems, but they use about 20 to 30 % additional energy.

This technology might be interesting for Nordic countries (and Northern Europe) where air conditioning is needed only for a few days during the year. The additional energy consumption could be compensated by the light weight and the emissions savings of HFCs (Öko-Recherche, 2011).

Some manufacturers have developed prototypes with CO₂ refrigeration systems which have been presented at trade fairs. One leading German manufacturer has tested a prototype in a tram, and the energy efficiency has shown to be about 10 % higher (Öko-Recherche, 2011).

Integral reefer containers

The company Maersk Line is the world's leading carrier of refrigerated goods and has a big fleet of reefer containers in traffic at global level.

Since 1993, all new refrigeration systems have been installed with R134a as refrigerant. Maersk Container Industry had a considerable production of integral reefer containers in Denmark, but this production has been moved to low-income countries. CO₂ has been suggested as a refrigerant in reefer containers and Carrier offers refrigeration systems for containers with this refrigerant.

Emissions to the surroundings/accumulation in scrapped products

There is a relatively large leakage from integral reefer containers because of the violent actions they are subject to in ports and at sea. The leakage rate is of the same order of magnitude as for 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 the standard use on ships today. There is a large leakage of refrigerant from these ships because of rough physical actions at sea. Experts estimate a substantial annual leakage rate for reefer ships.

Large, new or retrofitted ships are also using ammonia as refrigerant, but ammonia cannot always be used in old ships.

Before 2000, HCFC-22 was the preferred refrigerant on board fishing vessels in the Nordic countries. Some of these ships are still in operation.

During the last 15-20 years, ammonia has become a common alternative to HFCs in new fishing vessels. In Norway, most of the new vessels over a certain size are equipped with ammonia systems. Recently, an RSW chiller with transcritical CO₂ process was designed and installed in a Norwegian fishing boat, Båragutt MS, as part of a research project at SINTEF. The system has been tested with very good results. This means that the fishing industry has got yet another environmentally friendly alternative which will be practicable for smaller boats as well. So far, the investments are higher compared with HFC alternatives, but the difference is believed to be reduced as the commercialisation of the system takes place (Haukås, 2013).

An example of a fishing vessel converted from HCFC-22 to ammonia is given in chapter 5.

Air-conditioning in aircrafts

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

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, the 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, commercial heat pumps, often combined with air conditioning, industrial heat pumps, medium sized heat pumps for heating groups of buildings 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

In the Nordic countries, about 1.5 to 2 million domestic heat pumps are installed, more than half of these in Sweden and most of them are air/air heat pumps.

The sale in 2011: Finland: 72,000, Norway: 83,000 and Sweden 107,000 (EHPA, 2012).

The sale in Denmark was about 30,000 in 2012.

The domestic heat pumps can be divided into 5 categories:

- 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 source: heat from ground/ Heat sink: hydronic system with water)
- Exhaust air heat pumps: (Heat source: exhaust air from the house/ Heat sink: hydronic system with water and/or inlet air to the house)
- Tap water heat pump: (Heat source: mostly exhaust air from house/ Heat sink: Tap water for local use in the building).

Liquid to water heat pumps and air to water heat pumps are mostly produced with R407C as refrigerant. A very small number of units are produced with propane (R290). A big production takes place in Sweden at a number of different producers.

Small exhaust air heat pumps and tap water heat pumps are often produced with R134a, even though at least one manufacturer (the big Swedish manufacturer Nibe) has chosen propane (R290) as refrigerant.

Figure 3: Nibe Fighter 200 exhaust air heat pump using propane (R290) refrigerant (from www.nibe.se).

Almost all air to air heat pumps are imported from Asia and they use R410A. This type of heat pump is normally reversible and can be switched to A/C-mode.

It is possible to make domestic heat pumps for propane without major additional costs. However, precautions have to be taken to eliminate the risk of fire. When the necessary infrastructure and service is in place, the additional cost of propane heat pumps is expected to be modest.

As mentioned earlier, CO₂ is very interesting in connection with heat pumps, and some manufacturers are committed to offering heat pumps with this refrigerant. The current price for CO₂ 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) at the moment. In the long term, it should be possible to deliver CO₂ heat pumps with modest additional costs.

A typical liquid/water heat pump is charged with 2.5 kg HFC and a tap water heat pump with 0.8 kg HFC. A typical split type air to air heat pump is charged with about 1 kg R410A.

