MODULE 3

Technical Options

NAMAs in the refrigeration, air conditioning and foam sectors. A technical handbook.

On behalf of

Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

Deutsche Gesellschaft
für Internationale
Zusammenarbeit (GIZ) GmbH

Imprint

As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development.

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn,
Germany

Programme Proklima

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
Phone: +49 61 96 79 - 1022
Fax: +49 61 96 79 - 80 1022

Email: proklima@giz.de
Internet: www.giz.de/proklima

Responsible
Bernhard Siegele, Proklima Programme Manager,
bernhard.siegele@giz.de

Authors
Dr. Daniel Colbourne, Dr. Maria Martin, Igor Croiset,
Dietram Oppelt (HEAT GmbH, Glashütten)

Editors
Claudia Becker (HEAT GmbH, Glashütten)

Review
Marion Geiss, Sebastian Wienges, Markus Wypior (GIZ),
Barbara Gschrey (Öko-Recherche GmbH)

Production
Sophie Charlotte Diesing, Franziska Frölich (GIZ Proklima)

On behalf of
German Federal Ministry for the Environment,
Nature Conservation and Nuclear Safety

Division E III 7, International Climate Finance,
International Climate Initiative

Köthener Straße 2-3
10963 Berlin, Germany
Phone: +49 (0)30 18 305 - 0
Fax: +49 (0)30 18 305 - 4375

Email: EIII7@bmu.bund.de
Internt: www.bmu.de

Photos
Titel: Marius Graf - Fotolia.com; S.3: Katarzyna Krawiec - Fotolia.com; S.4: Mark Yuill - Fotolia.com

Layout
Jeanette Geppert, Frankfurt

Place and date of publication
Eschborn, October 2013

Serial number
G-S01-2013-en-01

Proklima

Proklima is a programme of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Since 2008 Proklima has been working successfully on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) under its International Climate Initiative (ICI) to promote ozone-and climate friendly technologies.

Proklima provides technical assistance for developing countries since 1996, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) to implement the provisions of the Montreal Protocol on substances that deplete the Ozone Layer.

This publication has been compiled in the project "Development of NAMAs in the refrigeration, air conditioning and foam manufacturing sectors" funded by the BMU International Climate Initiative.

www.giz.de/proklima

The International Climate Initiative

Since 2008, the International Climate Initiative (ICI) of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has been financing climate and biodiversity projects in developing and newly industrialising economies, as well as in countries in transition. Based on a decision taken by the German Parliament (Bundestag), a sum of EUR 120 million is available for use by the initiative annually. The ICI is a key element of Germany's implementation of fast start financing. The Energy and Climate Fund launched by the German Government in 2011 is a further source of funding for international climate protection projects, and for activities to conserve biodiversity. Part of that funding is deployed through the ICI. That fund is replenished from the auctioning of emission permits. This innovative source makes Germany well-prepared to deliver long-term financing for climate and biodiversity projects worldwide.

The ICI is active in four areas: Mitigating greenhouse gas emissions, adapting to the impacts of climate change, conserving natural carbon sinks with a focus on reducing emissions from deforestation and forest degradation (REDD+), as well as conserving biological diversity.

www.international-climate-initiative.com

Contents

Executive Summary

This module introduces alternative technical options to conventionally used systems in the refrigeration, air conditioning and foam (RAC&F) sectors. The introduction of these systems will lead to a reduction of emissions, which is the core element of Nationally Appropriate Mitigation Actions (NAMAs).

An overview of the different existing subsectors in the RAC&F sectors and the corresponding systems is provided to help identify those that are widespread in the country. This overview is important in order to decide in which subsectors a conversion would have the highest potential to reduce direct and indirect emissions. This module introduces the most important technical options, explaining their basic working principles, availability, possible additional costs and potential improvements in efficiency. All options assume that indirect emissions are reduced or at least remain the same. The best alternatives for each subsector are identified. For example, a tried and tested way to reduce emissions from energy production is the introduction of minimum efficiency rules. This is usually supported by legislation, standards and labeling.

Different barriers hinder the introduction of technical options on the market. The most significant ones include safety-related restrictions, implementation costs, technical implications and technical competence. Their impact varies with the technical option to be implemented. In the foam sector, thermal conductivity, mechanical properties and standards also form important barriers. The module describes these barriers as well as ways to overcome them.

The information about the different technical options will help to identify the most suitable options for a NAMA. A preliminary list of five technical options for a subsector can be developed step-by-step. This preliminary selection will then be evaluated using more quantitative cost and emission reduction calculations in module 4.

1. Introduction

In this module, alternative technical options to conventionally used systems in the RAC&F sectors are introduced. The introduction of these systems will lead to a reduction of emissions, which is the core element of NAMAs.

Products and applications in the various RAC&F subsectors range from domestic refrigerators to large-scale air conditioners and foam used in the automotive or shoe industry. It is important to first gain an overview of the different subsectors. Based on the overview, it will be possible to identify the subsectors that are most relevant for emission reductions and corresponding technical options to be introduced in a certain country.

Chapter 2 of this module gives an overview of the conventionally used systems as well as currently used refrigerants. The RAC sector can be divided into refrigeration and air conditioning subsectors. The first subsector includes domestic, commercial, industrial and transport refrigeration and the latter includes unitary and mobile air conditioners and chillers. The main sub-applications in the foam sector are polyurethane (PU) and polystyrene (PS) applications.

This module then introduces alternative technical options by which emission reductions may be achieved. It identifies the most suited target systems, discusses additional costs, efficiency implications and availability. The technical options include changes to the system, such as making it more leak-tight, changes of refrigerant type, and combinations of both, which is called a "concept change". This overview will help to identify those options that are most suitable for a certain country.

The introduction of technical options usually faces certain hindrances. These barriers vary in terms of time, cost and effort needed to overcome them. Barriers are not equally relevant for all technical options in all subsectors. They may also differ substantially between different countries. It is important to know and understand them well in order to make sound decisions in the selection of technical options. The most important barriers, their implications and ways to overcome them are described in this module.

A parameter that indicates how easily a specific technical option can be placed on the market is the so-called penetration rate (cf. chapter 2.3). The penetration rate is defined as the maximum market potential of a technical option for replacing a conventional technology in a subsector. Market introduction may be limited, due to safety concerns or efficiency constraints. Additional measures may be needed to raise safety levels or increase efficiency of the new system so that it can be accepted to replace the conventional system.

The foam section describes the technical options for foam blowing agents, in particular polyurethane (PU) and polystyrene (PS). This module presents the essential information on the various foam applications, alternative options and barriers to their introduction in the foam sector.

To sum up, this module provides an overview of the RAC&F sectors and subsectors, presents different technical possibilities to convert conventional systems and finally identifies possible barriers. It will help to identify the best suitable options to be implemented through a NAMA. For identifying those options that combine highest potential for emission reduction and lowest barriers, a list of the five most promising technical options for a subsector can be developed. This preliminary selection can then be narrowed down using marginal abatement cost curves which evaluate costs and related emission reductions in more detail (cf. module 4).

2. Methodology: Selection of technical options for mitigation of emissions in the RAC&F subsectors

This chapter introduces the different RAC&F subsectors. It discusses the most important technical options for introducing climate friendly technologies. Finally it describes the barriers that stand in the way to introducing these technical options and possible ways to overcome them as well as market penetration rates.

2.1 RAC subsectors

2.1.1 Description of RAC subsectors

This section introduces the different appliance systems[1] where cooling – either for air conditioning or for refrigeration - is wanted. Module 2 of this handbook provides an analysis of the growing demand and demand drivers for the specific systems.

Unless mentioned specifically, all refrigeration systems described are vapour compression types.

All subsectors and refrigerating systems are listed in Table 1. Systems are grouped, for example, where the majority of technical implications are similar (cf. module 1).

TABLE 1
Suggested definition of subsectors and systems for refrigeration and air conditioning

Sector	Subsector	Refrigerating system	Examples
Air conditioning	Unitary air conditioning	Self-contained air conditioners	Window units, "through the wall" units, packaged terminal units
		Split residential air conditioners	
		Split commercial air conditioners	
		Duct split residential air conditioners	
		Commercial ducted splits	
		Rooftop ducted	
		Multi-splits	
	Chillers	Air conditioning chillers	
		Process chillers[2]	
	Mobile air conditioning	Car air conditioning	Passenger cars
		Large vehicle air conditioning	Truck cabins, buses, trains

---

[1] It is important to distinguish between an application and a refrigerating system. An application is characterised by the purpose of the cooling (or heating). For example, residential air conditioning, chilled food display, cold storage of frozen foods, domestic hot water heating and so on. A refrigerating system is characterised by the means by which that cooling (or heating) is achieved and is typically a refrigeration circuit of some form. For example, residential air conditioning may be achieved through the use of window, split type or ducted air conditioning refrigerating systems, or chilled food display may be cooled using a stand-alone cabinet, with the use of a condensing unit or a direct expansion centralised system. The systems are summed up in different sectors and subsectors, according to their application and the applied technical concept.

[2] Process chillers might be the same systems as air conditioning chillers (e.g. when used in industrial or commercial centralised systems). There is the potential of double counting.

TABLE 1
Suggested definition of subsectors and systems for refrigeration and air conditioning

Sector	Subsector	Refrigerating system	Examples
Refrigeration	Domestic refrigeration	Domestic refrigeration	Refrigerators, freezers, combined refrigerator/freezer
	Commercial refrigeration	Stand-alone equipment	Vending machines, beverage coolers
		Condensing units	Used in small supermarkets/ bakeries
		Centralised systems for supermarkets	Larger supermarkets
	Industrial refrigeration	Stand-alone	Food processing, storing and distributing sector, cooling in industrial processes, leisure purposes like ice rinks and indoor ski-slopes (refers to all industrial refrigeration systems)
		Condensing units	
		Centralised systems	
	Transport refrigeration	Refrigerated trucks/trailers	

Subsector: Unitary air conditioning

This subsector covers many different systems, which are all mainly used to cool the air in rooms ranging from residential buildings to commercial locations.

FIGURE 1
A self-contained AC unit

Self-contained air conditioners: In these systems all components are located within one housing. Self-contained ACs (Figure 1) are either built into a window, "through the wall" units or packaged terminal units. The main refrigerant used is HCFC-22, although hydrofluorocarbon (HFC) blends, such as R-410A and R-407C, are increasingly being used. Hydrocarbons are applied less frequently.

Split air conditioners: Split air conditioners (Figure 2) can be divided into residential units applied to cool rooms in private households and small commercial units applied in offices or other commercial buildings. They consist of two elements: The one including the compressor and the condenser, which is mounted outside the room, and an indoor unit with the evaporator supplying cooled air. Both units are connected via refrigerant piping. To date, the main refrigerants used are HCFC-22 and R-410A, in developed countries almost all new products use HFCs, but in developing countries most new refrigerating systems still employ HCFC-22. As these systems have to be assembled on site, the leak rate is higher than for self-contained AC systems.