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

Some cheap split type air to air heat pumps have been sold from supermarkets. Educated refrigeration technicians are required for the installation of such systems, but it is assumed that many systems have been installed by DIY people resulting in a considerable part of the refrigerant being emitted to the atmosphere. In such cases, the heat pump might not work or it will work with poor efficiency because of the lack of refrigerant. Finally, air might have entered the refrigeration cycle and this will also reduce the efficiency of the appliance.

Medium sized heat pumps

Heat pumps for heating single commercial buildings or groups of buildings, e.g. dwellings, cover a capacity range from approximately 50 kW to a couple of MW. Traditionally, HFCs have been used as refrigerants. In Norway, an increasing number is now using ammonia.

Large heat pumps

Johnson Control International and other companies use ammonia or hydrocarbons as refrigerant. CO₂ is also interesting for large heat pumps and the company Advansor is offering large CO₂ heat pumps.

Large heat pumps using water vapour compression is also a possibility and some R&D work is on-going.

5. Refrigeration systems changed from HCFC-22 to natural refrigerants

Case 1: Rebuilding a fishing vessel from R-22 to ammonia (R-717)

This example concerns an auto line vessel with an overall length of 46.95 m. It was built in 1998 and it is a typical representative of the auto liners built in the mid-nineties. The vessel was equipped with a traditional HCFC-22 refrigeration system.

In 2012, the HCFC-22 system was rebuilt to use ammonia. The main reasons for choosing ammonia were to get a lasting solution and to save costs in the future for recharging very costly HFC. In addition, the experience with ammonia refrigeration in fishing vessels since the first installations in the mid-nineties was very good. Ammonia had become more or less standard for new boats of the current size.

The rebuilt vessel is Frøyanes Senior, owned by Ervik Havfiske, Stadlandet, Norway. The rebuilding was performed by Pam Refrigeration AS, Halden, Norway.

*Photo 19: The Norwegian fishing vessel Frøyanes Senior.
The refrigeration system onboard this boat was rebuilt from HCFC-22 to ammonia.*

The refrigeration system

The vessel was equipped with three vertical plate freezers with 20 blocks per freezer, one horizontal plate freezer, one blast freezer for 4-5 tons per day and two freeze storages of 250 m³ each. Nominal temperatures were -37°C for freezing and -30°C for storage.

The HCFC-22 refrigerating system was a conventional single stage pump circulation system with a refrigeration capacity of approximately 130 kW. It consisted of:

- two single stage screw compressor units
- one sea water cooled condenser with tubing in copper/aluminum
- a 1500 l liquid separator with two refrigerant pumps in parallel
- finned air coolers in galvanized steel for blast freezer and storage
- carbon steel piping, except in the production area where stainless steel was used

The freezer plates were in aluminum.

The refrigeration system was in fairly good shape, except for the carbon steel valves in the production area, which were heavily corroded. Parts of the carbon steel piping also suffered from corrosion. After 14 years in operation, the plate freezers were ripe for replacement.

Required modifications

In general

Copper and copper alloys, which are widely used for piping and pipe accessories in HCFC-22 systems, are not compatible with ammonia. Similarly, commercial compressors for HCFC-22 contain parts in copper, e.g. motor windings in (semi)hermetic units, and cannot be used with ammonia. This is a serious obstacle in converting HCFC-22 systems to ammonia in general.

However, in industrial HCFC-22 systems the main piping is normally in steel. Open type compressors are used, which differ only marginally or not at all between HCFC-22 and ammonia versions.

At actual operating conditions (-40/+25°C), the compressor capacity is 10-12 % less with ammonia than with HCFC-22. Even though this deficiency is compensated for to some degree by more efficient heat exchangers, additional compressor capacity may be required with ammonia.

Fishing vessels are often approved by a classification society, e.g. Det Norske Veritas (DNV). This also applies to the refrigeration system on board. The requirements for approval are significantly stricter for ammonia systems than for HCFC-22 (or HFC) systems, especially with respect to machinery rooms. This makes an extra economic hinder for rebuilding to ammonia, which in some cases may exclude this alternative. However, to ignore machinery room requirements like those given by DNV is not an option, since this may jeopardize safety on board.

The fishing vessel in question had and should continue to have DNV approval.

Compressors

The compressors went through a major overhaul, according to the number of operating hours. No modifications were done due to the refrigerant change itself. The power consumption is less with ammonia than with R-22, so the compressor motors were sufficient. However, to compensate for reduced capacity with ammonia and to improve compressor efficiency at part load, the compressor

motors were equipped with frequency controllers. Maximum rpm was 4200, up 16 % from originally 3600 rpm. Together with more efficient evaporators, this fully compensated for the lower volumetric capacity with ammonia.

The oil separators had to be renewed according to DNV requirements. At the same time, the separators were modernized to reduce the oil discharge from the compressors.

The discharge temperature becomes significantly higher with ammonia than with HCFC-22. For this reason, the oil coolers had to be replaced. At the same time, the oil cooling system was modified from sea water cooling to thermosiphon cooling by high pressure ammonia liquid. In this way, the energy consuming sea water pump could be eliminated.

Plate freezers

The plate freezers were completely renewed as a general maintenance task, independently of the refrigerant change. If the freezers had been newer, only the refrigerant distribution nozzles and hoses would have had to be replaced. New plate freezers with ammonia should be significantly more efficient than the old with HCFC-22, which proved to be true. Suction pressure could be increased from -40°C with HCFC-22 to -36/-37°C with ammonia, saving at least 10 % power consumption.

Evaporators

The galvanized steel evaporators were kept. The blast freezer evaporators were designed specifically for HCFC-22, while the natural convection coils in the freeze stores had an “all round” design applicable for any type of refrigerant. Even with the higher evaporation temperature and a non-optimal ammonia evaporator design for the tunnels, the air cooling demands were met.

Condenser

The copper/aluminum condenser had to be replaced by a tube-in-shell condenser with titanium tubes.

Liquid separator

Change over from HCFC-22 to ammonia leads to stricter requirements for approval of pressure vessels. According to DNV's vessel classifications, the liquid separator came under class II with R-22 and under class I with ammonia. Class I implies among others 100 % non-destructive-testing (X-rays) of the welds. Upgrading of the existing vessel was not a practicable alternative, and the separator was replaced. The new separator was equipped with new local piping, valves and other equipment.

Refrigerant pumps

The existing refrigerant pumps were of the canned type and possible to use with any refrigerant. The required flow rate with HCFC-22 is bigger than with ammonia. Therefore, the pumps were supplied with new orifices to match the new flow demand.

Air purger

The original system was not equipped with an air purger. Due to operation at sub atmospheric pressure with ammonia, a standard air purger was installed.

Piping and pipe components

Corrosion is a common problem in the harsh environment on board fishing vessels, which also was the case for the actual boat. In addition, piping related to oil return had no function with ammonia, since manual oil tapping is used. For these reasons most of the carbon steel piping was removed. O-rings and gaskets were renewed in all reused valves.

The stainless steel piping in the production area was kept, but all carbon steel valves were renewed, primarily due to corrosion.

Control system, electrical installations

The control cabinet was renewed due to the installation of frequency converters and a new PLC. Parts of the electrical installations in the machinery room were renewed. However, it was possible to keep the main power supply to the room.

Some additional electrical and control equipment had to be supplied due to extra safety requirements. (See below).

Machinery room

Additional requirements to the machinery rooms from the classification societies may be the main hurdle to pass. With ammonia as refrigerant, the following requirements apply for DNV approval:

- a separate machinery room with gas tight walls and doors
- gas detectors connected to an alarm system
- emergency ventilation with automatic start at gas detection
- automatic power cut for the machinery room after high alarm (except equipment to be in operation after a heavy ammonia leak, i.e. gas detectors, emergency ventilation, emergency lighting)
- equipment in operation after high alarm must be EX-classified
- emergency shower and equipment for personal protection must be in place

On this vessel, a separate machinery room already existed with an exit in both ends and the power cut also existed. This facilitated the changeover to ammonia significantly. The other safety requirements were fulfilled as part of the rebuilding.

The cleaning process

Ammonia and HCFC-22 react chemically with each other to form a powder (ammonium chloride), which can block filters and valves and pollute the compressor oil. Therefore, a very thorough cleaning of components and piping which are to be reused is necessary. Since oil may contain small amounts of HCFC-22 and chlorine from HCFC-22 breakdown, all residual oil must be removed.

A water based degreasing solvent was pumped through the piping and components which were to be cleaned and recirculated for a minimum of 30 minutes. Afterwards, clean water was used to remove any traces of the solvent and finally, nitrogen gas was flushed through for drying.

Cost

The actual cost of the rebuilding was approximately 20 % lower compared to a completely new system. Since the renewal of the plate freezers, which accounted for about 35 % of the total cost, would have taken place anyhow, the cost savings for the parts of the system that relate directly to the refrigerant change becomes close to 30%.

Time

The cleaning process was fairly time consuming. Therefore, little time was saved compared to a complete renewal.