FIGURE 2
A split air conditioner, with the outside (left) and the inside (right) unit

Duct split residential/commercial air conditioners: Residential as well as commercial duct split AC refrigerating systems are mainly used to cool multiple rooms in larger buildings. Ducted means that already cooled air is directed into the rooms, in contrary to the systems that cool the room air itself. This is achieved by a duct refrigerating system, in which the evaporating units provide the cooling.
The main refrigerants are HCFC-22, R-407C and R-410A. Almost all new products in developed countries employ HFCs, but in developing countries HCFC-22 is mainly used, and to a minor extent HFCs. In recent years, several countries aimed to increase the efficiency of new duct split AC refrigerating systems, which often led to an increased refrigerant charge per system.

Rooftop ducted systems: Here, a single refrigerating system is mounted on the roof of a building. The evaporator and fan assembly is within an enclosure, from where ducting is led to the inside of the building. In developing countries the predominant refrigerant is HCFC-22, while in developed countries, these systems tend to use R-407C and R-410A.

Multi-splits: In multi-split air conditioning units, one or more compressor/condensing units are mounted outside the building. They are connected to several indoor units each housing an evaporator. These installations are mainly used for cooling commercial buildings and often also include a heating function. The main refrigerants used are HCFC-22 and R-410A. Almost all new products in developed countries employ HFCs, but in developing countries still mainly HCFC-22 is used, and only to a minor degree HFCs.

Subsector: Chillers

AC Chillers: In general, in chillers a liquid, usually water, is cooled by a conventional refrigeration cycle. This liquid is then distributed to cooling - and sometimes heating - coils within the building. Air conditioning chillers are mainly applied for commercial and light industrial purposes. Most AC chillers are single packaged units whilst a minority employs a remote condenser that needs to be installed and connected on-site. The main refrigerants are HCFC-22, HFC-134a, R-410A, R-407C and R-404A, and to a lesser extent HC-290, HC-1270, R-717 and R-744. In developed countries, mainly HFCs are employed, whilst in developing countries it is HCFC-22.

Centrifugal chillers are a particular sub-category of AC chillers, which use centrifugal compressors (as opposed to positive displacement types). Centrifugal chillers are in the majority of cases water cooled systems, especially with capacities exceeding 1 MW. They typically use flooded type evaporators and condensers, which means that they require large refrigerant charges and that mixture refrigerants with a temperature glide are impractical to use. Most centrifugal chillers are in the range of 500 kW to 20 MW, although machines in excess of 150 MW have been installed. In terms of numbers, centrifugal chillers represent less than 5 % of the market, but because of their large capacity they represent about 20 % of the cooling capacity and 25 % of the refrigerant consumption.

Process Chillers: Chillers are also used for cooling (and occasionally heating) in industrial refrigeration, including process cooling, cold storage, data centres, electronic fabrication, moulding, etc. Typically these machines are the same technology as chillers used for air conditioning, but are set to operate at different temperature levels (such as medium and low temperature) and can often operate for a much longer duration than those used for air conditioning applications. Approximately one-third of chillers are used for process applications.

Subsector: Mobile air conditioning

Mobile air conditioning provides air cooling in all kind of vehicles, such as passenger cars, trucks or buses, but also trains and ships. They are usually belt driven by the engine of the vehicle, and mainly a single evaporator system is used. Only HFC-134a is currently applied as refrigerant.

Subsector: Domestic refrigeration

This subsector covers all domestic appliances, which are refrigerators, freezers, and combined refrigerator/freezer products. Most domestic refrigerating systems are factory-assembled for an easy set-up and use by consumers. Globally, the main refrigerants applied here are HFC-134a in about two third of new products and R-600a in the remainder. A very small number uses HFC-152a, HCFC-22, or blends including them. The regional differences are large: R-600a is used in the majority of European and Chinese products, whereas in other regions the dominant refrigerant is HFC-134a.

Subsector: Commercial Refrigeration

Commercial refrigerating systems include the cooling of stored or displayed food and beverages. Two temperature levels are mainly applied: goods are either kept chilled at medium temperatures above 0°C, which is called “plus cooling”, or frozen below 0°C. The different temperature zones for different purposes in commercial refrigeration can be classified as follows (Table 2):

TABLE 2
Temperature zones in commercial refrigeration (UBA, 2009)

Product type	Temperature zone
Frozen Food	-29 up to -18 °C
Ice cream	-26 up to -22 °C
Fish and seafood	-5 up to -1 °C
Meat and poultry	-1 up to 3 °C
Fresh products	-3 up to 8 °C
Fruit and vegetables	7 up to 10 °C

Stand-alone units: Stand-alone units (Figure 3) are for example vending machines and beverage coolers. The whole stand-alone unit is factory assembled and built into one housing. The main refrigerants used in new units are R-404A, R-744, HC-290 and R-600a.

FIGURE 3
Stand-alone unit for ice cream

Example 1
Choosing technical options for the supermarket chain Pick n Pay in South Africa

In South Africa, almost all newly installed supermarket refrigeration systems operate on fluorinated refrigerants, the so-called F-gases, with high global warming potential (GWP) and/or high ozone depleting potential (ODP). Due to rising energy costs, the supermarket chain Pick n Pay started to explore alternative technologies.

The conventional technology for supermarket systems relies on a centralised "rack" or "pack" concept, where multiple compressors are put together to feed display cases and cold stores via refrigerant distribution lines. Such systems are known to have larger refrigerant charges and also suffer from high leakage rates (UNEP, 2010). There are three emission reduction options for these type of systems, which may also be applied in combination:

- Eliminating leaks of installed refrigeration and distribution systems,
- Substituting HFC refrigerants with low-GWP alternatives,
- Improving energy efficiency.

These emission reduction measures can be achieved through adopting various different technologies. Those of most interest include systems using natural refrigerants, for example in single-phase secondary systems, secondary systems using evaporating heat transfer fluids (i.e. R-744), cascade systems and water cooled secondary distributed systems. Amongst these system variants, the main primary refrigerants presently used include natural substances such as R-744, HC-290, HC-1270, R-717 or low-GWP HFCs. The particular choice of technology combination is dependent upon a variety of considerations, such as suitability to local climate, availability of refrigerant, availability of system components, parts and equipment, national rules, standards and regulations. Other, less tangible issues include the level of local expertise and confidence of local engineers and technicians in the technology concept.

Supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), Pick n Pay initially converted three supermarkets to alternative, so-called cascade systems operating with climate- and ozone-friendly natural refrigerants: R-717 (ammonia) serves as the primary refrigerant, where the system is located in a machine room away from sales areas. A glycol-water solution is used to distribute the cooling inside the store. The secondary cascade operates with R-744 (carbon dioxide) and provides the cooling for the low temperature applications. This technology was chosen the most appropriate solution under local conditions and combines all three reduction options listed above (Ederberg et al., 2012).

Condensing units: A condensing unit is a factory-assembled unit, holding one or two compressors. The condenser is separated from the evaporator, thus, the condensing unit can be placed outside the building and can be cooled by air. These refrigerating systems are often used in small shops such as bakeries or small supermarkets. The main refrigerants used are HCFC-22 in developing countries, HFC-134a and to some extent R-404A.

Centralised systems: Centralised systems are often used for larger supermarkets. "Direct" centralised refrigerating systems comprise several compressors, which are placed in a separate machinery room together with a common condenser outside the sales area. They are connected to numerous evaporators within the shop, either in display cabinets or cold stores. Centralised systems may also be found in indirect refrigerating systems, where a chiller-type system is used to cool a secondary fluid, which is then circulated to the cooling coils within the cabinets and cold stores. The main refrigerants are HCFC-22 in developing countries, R-404A, HFC-134a and R-744. For indirect systems, which are less common than direct systems, HC-290, HC-1270 and R-717 are applied.

Subsector: Industrial Refrigeration
Industry mainly needs refrigeration in the food processing, food storing and distributing sector and for cooling in industrial processes. The food sector with food processing and cold storage accounts for 75 % of the industrial refrigeration. The remaining 25 % are needed for process cooling, i.e. for applications including gas compression, oil and gas processing, petrochemicals, power generation, carbon capture. To a minor extent, cooling is also needed for leisure purposes like ice rinks and indoor ski-slopes. Industrial refrigerating systems differ from other systems by size and the temperature range that is covered. They are very often specifically produced to fit a certain application. For smaller industrial applications, a possible overlap with commercial refrigeration applications exists.

This subsector can be divided into stand-alone - or integral - units, condensing units and centralised units. Conceptually these are similar to the refrigerating system described for commercial refrigeration. R-404A is often applied as refrigerant. From 2000 onwards, HCFC-22 was broadly forbidden in new refrigerating systems in developed countries. Mainly R-717 (ammonia) was used instead, which has a long tradition in this subsector but it is more expensive, especially in the lower capacity range. In developing countries, both HCFC-22, R-717 and to some extent HFC-134a are applied.

Subsector: Transport refrigeration
Transport refrigeration (Figure 4) covers cooling that is required during the transportation of goods on roads by trucks and trailers, but also by trains, ships or in airborne containers. The dominant part is road transport. The other means of transport are therefore not considered in the following. Usually one refrigeration unit per road vehicle is installed. These refrigerating systems have to work under different weather conditions, and often carry several types of goods at different temperature levels at the same time. Furthermore, they need to be able to withstand vibrations and shocks caused by travelling. These demands lead to high technical requirements. Most new refrigerating systems apply HFC-134a, R-404A, R-410A or R-407C.

FIGURE 4
Inside of a truck with a transport refrigerating system

2.1.2 Technical options in the RAC sector

There are many different technical options, which will result in a substantial reduction of emissions of RAC appliance systems. They can be applied to some or all of the different RAC subsectors introduced above and range from leak reduction methods to utilising entirely new concepts for cooling. Passive measures as altering the architectural design for new buildings were not considered in this study. Some of these options are already introduced in the market and applicable whilst others are promising but currently under development or are being trialed. It is assumed that any technical option will be selected and designed in a way that the energy consumption and thus electricity-related indirect emissions will be at least equal to, if not lower, than the previous technology.

Technical options are categorised into the following groups:
1. **Improved containment:** Applying technologies which will avoid the leaking of refrigerant during manufacture, use and disposal,
2. **Alternative refrigerants:** Applying alternative refrigerants to existing types of refrigerating systems that have a considerably lower GWP than the ones previously used,
3. **Alternative system concept:** This refers to a change of both refrigerant and refrigerating system; this is also called a “concept change”.

There are typically several specific technical options within each of these categories. The most important ones will be summarised in the following. A more detailed description of the different technical options is included in the annex to this module. In addition, an overview of which technical option to apply best in which cooling subsector or refrigerating system can be found in Table 6. An outlook on new technologies that are still under development or that could be used more widely can be found in the annex to this module.