Experience

The operational experience after the refrigerant change has been very good. There have been no problems at all related to the rebuilding. Refrigerant leakage is practically eliminated and the maintenance costs have decreased considerably. The ship owner is very satisfied. A key to this encouraging result is obviously the very thorough cleaning of every tiny piece that were to be reused.

Case 2: Fish processing plant

Rebuilding of a fish processing plant from HCFC-22 to ammonia (R-717).

In the seventies and eighties, a trend towards moving from ammonia to HCFC-22 as refrigerant in small and medium sized industrial refrigeration systems was seen in Norway. The fish processing plant presented in the current rebuilding case is a typical representative for this development.

The plant is situated at the western coast of Norway and it consists of two freezing stores for fish, two heat pump fish driers and five small cold rooms. The refrigeration demand was approximately 150 kW for freezing and 40 kW for cooling. The heat pumps were designed for 220 kW and 330 kW heat output, respectively.

The freezing stores were originally connected to a centralized refrigeration system with pump circulation of HCFC-22, while the heat pump driers and the cold rooms each had a separate HCFC-22 dry expansion system. The installations were erected in 1988.

The rebuilding of the plant to ammonia took place in 2001 and it was performed by Pam Refrigeration AS, Halden, Norway. There were two main reasons for the rebuild; low system reliability and leakage problems.

The centralized system was in fairly good shape, while the heat pumps in the driers suffered from low reliability and frequent refrigerant leakages. Moreover, the small cooling systems for the cold rooms were ripe for replacement.

It was decided to rebuild the centralized system to use ammonia and extend it to cover the cold rooms as well. For the heat pump driers, replacement by separate ammonia systems was chosen. The new heat pumps had dry expansion, similar to the HCFC-22 units.

The installations in the cold rooms were made with copper tubing and copper/aluminum air coolers. None of these could be reused. Most of the heat pump systems were scrapped for the same reason. However, the compressors and (parts of) the electrical and control systems were kept.

Centralized refrigeration system

The centralized system was a standard two stage system with cooling capacity of approximately 150 kW at -37°C. It was equipped with:

- two two-stage piston compressors
- a sea water cooled tube-in-shell condenser with tubing in cupronickel
- a 1800 l liquid separator
- a 1000 l closed intermediate pressure vessel
- two hermetic (canned) refrigerant pumps in parallel
- four air coolers in galvanized steel in each of the freezing stores

The piping was in carbon steel, which facilitated the rebuilding to a large degree.

Required modifications

In general

Most of the equipment and piping in the centralized system could be reused in that it was made of steel, and because government regulations and requirements in the standards with respect to system design and construction did not differ much between the two refrigerants. However, completely new installations for the cold rooms and an updating of the safety system in the machinery room were necessary.

Compressors

One of the compressors was replaced by a new one due to wear. The other compressor went through a major overhaul, after 30,000 hours of operation. The capacity of the new compressor was increased to compensate for a bigger load at intermediate pressure and for lower volumetric capacity with ammonia. The new compressor was equipped with frequency control to get a more smooth and energy efficient part load operation.

The existing compressors had water cooled top and side covers, which is an “obligatory” feature for ammonia compressors.

The control system was kept, except for the new compressor. Compressor instrumentation was renewed in order to adopt it to the new refrigerant.

Evaporators

The galvanized steel evaporators in the freezing stores, as well as piping, valves and other pipe components were kept. The installations in the small cold rooms were completely renewed.

Condenser

The condenser was replaced by a shell and tube condenser with titanium tubes.

Liquid separator

In this case, the liquid separator could be reused. The only modifications were the change of instruments that were made specifically for HCFC-22.

Refrigerant pumps

The existing refrigerant pumps were hermetic of the canned type, similar to the ones in the fishing vessel in case 1. The pumps were kept, but supplied with new orifices to deliver the correct ammonia flow rate.

Purger

The original system was not equipped with an air purger. Due to operation at sub atmospheric pressure with ammonia, a standard air purger was installed.

Piping and pipe components

Most of the steel piping was in good condition and could be kept. All valves were upgraded with new stem seals. Gaskets were changed in valves, filters and other pipe components. The filter drier was replaced by a pure liquid filter. All piping and components related to the automatic oil return system were removed.

Control system, electrical installations

Most of the control system for the refrigeration plant was kept. However, a new compressor control was installed with the new compressor. Moreover, the electrical installations were kept and additional equipment and controls had to be supplied due to extra safety requirements. (See below).

Machinery room

The room itself fulfilled the requirements to a machinery room for ammonia systems in the standard. The safety installations were upgraded to match the requirements for ammonia machinery rooms, ie new EX-classified fan for emergency ventilation, EX-classified lighting, ammonia gas detectors and alarms according to the standard and so on. A main power switch for the machinery room already existed. Emergency showers and personal protection equipment were added.

The cleaning process

A similar cleaning process was used as described for the fishing vessel in case 1. Due to very long piping, the pipes were cleaned in sections.

Drying of the big liquid separator turned out to be a challenge in that accumulated water from the cleaning process in the bottom of the vessel was impossible to remove by drying only.

To overcome the problem, ammonia liquid was pumped into the vessel to absorb the water. The major part of the water was then drained together with the ammonia. The water containing ammonia was returned as special waste. A certain amount of “wet ammonia” was left in the separator. However, a minor water content in the ammonia does not affect the refrigeration process. (On the contrary, small amounts of water in the ammonia prevent stress corrosion).

Cost

The actual cost of the rebuild was estimated to be less than 40 % compared to a completely new system.

Time

Since most of the centralized system could be reused, the time required for the rebuilding was much shorter than for a complete renewal, probably less than half.

Experience

The experience has been very good and no particular problems have shown up after the rebuild. The capacity and reliability of the heat pump driers have improved remarkably.

Case 3: Ice rink

The ice rink was built in 1981 and had an HCFC-22 system with 6000 kg refrigerant. In 2009, it was renewed and the cooling system was changed to ammonia (NH_3). The ice rink is owned by the municipality of Turku, Finland, and the cooling system was renovated by Johnson Controls Finland.

CO_2 as a refrigerant was considered, but it was decided to go with NH_3 and indirect cooling with a secondary fluid, which was more widely used in Finland. The refrigerant charge is now only 132 kg ammonia. The heat from condensation is used to heat adjacent sport halls (Kylma, 2009).

The costs of the renovation of the ice rink was 1350000 euros.

Case 4: Cold storage

Fintermos Oy (<http://www.fintermos.fi/>) is a Finnish company which has frozen food storage warehouses in Naantali, near the harbor of Turku. The first parts of the warehouses were built in the 1970's. The total size of the cold storage is 30 000 m³ of which 85 % is frozen food storage space. Usually, the temperature is kept at - 20°C.

The process of replacing the HCFC-22 cooling equipment started a couple of years ago and ended at the end of 2013. A NH_3/CO_2 -secondary system was chosen as the replacement (except for one smaller cool storage space where direct expansion with R-407F was used). In the NH_3/CO_2 secondary system, the carbon dioxide is a “volatile secondary” refrigerant, which evaporates and condenses at nominally the same pressure. In the system, the liquid CO_2 is pumped from the receiver to the evaporators/air coolers in cold stores. Here, it is partly evaporated before it returns to the receiver. The evaporated CO_2 is then condensed in the CO_2/NH_3 -heat exchanger, which at the same time acts as an evaporator in the NH_3 circuit.

Technical information about the new NH_3/CO_2 -secondary system:

- Cooling capacity 450 kW
- CO_2 charge 2500 kg
- NH_3 charge 300 kg
- Grasso two stage, industrial type NH_3 -compressors
- Vahterus CO_2/NH_3 -heat exchangers, liquid-vapor separators and NH_3 -condensers
- Alfa Laval dry coolers in the cooling circuit of NH_3 -condensers
- Alfa Laval air coolers in cold stores
- Siemens S7 automation, programmed by Oilon Scancool Oy
- Installation of refrigeration equipments, Oilon Scancool Oy

The system has been designed and constructed in a way so that extension of the storage and cooling capacity is possible in the future. In the long-term life-cycle, energy efficiency savings are expected.

The project has already shown, that a NH_3/CO_2 -secondary system is an excellent way to reduce NH_3 charge in situations where a direct ammonia system is not feasible.

In Finland, a CO₂ secondary system has also been used for example in a huge ice laboratory (Aker Arctic), which is used for the development and design of icebreakers and other ice-going ships.

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Appendix A: Refrigerants and refrigerant mixtures

The following table shows the most common refrigerants consisting of single substances. ODS and GWP figures for HFCs and PFCs are from UNEP, RTOC 2010 report.