Containment methods

This group of technical options refers to technologies reducing the possible emissions of refrigerants during the life-cycle of the refrigerating system. This can also lead to a reduction of energy requirements for some options. The main characteristics of all containment methods are summarised in Table 3.

Leakage reduction (design/construction): The first possibility is to reduce leaks caused by the design or construction of the device. It includes introducing improvements to the system design, applying improved manufacturing and assembly methods that minimise the amount of refrigerant leakage. This may involve using different types of jointing methods and components, as well as carrying out certain types of testing, introducing more thorough tests within the production line, improved training for workers and so on. It is most effective for factory produced and sealed refrigerating systems, whereas systems assembled on site benefit least from these options. A variety of standards are currently available to direct enterprises. Expertise and most test equipment are also available. However, the practices are currently rarely applied. For manufacturers who do not already apply these practices, there is a considerable cost for purchase of equipment and reorganisation of production facilities, development of new quality systems, etc. For enterprises that assemble refrigerating systems on site, the additional initial cost is less, since expenditure is limited to additional installation time and tooling. Leakage typically implies less energy efficiency. For example, a refrigerating system that loses 5 % of refrigerant per year will use around 10 % more energy than a more leak-tight system. Therefore, reduction in refrigerant loss improves system efficiency.

Leakage reduction (maintenance): Leaks can also be reduced by good maintenance of the refrigerating system where routine maintenance involves leak checking and, if needed, immediate repair. This may also include the application of fixed gas detection systems that alert in case of refrigerant leakage. This option that can be applied to all refrigerating systems, and all relevant procedures; equipment and instrumentation are widely available. For direct maintenance activities, the main cost implications relate to transportation and technicians work time. Thus, larger refrigerating systems and those with higher leakage rates tend to be more suitable. Gas detection systems are fairly expensive and are therefore more suitable for larger systems. The resulting reductions in refrigerant loss improve the system efficiency, especially for critically-charged refrigerating systems. For larger systems such as in larger supermarket or industrial systems, which tend to use liquid receivers, leakage typically has comparatively little effect on the efficiency.

Charge size reduction: The charge size may be reduced during the design and construction of a refrigerating system. Approaches for this may include the use of reduced volume heat exchangers or low solubility lubricants. Alternatively, it may involve the transition from a direct to an indirect refrigerating system type. These techniques are widely applicable and a variety of technologies are currently available for achieving significant reductions in charge sizes. Research and development is going on continually to reduce the charge size further. Cost implications can vary depending upon the type of refrigerating system, charge reduction approach and the refrigerant involved. Efficiency levels of the refrigerating system can be maintained through this technical option. However, systems become more sensitive to leakage, so a loss of a given amount of charge would result in higher energy consumption.

Recovery and recycling: Correct recovery and recycling of refrigerant is a possibility to reduce refrigerant emissions, which can be applied to all refrigerating systems without impacting their efficiency. It involves the use of recovery machines when removing the refrigerant from refrigerating systems during repair or servicing activities or prior to the disposal of a refrigerating system. This must be coupled with training of technicians and the adoption of an infrastructure for recycling and reuse or destruction of the recovered refrigerant. Generally, equipment necessary for refrigerant recovery and recycling is widely available. However, suitable destruction facilities are absent in many regions. Capital expenditure is necessary for purchase of recovery machines, cylinders and storage facilities as well as recycling machines. Expenditures are also required to provide technicians training. In addition, if destruction facilities are not available, considerable investment is required to set up such facilities or to arrange for shipment of refrigerants to a region which does have them.

TABLE 3
Summary of the different containment technical options

Containment option	Suitable refrigerating systems	Availability	Additional costs	Improvement in efficiency
Leakage reduction (design and construction)	factory produced and sealed refrigerating systems	widely	yes	yes (due to prevention of sub-optimal charge effects)
Leakage reduction (maintenance)	larger refrigerating systems with higher leakage	widely	possible	Notable for critically charged systems, less for larger systems
Charge size reduction	all	widely	possible	none*
Recovery and recycling	all	widely	yes	none

* Depending on the specific approach, efficiency can improve, reduce or remain unchanged. However, system efficiency can become more sensitive to leakage.

Refrigerant options

To avoid emissions, HCFC or HFC refrigerants with high GWP are replaced with low-GWP refrigerants within a given refrigerating system. The ones discussed in this handbook are R-600a, HC-290, HC-1270, R-717, R-744, unsaturated-HFCs (HFC-1234yf, HFC-1234Ce, HFC-1243zf), and low-GWP blends thereof. Due to differences in thermodynamic and transport properties, the substitution of refrigerants is normally accompanied with changes in other components of the refrigerating system, such as the compressor, heat exchanger design, pipework or other ancillary components. Modifications to electrical components in order to meet safety requirements may be necessary depending on the substituting refrigerant. Only when substituting with HFC/unsaturated HFC blends, these changes may not be necessary or only to a smaller extent. In these cases, it is likely that the blends will be formulated to closely match existing refrigerants' thermodynamic properties, so substitution may be possible on a "drop-in" basis.

Additional costs may be caused by modifications to electrical components or in construction materials, to safety systems and alternative electrical components in order to meet safety requirements or pressure safety and minimum efficiency requirements, especially at high ambient temperatures. For the blends, there may be further additional costs due to changes to refrigerating system components, and higher expenses for the substances as they are expected to be about five to ten times more expensive than existing refrigerants. The change in efficiency when refrigerating systems are redesigned also varies with the technical options. The greatest increase in efficiency in the refrigerating system is expected when applying R-717 (ammonia) whilst no increase is to be expected with blends or unsaturated HFCs.

The applicability of this group of technical options to different refrigerating systems varies depending on the chosen low-GWP refrigerant. Some are already used widely in domestic, commercial or industrial applications worldwide, and are thus easily available. Others are not used commercially as refrigerants yet, but are currently under development and investigation. It is likely that various products will soon become available. The applicability, availability, possible additional costs and the impact on the efficiency of the refrigerating system when introducing new refrigerants are summarised in Table 4.

TABLE 4
Summary of the different refrigerant technical options

New refrigerant	Suitable refrigerating systems	Availability	Additional costs	Improvement in efficiency
R-600a	smaller capacity	widely	possible	minor
HC-290/HC-1270	medium and larger capacities	HC-290 widely, HC-1270 less widely	possible	moderate
R-717	larger capacity in non-domestic, non-commercial situations	widely	yes	notable
R-744	in non-tropical climates due to degradation in system efficiency (or increase in system cost) with ambient temperatures above +35° C	widely	yes	at lower ambient temperatures, poorer at higher ambient temperatures
Unsaturated-HFCs (HFC-12324yf, HFC-1234ze, HFC-1243zf)	small and medium capacities, larger self-contained packaged systems (e.g. chillers)	not commercially available yet, but expected to be produced on a commercial scale	possible	none
HFC/unsaturated-HFC blends	any	not commercially available yet, but likely to be widely available eventually	possible	none

* So-called "refrigerant efficiency" is a complex topic and whilst the theoretical efficiency (based on thermodynamic properties) may indicate that one fluid is more efficient than another, the practical efficiency (also accounting for transport properties and interaction with system components) may demonstrate the opposite. From a market perspective, any refrigeration equipment manufacturer, independent from his preference for a refrigerant, will focus on complying with existing energy, safety and product standards. Therefore, setting energy standards for refrigeration equipment in the market is the only reliable measure to control energy efficiency. However, in order to control overall emissions of refrigeration equipment, energy standards should include aspects of the direct emission potentials of refrigerants, like for example, reflected in the latest EU eco-design directive for air conditioners.

Concept change: Refrigerant and system

In these technical options, both the refrigerant is replaced with a low-GWP one and the refrigerating system itself is changed to better suit the new refrigerant and for further minimising the leakage rate of the refrigerating system. A summary of the systems can be found in Table 5.

Liquid secondary systems (centralised): The first of these technical options is to replace a conventional direct expansion system using HCFC or HFC refrigerants within a liquid secondary system, utilising a low-GWP refrigerant. Liquid secondary means that the cooling cycle with the new refrigerant is coupled to a secondary circuit by heat exchangers distributed throughout the application through which the single-phase liquid in the secondary circuit is cooled. The cooled liquid is then pumped to where the cooling is required. Due to differences in the use of fluids and distribution mechanisms, the substitution is accompanied with changes in pipework and primary refrigerating system components. As the use of low-GWP refrigerants is limited in certain locations due to their toxicity or flammability characteristics, the advantage of liquid secondary systems is that the primary refrigerant can be stored in a separate, controlled location.

These refrigerating systems are used widely in northern Europe in supermarkets and worldwide in air conditioning systems. They are preferentially applied to medium to large capacity air conditioning systems and medium temperature supermarket systems.

The cost for the refrigerating systems varies depending on the baseline refrigerating system used for comparison, although differences are smaller with larger capacity applications. The relative efficiencies are variable depending upon the baseline refrigerating system, the temperature level and the design approach used, although they are typically better with higher application temperatures.

Liquid secondary systems (discrete): A secondary refrigerating system may also be applied discretely with a low-GWP refrigerant in the first circuit. This means that a single-evaporator remote refrigerating system is substituted to use a single secondary circuit. For example, a condensing unit which feeds an evaporator within a cold store is replaced with a small chiller and the secondary liquid is circulated to a coil within the cold store instead. As with centralised systems, this approach enables the primary refrigerant, which may be a flammable or higher toxicity fluid, to be removed from the occupied space. Whilst the system is comparatively simpler than a centralised system, the additional cost for the additional piping and heat exchanger results in an increased capital cost.

Evaporating secondary fluid system: Another technical option is to use a low-GWP refrigerant with an evaporating secondary fluid. The concept is similar to the refrigerating system described above, where the hazards of low-GWP refrigerants in certain locations is avoided. The difference in the concept is that the secondary fluid undergoes a phase change from liquid to vapor and back, so that energy can also be stored in latent heat. The typical phase-change fluid used is CO_2. These refrigerating systems have moderate application in food processing and air conditioning systems and widespread use in supermarket refrigerating systems and are preferentially applied to medium to large capacity, low temperature systems. Costs and efficiencies vary similar to those for liquid secondary systems.

Cascade system: Low-GWP refrigerants can also be used with a cascade type system, where two or three refrigeration circuit cycles are coupled: the first cycle removes heat from the low temperature application and rejects heat to an intermediate temperature level, from where a second refrigeration circuit removes the heat and rejects it to the ambient air. This has the advantage that the most suitable refrigerant can be chosen for the pressure-temperature-level of each cycle and thereby the most favourable characteristics of certain low-GWP refrigerants can be exploited. The high-temperature stage refrigerant is typically a flammable hydrocarbon or higher toxicity (R-717) refrigerant, which can be contained outside or in a separate room, whilst the medium- and low-stage refrigerant may be R-744. The refrigerating systems have moderate application in food processing and air conditioning systems and widespread use in supermarket refrigerating systems and are preferentially applied to medium to large capacity systems. Costs and efficiencies vary similar to those for liquid secondary systems.

Distributed water-cooled systems: Distributed water-cooled systems are used in supermarkets with numerous display cabinets and cold stores. Cabinets and cold stores are assembled with self-contained, i.e. integral, refrigeration systems, which employ water-cooled condensers. The heat is removed from these condensers by chilled water that is supplied from a chiller which is located on the roof or outside the building. The main advantages of this refrigerating system are that the refrigerant charge can be reduced and the larger charge system, i.e. the chiller, is located externally thereby enabling hydrocarbons or ammonia to be used. The reduction of joints also minimises leakage. These refrigerating systems are not widespread except in the UK and in the USA, where HFCs are used as refrigerants. The cost is normally similar to conventional direct refrigerating systems. The efficiency varies depending on the baseline refrigerating system and on the specific variations of the systems and refrigerants.

District cooling: District cooling is already very widely applied. For district cooling with low-GWP refrigerants, conventional direct expansion refrigerating systems using HCFC or HFC refrigerants are replaced with localised secondary cooling coils within the application. They are fed from a remotely located large-scale chiller, which provides chilled water to a very large number of these localised cooling coils, normally distributed across a number of buildings. Any primary refrigerant can be applied, thus, high-GWP refrigerants can be avoided. Also the overall mass of higher-GWP refrigerant per kilowatt of cooling can be reduced. Such refrigerating systems are applicable in any location where there is a fairly high population density. It is currently used in a number of countries, both in hot and cooler climates. There are a number of companies that provide equipment and services. A direct cost comparison is difficult since the technology requires the purchase and installation of one single very large refrigerating system instead of individual purchases of a number of small refrigerating systems. However, theoretically the overall cost per kilowatt of cooling will be lower and also the efficiency will be greater compared to the combination of discrete refrigerating systems, especially if the chosen chiller is of high efficiency and the distribution system is well designed.

TABLE 5
Summary of the different refrigerant and system technical options

New system (together with low-GWP refrigerant)	Suitable refrigerating systems	Availability	Additional costs	Improvement in efficiency
Liquid secondary (centralised)	medium and larger capacity AC systems, supermarket refrigerating systems	widely	differs with baseline system, less for larger capacity systems	variable, better potential for applications with higher temperatures
Liquid secondary (discrete)	medium and larger capacity systems at higher temperatures	widely	yes, increased capital costs	typically poorer efficiency
Evaporating secondary fluid	medium and larger capacity AC systems, supermarket refrigerating systems	moderate in food processing and AC, widely for supermarkets	differs with baseline system, less for larger capacity systems	variable, depends on individual systems design
Cascade	medium and low temperature refrigerating systems	widely in food processing and, supermarkets	differs with baseline system, less for larger capacity systems	variable, depends on individual systems design
Distributed water-cooled	medium and larger capacity centralised systems	not widely	differs with baseline system, less for larger capacity systems	very variable, depends on individual systems design
District cooling	very large capacity distributed AC applications	widely	costs should be lower	typically higher efficiency

Table 6 provides an overview and shows the different technical options that can be applied to various systems that have previously been introduced.

TABLE 6
Applicability of the different technical options of different RAC systems

Technical option	Unitary air conditioning							Chillers		Mobile AC	
	Self-contained	Split residential	Split commercial	Duct split residential	Commercial ducted splits	Rooftop ducted	Multi-splits	Air conditioning chillers	Process chillers	Car	Large vehicle
Leak reduction (design/const.)	×	×	×	×	×	×	×	×	×	×	×
Leak reduction (maintenance)	×	×	×	×	×	×	×	×	×	×	×
Charge size reduction	×	×	×	×	×	×	×	×	×	×	×
Recovery and recycling	×	×	×	×	×	×	×	×	×	×	×
R-600a											
HC-290 / HC-1270	×	×	×	×				×	×	×	
R-717								×	×		
R-744				×	×	×	×	×	×	×	×
unsat-HFC	×	×	×	×	×	×	×	×	×	×	×
HFC / unsat-HFC blends	×	×	×	×	×	×	×	×	×	×	×
Low-GWP + liquid secondary (centralised)					×	×	×				
Low-GWP + liquid secondary (discrete)		×	×	×	×	×				×	
Low-GWP + evap. secondary					×	×	×				
Low-GWP + cascade											
Distributed water-cooled	×	×	×	×	×	×	×				
District cooling	×	×	×	×	×	×	×	×			

TABLE 6
Applicability of the different technical options of different RAC systems

Technical option	Domestic	Commercial refrigeration			Industrial refrigeration			Transport
	Domestic refrigeration	Stand-alone equipment	Condensing units	Centralised for supermarkets	Stand-alone equipment	Condensing units	Centralised systems	Refrigerated trucks/trailerse vehicle
Leak reduction (design/const.)	×	×	×	×	×	×	×	×
Leak reduction (maintenance)	×	×	×	×	×	×	×	×
Charge size reduction	×	×	×	×	×	×	×	×
Recovery and recycling	×	×	×	×	×	×	×	×
R-600a	×	×			×			
HC-290 / HC-1270		×	×		×	×		×
R-717				×		×	×	
R-744		×	×	×	×	×	×	×
unsat-HFC	×	×	×		×	×	×	×
HFC / unsat-HFC blends	×	×	×		×	×	×	×
Low-GWP + liquid secondary (centralised)				×			×	
Low-GWP + liquid secondary (discrete)			×			×		×
Low-GWP + evap. secondary				×			×	
Low-GWP + cascade				×			×	
Distributed water-cooled			×	×		×	×	
District cooling								

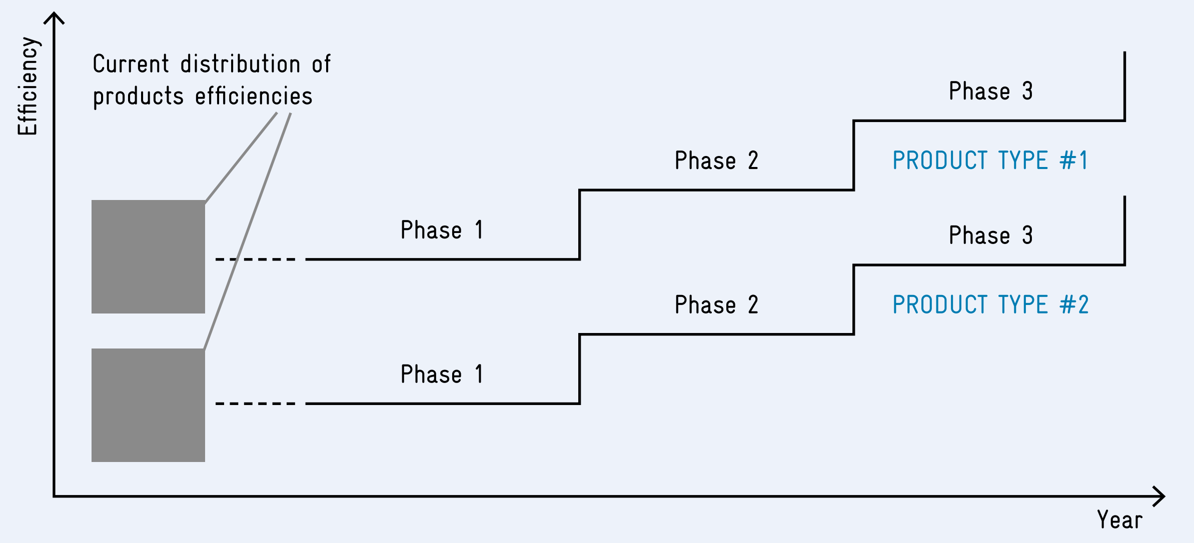
Discussion on efficiency improvements

Demanding a minimum efficiency of systems can be a means of indirectly reducing emissions from energy production, via reduction of energy consumption. Energy is typically consumed through electricity or from fuel used for transport systems, such as diesel, petrol or gas.

For RAC equipment, the minimum efficiency may be expressed in terms of
a) Coefficient of Performance (COP) or total energy consumption (TEC) at specific rated conditions,
b) COP or TEC based on a range of predetermined seasonal conditions, or
c) COP or TEC based on seasonal conditions with a corresponding variation in cooling (or heating) load.

Typically, efficiency improvements evolve over time in incremental steps where increasing efficiencies are prescribed for, as illustrated in Figure 5.

FIGURE 5
Illustration of evolution of minimum efficiencies for different product types with different technical characteristics.



There have been a number of studies related to the potential efficiency improvements of various different RAC systems. Several of these studies were based on evaluating different methods of efficiency improvement and the associated costs. For each product group, these lead to the best and most cost-effective improvements, which can be implemented over certain periods.
These studies will be used as a basis for proposed minimum efficiency improvements and associated costs for the different subsectors (cf. Table 7).

A summary of the possible efficiency improvements in the different subsectors can be found in Table 7. However, it should be noted that

- the time period and efficiency targets may be considered somewhat approximate since they assume initial average product efficiencies,
- the costs of different means of improving efficiency such as system components, controllers etc. are sensitive to geographical region, availability, extent of uptake and material prices in the future,
- within a particular product category such as commercial refrigeration, stand-alone or condensing units, the number of potential technology options for making improvements is extensive and can vary widely within a particular product group amongst sub-types of equipment,
- the improvements are assumed to be about linear from 2010 to 2030,
- the performance is sensitive to local climatic conditions.