Substance	R-number	Chemical formula	ODP value	GWP value (100 yrs)
Halon-1301	R-13B1	CBrF_3	15.9	7,140
CFC-11	R-11	CFCl_3	1.0	4,750
CFC-12	R-12	CF_2Cl_2	0.82	8,500
CFC-115	R-115	CClF_2CF_3	0.57	7,230
HCFC-22	R-22	CHF_2Cl	0.04	1,790
HFC-123	R-123	$\text{C}_2\text{HF}_3\text{Cl}_2$	0.01	77
HCFC-124	R-124	CF_3CHClF	0.02	619
HCFC-142b	R-142b	$\text{C}_2\text{H}_3\text{F}_2\text{Cl}$	0.06	2,220
HFC-23	R-23	CHF_3	0	14,200
HFC-32	R-32	CH_2F_2	0	716
HFC-125	R-125	C_2HF_5	0	3,420
HFC-134a	R-134a	$\text{CH}_2\text{F}_2\text{CF}_3$	0	1,370
HFC-143a	R-143a	CF_3CH_3	0	4,180
HFC-152a	R-152a	$\text{C}_2\text{H}_4\text{F}_2$	0	133
HFC-227ea	R-227ea	C_3HF_7	0	3,580
HFC-236fa	R-236fa	$\text{C}_3\text{H}_2\text{F}_6$	0	9,820
HFC-245fa	R-245fa	$\text{C}_3\text{H}_3\text{F}_5$	0	1,050
HFC-1234yf	R-1234yf	$\text{CH}_2=\text{CFCF}_3$	0	4
HFC-1234ze	R-1234ze	$\text{CHF}=\text{CHCF}_3$	0	6
PFC-14	R-14	CF_4	0	7,390
PFC-116	R-116	C_2F_6	0	12,200
PFC-218	R-218	C_3F_8	0	8,830
Butane	R-600	C_4H_{10}	0	(20)
Isobutane (HC-600a)	R-600a	$\text{CH}(\text{CH}_3)_3$	0	(20)
Pentane	R-601	C_5H_{12}	0	(20)
Isopentane	R-600a	$\text{CH}_3(\text{CH})_2\text{CH}_3$	0	(20)
Propane (HC-290)	R-290	C_3H_8	0	(20)
Ethane (HC-170)	R-170	C_2H_6	0	(20)
Ethene (Ethylene)	R-1150	CH_2CH_2	0	(20)
Propylene (HC-1270)	R-1270	C_3H_6	0	(20)
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	< 1

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, weighing 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	1200	53/13/34
R-402A	HCFC-22/HFC-125/HC-290	2700	38/60/2
R-403A	HCFC-22/PFC-218/HC-290	3100	75/20/5
R-403B	HCFC-22/PFC-218/HC-290	4400	56/39/5
R-404A	HFC-143a/HFC-125/HFC-134a	3700	52/44/4
R-406A	HCFC-22/HC-600a/HCFC-142b	1900	55/4/41
R-407C	HFC-32/HFC-125/HFC-134a	1700	23/25/52
R-407F	HFC-32/HFC-125/HFC-134a	1825	30/30/40
R-408A	HCFC-22/HFC-143a/HFC-125	3000	47/46/7
R-409A	HCFC-22/HCFC-142b/HCFC-124	1600	60/15/25
R-410A	HFC-32/HFC-125	2100	50/50
R-412A	HCFC-22/HCFC-142b/PFC-218	2200	70/25/5
R-413A	HFC-134a/PFC-218/HC-600a	2000	88/9/3
R-414A	HCFC-22/HCFC-124/HCFC-142b/HC-600a	1500	51/28.5/16.5/4
R-415A	HCFC-22/HFC-152a	1500	82/18
R-417A	HFC-125/HFC-134a/R-600	2300	46.6/50/3.4
R-422A	HFC-125/HFC-134a/R600a	3100	85.1/11.5/3.4
R-422D	HFC-125/HFC-134a/R600a	2700	65.1/31.5/3.4
R-424A	HFC-125/HFC-134a/R600a/R600/R601a	2400	50.5/47/0.9/1/0.6
R-427A	HFC-32/HFC-125/HFC-143a/HFC-134a	2100	15/25/10/50
R-428A	HFC-125/HFC-143a/R290/R600a	3500	77.5/20/0.6/1.9
R-434A	HFC-125/HFC-143a/HFC-134a/R600a	3100	63.2/18/16/2.8

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	4600	51/49
R-507A	HFC-143a/HFC-125	3800	50/50
R-508A	HFC-23/PFC-116	13000	39/61
R-508B	HFC-23/PFC-116	13000	46/54
R-509A	HCFC-22/PFC-218	5700	44/56