TABLE 7
Overview of the RAC subsectors and the possible efficiency improvements

Sector	**Subsector**	**Efficiency improvement**	**Efficiency measure****	**Additional cost**	**Reference year**	**Source**
Domestic refrigeration	Domestic refrigeration	50%	TEC	90%	2030	TREN Lot 13
Commercial Refrigeration	Centralised systems for supermarkets	60%	TEC	[30%]*	[2020]*	Various
	Condensing units	31%	TEC	148%	2020	ENTR Lot 1
	Stand-alone equipment	52%	TEC	11%	2025	TREN Lot 12
Industrial refrigeration	Centralised systems	30%	TEC	[50%]*	[2030]*	Various
	Condensing units	31%	TEC	148%	2020	ENTR Lot 1
	Stand-alone equipment	75%	TEC	262%	2020	ENTR Lot 1
Unitary air conditioning	Commercial ducted splits	73% (from 3.97 to 6.87)	Seasonal COP	74%	2030	ENTR Lot 6
	Duct split residential air conditioners	118%	Seasonal COP	46%	2030	TREN Lot 10
	Multi-splits	56% (from 3.53 to 5.51)	Seasonal COP	19%	2030	ENTR Lot 6
	Self-contained air conditioners	118%	Seasonal COP	46%	2030	TREN Lot 10
	Rooftop ducted	80% (from 3.88 to 7.00)	Seasonal COP	50%	2030	ENTR Lot 6
	Split residential air conditioners	118%	Seasonal COP	46%	2030	TREN Lot 10
	Split commercial air conditioners	73% (from 3.97 to 6.87)	Seasonal COP	74%	2030	ENTR Lot 6
Chillers	Air conditioning chillers	55% (from 3.58 to 5.56)	Seasonal COP	49%	2030	ENTR Lot 6
	Process chillers	50%	TEC	100%	2020	ENTR Lot 1
Mobile AC	Car air conditioning	30%	TEC	[50%]*	[2020]*	Various
	Large vehicle air conditioning	30%	TEC	[50%]*	[2020]*	Various
Transport Refrigeration	Refrigerated trucks/ trailers	50%	TEC	[50%]*	[2030]*	Burke and Grosskop (2011)

NOTE: For additional cost, a value of 100% is equivalent to doubling the baseline cost of the product.
* Approximated value
** Two alternative indicators, Total Energy Consumption (TEC) and Co-Efficient of Performance (COP), indicate the Efficiency Improvement as "Efficiency Measure". TEC shows the Efficiency Improvement where the auxiliaries have a proportionally significant share of the energy consumption of the subsector appliances and systems. COP shows the Efficiency Measure for appliances and systems where the compressors is the (single) dominating factor for the energy consumptions.

The annex to this module summarises several additional technologies that are still under development or that could be used more widely. These are promising new technologies that could lead to further reductions of energy use and of refrigerants with higher GWP.

2.1.3 Barriers to applying alternative technical options in the RAC sector

Barriers are hindrances that stand in the way of the smooth implementation of different technical options, which produce in the long-term sustainable benefits that outweigh the costs and avoid or limit the emissions of greenhouse gases. Nevertheless, these technical options are underinvested in due to barriers which hinder a long-term economically and environmentally sustainable outcome. The barriers are characterised in a number of ways and can be divided into several subcategories. The following evaluation identifies possible barriers and possible interventions to overcome them and to achieve a certain degree of market penetration, including the corresponding time and cost implications. The barrier analysis provided in this module mainly focuses on RAC&F sector specific aspects. A more general approach, including the evaluation and weighting of barriers, both technical and economic barriers, can be found in GIZ Climate Results Sourcebook (GIZ, 2011) within the Barriers-to-Objective Weighting Method (BOW), in the GIZ NAMA Tool (GIZ, 2012) and in the TNA Guidebook series by UNEP Risoe Center (Boldt et al., 2012).

It is important to recognise that while the barriers for one subsector may be identical to another, the necessary intervention may not be the same. However, if a barrier is overcome for one subsector, it may not be necessary to intervene in another subsector anymore. An example is the availability of refrigerant: if poor availability of HC-290 is identified as one of the barriers for residential air conditioning and therefore efforts are made to make HC-290 widely available, then this would resolve the issue, i.e. remove the barrier, for commercial refrigeration, industrial refrigeration and chillers as well. The same situation may arise for other barriers, such as technician competence, safety standards, regulations, availability of components, etc.

An overview of the different barriers in the RAC sectors and which technical options they affect is given in Table 8[3].

Component availability: Certain components or refrigerants that are used to apply a technical option may not be available in a country or region. A reason for this may be that there was no demand for them before. For refrigerants, producers may not have supplied them or they may not even be commercially available to the suppliers. This can be overcome by working with existing refrigerant distributors to stock the desired refrigerant, develop import channels from overseas producers to local suppliers, establish cylinder populations, bulk storage and transfer facilities or install gas purification plants. Other components that may not be available include compressors, system components such as valves or filter/dryers, ancillary components such as pressure switches and gauges, thermostats, controllers, fans. Service tools and equipment such as gas detectors, recovery machines, torque wrenches, gauge/manifold sets may also be lacking. This barrier could be overcome by sourcing the components from overseas and setting up a distribution infrastructure. Furthermore, existing manufacturers could start to develop new components and adapt or convert production lines.

Technician competence: There may not be sufficient technicians and engineers that are trained for working with specific technical options. Technicians need to be able to work on the specific technology, either at installation, service/maintenance or disposal level. Engineers need to be trained to design refrigerating systems using the specific technologies. Possible interventions include train-the-trainers courses, widespread training of technicians and engineers at companies, working with training colleges, universities or introducing applicable syllabi. For engineers, there is also the possibility to develop codes of practices and national standards for design requirements. Another barrier within this subcategory is poor technician discipline. Established practices of technicians, cultural aspects or time pressures may result in insufficient discipline to work well with the given technical option. This may be overcome by implementing an incentive scheme.

---

[3] For a more generic list of barrier categories, cf. Boldt, 2012, Annex A

TABLE 8
Overview of the different barriers and for which technical options they are mainly important

Technical option	Implication																	
	Component availability					Technician competence			Safety-related restrictions		Technology		Implementation costs		Regulatory matters		Consumer issues	
	Refrigerant	Compressor	System component	Ancillary components	Service tools / equipment	No trained technicians	No trained engineers	Poor techn discipline	Charge size limits	Installation restrictions	Further development	Poor system efficiency	High production costs	High material costs	Regulatory prohibition	Peripheral regulations	Awareness	Higher upfront cost
Leak reduction (design / construction)			X				X				X		X	X			X	X
Leak reduction (maintenance)					X	X		X									X	X
Charge size reduction			X				X				X			X			X	X
Recovery and recycling					X	X		X									X	X
R-600a				X	X	X	X	X					X		X	X	X	X
HC-290 / HC-1270	X	X	X	X	X	X	X	X	X	X			X		X	X	X	X
R-717	X				X	X	X	X	X	X			X	X	X	X	X	X
R-744		X	X	X	X	X	X	X			X	X	X	X		X	X	X
unsaturated-HFC	X	X	X	X	X	X	X	X						X	X	X	X	X
HFC / unsaturated-HFC blends	X	X	X	X	X	X	X				X	X			X	X	X	X
Low-GWP + liquid secondary (centralised)	X					X	X				X			X			X	X
Low-GWP + liquid secondary (discrete)	X					X	X				X	X		X			X	X
Low-GWP + evap secondary	X		X			X	X				X			X			X	X
Low-GWP + cascade														X			X	X
Distributed water-cooled						X	X										X	X
District cooling						X	X			X			X	X		X	X	X

GIZ Proklima has published several technical training handbooks such as the Guidelines for the safe use of hydrocarbon refrigerants (2010) and Good Practices in Refrigeration (2010)[4].

Safety-related restrictions: As low-GWP refrigerants are often toxic and/or flammable or operate at particularly high pressures, systems often require charge size limits, installation restrictions and special pressure safety precautions. For certain refrigerants, safety standards impose restrictions on the amount of refrigerant that can be used in certain locations or the construction features of the refrigerating systems. This means that refrigerating systems using certain refrigerants may be limited in terms of the cooling (or heating) capacity of the system or the type of system that can be used. Depending on the situation, some technical options may not be applicable. This can be overcome by developing alternative national standards that permit larger quantities or wider application of those refrigerants or develop safety control systems that enable alternative means of achieving the same level of safety. Carrying out R&D activities to find alternative designs of refrigerating systems or to enable a lower charge may also help to overcome this type of barrier.

Technology implications: There might be a lack of knowledge or experience with new technologies or at least with technologies implemented under new climatic or other conditions. Limited technological development and poor refrigerating system efficiency can be a barrier to implementing certain technical options. The first refers to limitations in the development of a specific technology which covers a fairly broad range of issues. They may be within the areas of particular refrigerating system design concepts, component selection, optimum control strategies, system balancing and so on. Poor refrigerating system efficiency can be exhibited by certain technical options under specific conditions, which can dissuade their use due to higher energy-related emissions and higher energy costs. In some cases, it is possible to implement special designs for the technical options in order to maximise efficiency to an acceptable level. Possible interventions for these barriers include the initiation of collaborative R&D projects at institutes, universities and manufacturers, the development of cooperation with overseas enterprises which have greater experience with the particular technical option or the development of design guidelines based on knowledge gained in regions with previous experience.

Implementation costs: The introduction of the technical option may also incur higher costs for setting up production of refrigerating systems. This may lead to higher production equipment costs, the so-called investment costs and/or higher system material costs, the so-called operating costs. High production costs may include new production line equipment such as charging machines, leak/pressure test equipment, but also heat exchanger dies, safety systems, refrigerant storage and feed equipment. These higher production equipment costs might become acceptable or kept at a minimum by funding the purchase of additional, new equipment and guidance documentation on best practice for new production equipment. Higher system material costs may include the use of more expensive raw materials, additional components, alternative components that cost more due to economies of scale or more expensive refrigerants. Possible interventions include funding of the additional incremental cost and R&D activities to identify means of optimising them, through, for example, alternative designs. In order to mobilise technology providers, a contracting business unit can be set up which bears the risks, finances the investments upfront, and afterwards collects the revenues or savings – especially for technical options with energy efficiency gains – and thereby refinances the upfront investment.

Regulatory matters: Regulations may currently interdict the application of certain technical options, particularly concerning refrigerants. This may include the prohibition of using flammable refrigerants in buildings or having large quantities of higher toxicity refrigerants close to residential areas. Peripheral regulations may be in place that inadvertently negatively impact on the application of certain technical options, such as requirements for transport and storage of flammable substances, maximum capacities or power demands of cooling equipment as well as tolerated noise levels in certain areas. A way to reduce these barriers is to work with national authorities and the technology providers who have already market access and those who have not yet market access in order to modify the relevant regulations.

---

[4] www.giz.de/proklima

Consumer issues: The last barrier subcategory concerns consumer issues, which include lack of awareness. Thus, whilst a refrigerating system may be available that employs a particular technical option, the consumers – whether members of the public or commercial building owners or operators – may have no idea that this particular technology is available. Furthermore, they may not know that it is desirable to purchase the alternative technology in favour of the existing technology. This might be intervened by working with authorities or environmental non-governmental organisations (ENGOs) to roll out awareness programmes or by developing a labeling scheme. Furthermore, there may be no acceptance for higher upfront costs or consolidation of first costs. Consumers, although aware of the technical option, may find that the purchase cost is higher or the implications of using the technical option are more complicated than of using the standard technology. The consumer may be indifferent to the issue of climate change. Possible interventions here include the work with authorities to develop incentives, the introduction of a financial disincentives programme for consumers of non-technical option systems, a financial incentives programme for all consumers, or legislation to phase-out non-technical option products.

2.2 Sub-applications in the foam sector

2.2.1 Description of sub-applications in the foam sector

This chapter discusses technical options for the mitigation of greenhouse gases for the most dominant applications in the foam sector, which are polyurethane (PU) and polystyrene (PS) foams. Other foams like polyethylene (PE) and polypropylene (PP) do use blowing agents but these are normally not HCFCs or HFCs and are thus not further discussed in this module.

A difference between PU and PS is the conversion, i.e. the transformation process from basic raw materials to the final product. This is done by a non-reversible chemical process for PU and a nearly reversible thermal process for PS. PS materials can easily be recycled while recycling of PU requires complicated chemical processes.

Overview of PU applications

The PU sector is quite versatile, including various applications in the plastic industry. PU foams are often chosen due to their excellent mechanical and gluing properties, e.g. in appliances where the metal sheets and inliner are kept together by the foam. The construction, appliance, automotive and shoe industry use HCFC or HFC blowing agents. These will be discussed in chapter 2.2.2 on alternative technologies. In few cases blowing agents are used for non cellular foams, as in elastomers, mostly known are shock absorbers damper. They are included here for completeness.

Table 9 shows a list of the applications, sorted by foam characteristics. The overall distinction is made between cellular and non cellular foams.

TABLE 9
List of PU applications

Polyurethane (PU) foams				
Cellular foams			Non cellular foams	
Flexible	Rigid	Integral	"Rigid"	Thin film
Slabstock	Rigid blocks	Semi rigid	Elastomers	PU paint and coatings
Moulded	Sandwich panels	Rigid	Thermoplastic	Leather and paper coating
Semi rigid	Flexible panels	Reinforced	PU-Rubber	Glues
	Spray foam			Binder
	Bottled foam			

Main applications for PU foams:

- **Comfort products (mainly flexible foams):** Mattress and bedding industry; seat cushions for cars, offices and furniture in general; special thin sheets for textile and cars clothing,
- **Construction (mainly rigid foam or insulation foam):** Metal sandwich panels used for industrial buildings; metal sandwich panels used for trucks and sea containers; flexible panels (paper facing) for house insulation; spray foam for on-site insulation (mainly with machinery); bottle foam used for cavity filling and insulation in construction,
- **Automotive (mainly integral foams):** Car parts, that have a high esthetical value, such as steering wheels, gear knobs, dashboards, sun screens, side parts (rubber like); window encapsulation and high end car bumpers and spoilers; fiber reinforced parts,
- **Shoe industry (integral foams):** Shoe soles; integrated shoe soles; leather coatings (non cellular),
- **Appliance industry:** Domestic refrigerators and freezers (rigid PU); commercial refrigerators and freezers (rigid PU); water heaters / boilers; refrigerated trucks,
- **Special applications:** Electrical industry; encapsulation of electrical parts e.g. potting of condensers or mobile phone chargers; all kind of electrical parts which require low electrical conduction; space shuttle main tank insulation; oil piping “pigs” (elastomers for cleaning the pipes); solar water heaters.

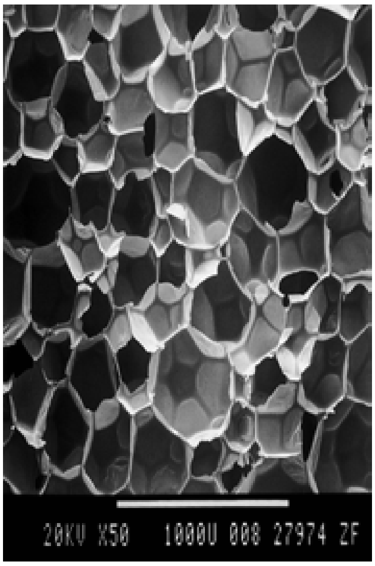
Overview of polystyrene (PS) applications

The polystyrene (PS) subsector has a similarly wide variety of applications, but mainly HCFC or HFC are used as blowing agents. The subsector can be differentiated with respect to the production method: for expanded polystyrene (EPS), beads are placed into a mould and expanded by vapour. For extruded polystyrene (XPS), beads are melted inside an extruder and extruded into boards. The beads from which EPS is made already contain the blowing agent. As these beads contain hydrocarbons (HC), the EPS sector can be disregarded. In XPS production the blowing agent is added separately.

Both applications, EPS and XPS, are used for sandwich panels, where the foam boards are glued on metal sheets. However, the insulation performance of EPS is far lower than that of PU panels. Note that these two methods are direct competitors in many applications and are therefore relevant regarding development and implementation of standards and regulations. In general, XPS and EPS foams are lightweight, reveal good insulation properties and they do not release fibres which can be harmful to human health.

EPS: Typical EPS products are blocks or moulded pieces of all shapes, such as roof panels with indents for placing the tiles or parts reinforced with steel for immediate cementing. Many shapes are cut out of blocks. Reinforced parts are also used for packaging of electronics or appliance goods.

FIGURE 6
A typical foam cell structure



XPS: XPS boards are usually without any metal sheet on them. The boards are used for the construction sector. In Europe, XPS has a distinguished position with regard to the insulation applications due to the high compression strength and the strength to carry loads such as in fundaments of building. In Asia, it is mainly used for insulation of facades. Thin XPS sheets are used for producing food trays or boxes as well as glasses. However, the production of these sheets has already been converted to climate-friendly isobutane or other hydrocarbons and will not be discussed here further.

Blowing agents in foams – HCFC and HFC

Blowing agents are used, as the name indicates, for inflating the foam and for the creation of a cell structure. Figure 6 shows a typical foam cell structure. A gas mixture of air and blowing agent is contained inside these cells.

Blowing agents are used as single products or as mixtures, which complicates identification of the quantities used. Some substances (HCFC-142b, HCFC-22, HFC-134a and HFC-152a) that are used as refrigerants also serve as foam blowing agents in the production of PS, EPS and XPS.

In PU foams, HCFC-141b, HFC-245fa, HFC-365mfc and HFC-365mfc/-227ea are used. They have a higher boiling point and are not suitable for refrigeration purposes. In the USA, only HFC-245fa is allowed for PU foams, whereas in the EU also HFC-365mfc is used. HCFCs are banned in the EU, Japan and in the US. HFCs are mainly used in developed countries. In the rest of the world, HFCs are not widely used in foams, except for companies exporting to the EU, Japan or the US.

Blowing agents are used to create a specific cell structure, to reduce density, for better skin, i.e. aesthetic properties, or to provide a more flexible product. The blowing agent will diffuse into the environment in a short period of less than one year. Thus, the resulting emissions are a relevant factor when choosing a blowing agent.

2.2.2 Technical options in the foam sector

Two major technical options can be found in the foam sector:

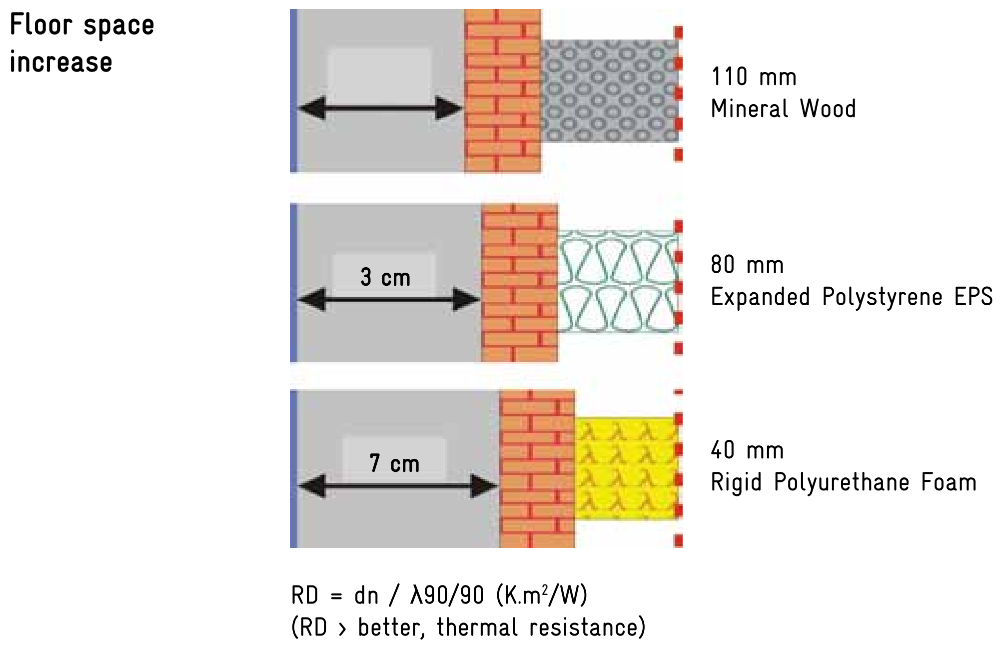
1. The replacement of the blowing agent,
2. Recycling of foam products with recovery of the blowing agent.

In the EU most companies choose hydrocarbons as technical option in the foam sector, mainly because of lower costs and lower GWP. Regarding technical options, it must be differentiated between foams that are used for insulation purpose and foams that are used for other purposes.

Technical options for foams with insulation properties

Insulation foams are mostly used in PU or PS applications and the cells contain either a blowing agent or air. The blowing agent can therefore contribute to slight improvements of the thermal conductivity (λ), which is used in construction to reduce thermal loss of buildings. The influence of the insulation properties is shown in Figure 7, where the increase of floor space is a function of the insulation material: the better the insulation properties, the less thick insulation is required. However, when looking into low energy buildings the heat storage capacity of the walls also has to be considered, especially if heavy insulation with high thermal capacity is required.

FIGURE 7
Influence of insulation properties on the floor space



With the use of alternative low-GWP blowing agents like hydrocarbons, however, the insulation properties typically decrease with the same thickness. To maintain the same thermal insulation the thickness of the material needs to be increased. However, the insulation properties do not solely depend on the BLA, but also on other factors such as regularity and cell size, wall thickness, mechanical strength and diffusion properties of a foam system. New foam systems with optimised cell and wall characteristics can compensate a theoretical loss of insulating properties when changing to a low GWP blowing agent.

Blowing agents in PU and PS production have different properties, mainly concerning the boiling point. PU foams require a boiling point of at least 25° C in order to avoid technical complications. For PS foams, preferably blowing agents with a low boiling point (< 0° C) are used, but they can also use blowing agents with boiling points around ambient temperatures.

Technical options for PU foam (insulation foams)

Pentane (HCs): Pentane as an alternative and climate-friendly blowing agent is chosen by the largest domestic refrigeration companies worldwide, with some exceptions in the USA. The technology is also used for the sandwich panel production, especially by continuous foam producers. As hydrocarbons are flammable, specific production equipment is required. However, given proper raw materials, there are no flammability issues for the final product. On the one hand, it shows a slightly lower thermal conductivity but so far this comparison is made with high end producers. On the other hand, hydrocarbons are widely available from many suppliers and therefore less expensive than all other options. The technologies are well known and the introduction does not present risks. Hydrocarbons also require less quantity.

HFC-245fa, HFC-365mfc: There is extensive experience with the use of HFCs, especially because of the ban of HCFCs in the EU. Drawbacks include that HFC-245fa requires specific equipment due to its low boiling point and that HFC-365mfc is flammable. The mixture of HFC-365mfc/HFC-227ea is less flammable but due to the different boiling points several raw material suppliers consider the flammable mixture. Both HFCs are considerably more expensive then HCFCs and due to their molecular weight the quantities required are about the same. They are not a low-GWP option, and thus do not present a long-term solution. The advantages include the well-known technology and the availability of the raw materials, although this may depend on patent issues.

Methylformate and Methylal: These blowing agents have also been known for a long time but never became widespread in developed countries. This is mainly due to their solvent character and the effects on the foam's mechanical and physical properties. Methylal is preferably used as co-blowing-agent as in some combinations with pentane the flammability will be lower. Methylformate is patented and is only supplied preblended together with the raw materials. Methylformate is flammable, and although by mixing the blowing agent inside the raw material the methylformate supplier claims it to be non-flammable. That eathylformate can only be used with a license and needs to be bought from the supplier along with the raw material is a major drawback. Consequently other major raw material suppliers do not provide suitable systems for methylformate. Another option is Methylal, which is advised as being used as a co-blowing agent and therefore a second blowing agent is needed.

Unsaturated-HFCs: FEA 1366 mzz and Solstice 1233 zd: The difference between HFCs and unsaturated-HFCs is that the latter have a double bond and a low GWP. Unsaturated-HFCs are new on the market and relevant data on their chemical characteristics, including information about their flammability, is not available yet. However, for producers in developing countries these blowing agents are not very promising as their costs are announced to be substantially higher than all other options and practically they will mainly be considered to be used as co-blowing-agents in order to balance costs and thermal insulation properties.

Waterblown foam: Waterblown means that the blowing agent effect is generated during the chemical reaction of polyol and isocyanate liquid, which releases CO_2. This CO_2 inflates the foam and constitutes a physical blowing agent. These systems do not need a separate blowing agent and are easy to use. As the thermal conductivity of this foam could be lower than that of any other of the introduced options, this alternative is less suitable for sectors in which insulation properties play a dominant role. The exception here is commercial refrigeration, where doors are frequently opened, such as bottle coolers, as well as open-top cabinets or display cabinets with openings and tailored designs that implicate intensive mechanical stress. These units demand more mechanical than thermal properties of the foam due to their frequent and heavy use. Also, many of the cabinets include glass doors that have a considerable lower insulation than PU foam. The high density of waterblown foam is optimal for tailored design of small series. It is especially advised for companies with low production and chemical know-how. The properties of these systems are nowadays equal to other systems using traditional blowing agents.

Technical Options for PS foam (insulation foams)

As mentioned above, this section will discuss only XPS as EPS does not contain HCFCs or HFCs. In contrast to PU, XPS generally uses several blowing agents at the same time. The typical HCFC combination consists of 60 % HCFC-142b and 40 % HCFC-22. HCFC-142b has good long term properties but it is flammable, whereas HCFC-22 is non-flammable and cheaper. Therefore when investigating XPS the content and ratio of the blowing agents used is of importance for calculating emissions and GWP. The blowing agents and combinations that are commonly used are shown in Table 10:

TABLE 10
Blowing agents used in XPS foams

Developing countries	Developed countries
HCFCs • HCFC-22 • HCFC-142b • HCFC-22 / -142b HFCs • HFC-152a	HFCs • HFC-134a / -152a blends • HFC-152a + aceton HCs (hydrocarbons, flammable) • Isobutane (mainly used in Japan) • LPG (mix of isobutane, propane and n-butane) CO_2 • CO_2 + organic solvents, e.g. ethanol, dimethylether (DME), aceton • 100% CO_2 (patented) Other • Vacuum technology (patented) • New – unsaturated-HFC-1234ze

All introduced technical options have one common disadvantage: flammability. Therefore some chemical adjustments are required for compliance with the standards in construction. These standards are usually based on the lifetime of a building, typically more than 50 years. During this time period the insulation is expected to maintain its properties. As building walls are not gas-tight, the blowing agent from XPS foams used as insulation is released into the atmosphere over time and replaced with ambient air. This is a diffusion process through the polymer and the rate of release depends on several factors. It is important to keep the lifetime of the buildings in mind.

HFC-134a and blends: HFC-134a is a high-GWP HFC and has been used historically as blowing agent and provides long term (about 20 years) benefits to the insulation. One drawback is the low solubility, which requires specific chemicals to be added. As HFC-134a has a high GWP, it is generally not considered as a technical option. It may only be considered as an interim option where the use of flammable refrigerants is not possible or not allowed and where CO_2 cannot be applied because of limitations for the thickness of foam panels. This may be the case, for example, in some specialised transportation applications.

HFC-152a: HFC-152a is mentioned separately as it allows an easy conversion from HCFC-142b or HCFC-22. It has a GWP of 124 and is accepted in the EU F-gas regulation, where the maximum GWP is set at 150. In some countries, however, such as Switzerland, Austria, Denmark, HFCs are forbidden for the use in foams. The disadvantages are its flammability and that the gas is quickly released from the foam cells, typically within a few months. Generally HFC-152a has little, if any, value added compared to hydrocarbons.

Hydrocarbons (HC): The substances considered in this group are isobutene, LPG, ethanol, DME and acetone, the latter three being solvents. The differentiation to CO_2 systems is not always clear as there are combinations of both, which may allow a reduction of the flammability classification dependent on the local regulations. However, there are also companies that use pure HCs, especially LPG. The major drawbacks is their flammability which requires safety measures and equipment adaptation. In certain countries the flammability classification is not achievable with pure HC-blown XPS boards. Advantages are that the technology is well known and that the blowing agent costs are low.

CO_2 and CO_2 blends: First of all, it is difficult to produce pure CO_2-blown XPS boards as the solubility of CO_2 is low. The more obvious option is the use of CO_2 together with additional blowing agents like ethanol, DME, acetone, which are solvents, but also HFCs with low GWP. When referring to CO_2 in XPS, a physical blowing agent is meant, in contrast to waterblown PU where CO_2 is generated by a chemical reaction. With PS, the process is a mixing of raw materials through the creation of a melt and not a chemical process. This technical option is widely spread. Although CO_2 has an excellent ratio of volume to the quantity used, it requires good equipment. There are only few machine suppliers who are able to provide extruders that produce good PS boards. The quantity which can be added is also limited due to its low solubility. The added solvents (ethanol, acetone and DME) are flammable, which requires specific handling. Advantages are the low cost for CO_2 and the good performance. Furthermore, the GWP is very low and future recycling will not need to include the capture of the contained blowing agent.

Example 2
Climate friendly XPS foam production in China

A production line of the Chinese company Beijing Beipeng New Building Materials, which is among the largest XPS producers in the country, was converted from the use of an HCFC mixture (HCFC-142b and HCFC-22) to the use of a CO_2 and ethanol mixture.

In this case, as the existing equipment was not suitable for conversion, the company received new extrusion equipment. Beipeng company installed all the ancillary equipment, including the storage tanks for CO_2 and ethanol, and introduces a safety system including gas sensor and ventilation.

The conversion, which was part of a project supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and funded by the German Federal Ministry for the Environment, led to the successful introduction of a new climate-friendly product on the Chinese market. The new production line has a capacity of producing 4,320 tonnes of high quality insulation foam annually to be sold to the Chinese construction industry. The experiences gained in this demonstration project will be used in China's HCFC phase-out plan.

Unsaturated-HFCs: Like in PU there is a recent development of unsaturated-HFCs as blowing agents. These are substantially more expensive than all other blowing agents and the use of only unsaturated-HFC will be practically impossible. The costs of the foam products would be so high that they could not compete with other products. Furthermore, there is a lack of relevant chemical data and future developments are unsure. It is likely that there will be combinations with CO_2 in order to improve insulation properties.

Technical options for foams with non-insulation properties

Compared to the insulation foams, the non-insulation foam sectors have little significance with regard to the consumption of fluorinated foam blowing agents. Non-insulation foam applications are used for comfort products, the automotive, shoe and special applications sectors. The automotive sectors in developed countries use mostly waterblown solutions.

End-of-life implications

End-of-life (EOL) treatment refers to recovery and recycling of foam products. Several substances, especially HCFCs and HFCs, are harmful to our climate and require specific disposal channels. The recovery of refrigerants and blowing agents as well as the recycling of metals and plastics is an established practice in developed countries, in particular for domestic refrigerators.

The EOL treatment of the technology plays a role for all stakeholders, from the producer up to the consumer and all institutions as recycling is a costly matter. In the EU, all appliances are subject to levies for covering the costs of recovery and recycling.

2.2.3 Barriers to applying alternative technologies in the foam sector

The main barriers to applying technical options in the foam sector are flammability and insulation properties. Problems arise due to safety considerations, fire danger, construction standards and regulations.

Safety constraints: Hydrocarbons as one of the main technical options as alternative blowing agent, are flammable. Therefore many countries have restriction on the use of these blowing agents during production or in products. For flammable blowing agent use in PU foams the production process needs to comply with the ATEX (ATmosphères EXplosives) directive and other relevant standards. In general, there is a wide experience for the introduction of flammable blowing agents in production processes in many developed and developing countries. Safety can be assured with appropriate production processes such as the use of gas sensors and appropriate gas ventilation.

Thermal conductivity: Decreased thermal conductivity due to the use of alternative blowing agents can be overcome by increasing the foam thickness. It is important that the specifications for the PU and PS industry allow for thicker PU and PS products to meet the targeted thermal conductivity values. With this PU and PS are properly kept as a technical option along with other alternatives such as rock-, mineral-, glass-wool or cork.

Mechanical properties: Foams have particular mechanical properties which make them suitable for different applications. These properties are determined by the polymer and not by the blowing agent. Therefore all new technologies will meet the existing mechanical properties. Only in case of the use of solvents such as ethanol, DEM and acetone in XPS production there is need to take specific care. The same is true for PU foams with methylformate.

Standards and regulations: Industry will not consider new technical options when standards or regulations are in place that prohibit the use of specific foams. At the same time there is a large demand for green technology. Therefore appropriate actions at governmental level are required to further acceptance and allowing the use of new technical options. In constructions this is the key element. In the automotive sector, the car industry, which is often located in other countries, is determining.

Consumer awareness: Generally, consumers do not know that foam products are of relevance to ozone depletion or climate change. In addition, they are not aware of or do not understand the information on foam blowing agents contained in foam product labels. This barrier could be overcome by clear, comprehensive labeling with additional information on the climate relevance, comparable to energy efficiency labels. Ideally, respective awareness programmes should also be considered.

2.3 Penetration rates

Existing and future market penetration is a key parameter for the calculation of the consumption and emission reduction potential of any technical option to current technology. The penetration rate is defined as the maximum market potential of a technical option to replace new products or equipment relying on current technologies in a particular subsector. Penetration rates are given for each technical option based on technical feasibility to replace existing technologies by a specific alternative technology. A possible penetration rate of 30 % means that 30 % of the application could potentially be replaced by systems using the particular technical option. A more detailed description of the determination and combination of penetration rates and their constraints can be found in the annex to this module.

However, no given technical option is universally applicable to all subsectors. Thus, maximum market penetration for replacement of current technology in a specific subsector could only be achieved by aggregation of two or more technical options. Table 11 provides an overview of the maximum technical possible penetration rates for RAC appliance systems.

TABLE 11
Penetration rates for different technical options in the RAC sector

Technical option	Unitary air conditioning							Chillers		Mobile AC	
	Self-contained	Split residential	Split commercial	Duct split residential	Commercial ducted splits	Rooftop ducted	Multi-splits	Air conditioning	Process	Car	Large vehicle
Leak reduction (design/construction)		100%	100%	100%	100%	100%		100%	100%		100%
Leak reduction (maintenance)			50%	50%	70%	70%		70%	70%	50%	70%
Charge size reduction							100%				100%
Recovery and recycling											50%
HC-600a											
HC-290/ HC-1270	100%	100%	100%	100%		50%		80%	80%	100%	
R-717								50%	80%		
R-744									80%	100%	
unsat-HFC	100%						100%			100%	
HFC / unsat-HFC blends					100%						
Low-GWP + liquid secondary (centralised)	50%				90%	90%	90%				
Low-GWP + liquid secondary (discrete)											
Low-GWP + evap secondary											
Low-GWP + cascade											
Low-GWP + distributed water-cooled											
Low-GWP + district cooling	50%	50%	50%	50%	50%	50%	50%	50%			

TABLE 11
Penetration rates for different technical options in the RAC sector

Technical option	Domestic	Commercial refrigeration			Industrial refrigeration			Transport
	Domestic refrigeration	Stand-alone equipment	Condensing units	Centralised systems for supermarkets	Integral	Condensing units	Centralised systems	Refrigerated trucks/trailers
Leak reduction (design/construction)	100%	100%	100%					100%
Leak reduction (maintenance)	50%	50%						
Charge size reduction	100%							
Recovery and recycling					50%			
HC-600a	100%	90%			90%			
HC-290/ HC-1270		90%			90%			90%
R-717						80%		
R-744			90%	90%	90%	80%		90%
unsat-HFC			100%					
HFC / unsat-HFC blends								
Low-GWP + liquid secondary (centralised)				90%			90%	
Low-GWP + liquid secondary (discrete)			90%			90%		
Low-GWP + evap secondary				90%			90%	
Low-GWP + cascade				90%			90%	
Low-GWP + distributed water-cooled				90%			90%	
Low-GWP + district cooling								

3. Practical application

Based on the information provided in this module, the following step-by-step guide shows you how to identify the most promising technical options for a specific country. The resulting list of technical options will be the basis for a more thorough evaluation in module 4.

Steps for identifying the most suitable technical options:

1. Identify the various RAC&F applications and products in use and available in your country and list them according to the relevant subsectors
2. Identify subsectors with highest emissions in your country
3. Identify possible technical options for the various products and applications in the subsectors
4. Consider implications and barriers for placing technical options in the market
5. List the top five technical options identifying those that combine highest penetration rates and lowest market barriers

Step 1: Identify the various RAC&F applications and products in use and available in your country and list them according to the relevant subsectors

The information provided in this module chapter 2.1.1 and 2.2.1 is the basis for this step. Use the subsector definitions provided in table 1, because these are also used in the model, with which the filtering of the technical options will be done in module 4. The most important subsectors in the country typically depend on the local climate and income structure. For example, more air conditioning units per household are usually used in warmer climates. The amount of commercial refrigeration units, on the other hand, strongly depends on the availability of equipment, manufacturers and assemblers in the country.

Step 2: Identify subsectors with highest emissions in your country

Compiling a list of the various subsectors in your country with their respective emissions will give you an idea of the climate action priorities. Use the emissions data from your inventory (cf. module 1). The focus should be on priority sectors where emissions are high and where you find the political support for mitigation action in a NAMA. The example of low-GWP requirements for mobile air conditioning in the EU demonstrates that implementation of a technical option in a chosen subsector can have significant impact in terms of lowering emissions. You can now shorten the list of possible subsectors from step 1 accordingly.

Step 3: Identify possible technical options for the various products and applications in the subsectors

Chapter 2.1 in this module lists the technical details, availability, applications, probability of further costs and possible efficiency improvements for each technical option. Be aware that some options are more suitable for certain climate zones or for certain refrigerating systems or certain system sizes. An overview of the applicability of different technical options for different applications can be found in table 6. Make a list of the possible technical options for the selected subsectors that are suitable for the specific needs and possibilities in the country. For example, can hydrocarbon refrigerants be introduced as main refrigerant for the domestic refrigeration sector?

Step 4: Consider implications and barriers for placing technical options in the market

The implications and barriers associated with the technical options are summarised in chapter 2.1.3 and 2.2.3. Several very different barriers may stand in the way of implementing a technical option. An overview of the barriers and the technical options they affect is given in table 8. Identify those barriers that are most obstructive for your country. For example, how difficult is it to make missing components available or would it be possible to change the current regulations?

Step 5: List the top five technical options identifying those that combine highest penetration rates and lowest market barriers

Table 11 lists the possible penetration rates for the various technical options. These will also help you choose the most fitting technical options for each subsector, as larger penetration rates mean that an option is applicable to a larger part of the market. Now, consider the most obstructive barriers and the highest possible penetration rates. The use of hydrocarbons for domestic refrigeration is a good example. This technology has reached market penetration in many countries, it is efficient and safe to handle. The situation is similar for the use of hydrocarbons in chillers, where most existing market barriers can be removed with relatively low effort. List a maximum of five top technical options per subsector to consider for implementation in your country.

4. References

Boldt, J., Nygaard, I., Hansen, U.E., Trærup, S. (2012). Overcoming Barriers to the Transfer and Diffusion of Climate Technologies. UNEP Risø Centre, Roskilde, Denmark.

BRA-FETA (2011). Code of practice for refrigerant leak tightness in compliance with the F-gas regulation. www.feta.co.uk

Burke M., Grosskopf P. (2011). Development of environmentally friendly Transport refrigeration machines. ICR 2011, August 21 – 26, Prague, Czech Republic

Code of practice for the minimisation of refrigerant emissions from refrigerating systems. (2009) The Institute of Refrigeration, United Kingdom. www.ior.org.uk

Colbourne, D.; Hühren, R.; Schrempf, B. (2010). Guidelines for the safe use of hydrocarbon refrigerants – A handbook for engineers, technicians, trainers and policy-makers – For a climate-friendly cooling. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Programme Proklima. Eschborn, Germany.

Ederberg, L., Papst, I., Oppelt, D., Usinger, J., Colbourne, D., Croiset, I., Kauffeld, M., et al. (2010). Task 3 Draft Progress Report.

Ederberg, L., Papst, I., Oppelt, D., Colbourne, D., Wypior, M. (2012). Mitigation of HFC and CO_2 emissions through nationally appropriate mitigation actions (NAMAs) in the refrigeration and air conditioning and foam blowing sector, paper for Gustav-Lorentzen-Conference, 278.

EN 16084 (2011). Refrigerating systems and heat pumps – Qualification of tightness of components and joints

ENTR Lot 1: Preparatory Studies for Eco-design Requirements of EuPs, ENTR Lot 1, Refrigerating and freezing equipment, Draft Final Report, May 2011 [NOTE: Data extrapolated linearly from 2015/2020 to 2030]

ENTR Lot 6: Preparatory Studies for Eco-design Requirements of EuPs, ENTR Lot 6: Air-conditioning and ventilation systems, Air conditioning systems, Draft report of Task 6, September 2011

GIZ (2011). Climate results. The GIZ sourcebook for climate-specific monitoring in the context of international cooperation. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

GIZ (2012). Nationally Appropriate Mitigation Actions (NAMAs) – Steps for Moving a NAMA from Idea towards Implementation (GIZ NAMA tool). Version 8.6. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Hasse, V.; Ederberg, L.; Croiset, I.; Usinger, J., Eds. (2009). Natural Foam Blowing Agents – Sustainable Ozone- and Climate-Friendly Alternatives to HCFCs. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Programme Proklima. Eschborn, Germany.

Hasse, V.; Ederberg, L.; Colbourne, D., Eds. (2008). Natural Refrigerants – Sustainable Ozone- and Climate-Friendly Alternatives to HCFCs. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Programme Proklima. Eschborn, Germany.

Hühren, R. (2010). Good Practices in Refrigeration. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (Programme Proklima).

Koronaki, I.P. D. Cowan, G. Maidment, K. Beerman, M. Schreurs, K. Kaarf, I. Chaer, G. Gontarz, R.I. Christodoulaki, X. Cazauran (2012). Refrigerant emissions and leakage prevention across Europe – Results from the RealSkillsEurope project. 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy, ECOS 2011. Volume 45, Issue 1, September 2012, pages 71–80.

Rhiemeier, J., Harnisch, J., Ters, C., Kauffeld, M., Leisewitz, A. (2009). Comparative assessment of the climate relevance of supermarket refrigeration systems and equipment, Report 206 44 300, Umweltbundesamt, Dessau-Rosslau. www.iea-dhc.org/index.php

Safety code for compression refrigerating systems utilising ammonia (2008). The Institute of Refrigeration, United Kingdom. www.ior.org.uk

Safety code of practice for refrigerating systems utilising A2 & A3 refrigerants (2008). The Institute of Refrigeration, United Kingdom. www.ior.org.uk

Safety code of practice for refrigerating systems utilising carbon dioxide refrigerant (2009). The Institute of Refrigeration, United Kingdom. www.ior.org.uk

TREN Lot 10: Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) TREN LOT10, Draft report of Task 8, March 2009, Policy, Impact and Sensitivity Analysis

TREN Lot 12: Preparatory Studies for Eco-design Requirements of EuPs, TREN Lot 12, Commercial refrigerators and freezers, Draft Final Report, August 2007

TREN Lot 13: Preparatory Studies for Eco-design Requirements of EuPs, TREN LOT 13: Domestic Refrigerators and Freezers, March 2008

United Nations Environment Programme (2011). 2010 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee.

United Nations Industrial Development Organization (2009). Preparing for HCFC phase-out: Fundamentals of uses, alternatives, implications and funding for Article 5 countries.

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices
Bonn and Eschborn,
Germany

Programme Proklima

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Germany
Phone: +49 61 96 79 - 1022
Fax: +49 61 96 79 - 80 1022
Email: proklima@giz.de
Internet: www.giz.de/proklima