MODULE 6

Technology Roadmap for the RAC&F Sectors

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

On behalf of:

Federal Ministry
for the Environment, Nature Conservation,
Building 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

Author
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
The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

Division K II 4, 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: kii4@bmub.bund.de
Internt: www.bmub.de

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

Layout
Jeanette Geppert, Frankfurt

Place and date of publication
Eschborn, April 2014

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, Building and Nuclear Safety (BMUB) under its International Climate Initiative (IKI) 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 BMUB International Climate Initiative.

www.giz.de/proklima

The International Climate Initiative

Since 2008, the International Climate Initiative (IKI) of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has been financing climate and biodiversity projects in developing and newly industrialising countries, as well as in countries in transition. Based on a decision taken by the German parliament (Bundestag), a sum of at least 120 million euros is available for use by the initiative annually. For the first few years the IKI was financed through the auctioning of emission allowances, but it is now funded from the budget of the BMUB. The IKI is a key element of Germany's climate financing and the funding commitments in the framework of the Convention on Biological Diversity. The Initiative places clear emphasis on climate change mitigation, adaption to the impacts of climate change and the protection of biological diversity. These efforts provide various co-benefits, particularly the improvement of living conditions in partner countries.

The IKI focuses on 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. New projects are primarily selected through a two-stage procedure that takes place once a year. Priority is given to activities that support creating an international climate protection architecture, to transparency, and to innovative and transferable solutions that have an impact beyond the individual project. The IKI cooperates closely with partner countries and supports consensus building for a comprehensive international climate agreement and the implementation of the Convention on Biological Diversity. Moreover, it is the goal of the IKI to create as many synergies as possible between climate protection and biodiversity conservation.

www.international-climate-initiative.com

Contents

Executive Summary

Rising cooling needs primarily in developing countries will drive the demand for additional refrigeration, air conditioning and foam (RAC&F) equipment with an increase of greenhouse gas (GHG) emissions to 12 Gt CO_2 equivalent (CO_2 eq) by 2030 in the business-as-usual (BAU) scenario. Such an increase will be inconsistent with the 2°C temperature target adopted in the Copenhagen Accord as upper temperature limit for allowable global warming[1].

The Proklima Programme of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) has submitted a global roadmap to the Technology Executive Committee (TEC) of the United Nations Framework Convention on Climate Change (UNFCCC)[2]. The roadmap outlines the framework aiming to limit GHG emissions from the RAC&F sectors at current levels of 4 Gt CO_2eq. To meet the growing cooling demand and to limit emissions at the same time can only be achieved by a combination of measures which includes the deployment of refrigerants with a low global warming potential (GWP), improved energy efficiency of the equipment and the de-carbonisation of the energy supply.

The global emission reduction goal can only be achieved if individual countries contribute their respective fair share to the global mitigation action. For a credible and systematic mitigation action, it is recommended that countries set up a national RAC&F roadmap in line with the targets and structure of the global roadmap. Further the RAC&F roadmap should be linked to the national climate action plan, the technology needs assessment (TNA) and technology action plans (TAP).

A RAC&F roadmap for a specific country describes its key targets and milestones to achieve direct and indirect emission reductions over time. It also describes the required regulatory, technical and market enabling environments under which the measures for emission reductions can be realised.

The two main elements of the roadmap are therefore the emissions pathway and the enabling environments:

- The emissions pathway includes the description of the BAU scenario, the baseline year emissions, the target emission reduction scenarios with direct and indirect emission reductions, the ranking of mitigation actions, and the individual subsector contributions.

  RAC&F specific elements of the emissions pathway are:
  - Reduction of direct emissions from HFC refrigerants, suggested to be aligned with the phase-out of HCFC, by 2030 to 2040,
  - Reductions of indirect emissions through the de-carbonisation of the energy supply and increase of energy efficiency standards,
  - Specific pathways for the key RAC&F sectors and subsectors (stationary air conditioning, industrial refrigeration, transport refrigeration, commercial refrigeration, domestic refrigeration, mobile air conditioning, and foams).

- The enabling environments describe the framework (regulatory, technology and market) required to replace old technology with low carbon technologies in order to achieve the target emission reduction.

This module introduces the key elements of the global RAC&F roadmap and the implications for a national RAC&F roadmap. Based on the previous modules of this handbook, module 6 provides an outline for policy makers on how to set up a roadmap specific for the RAC&F sector, including guiding questions on how to

- set up appropriate goals and emissions targets,
- set up appropriate milestones,
- identify gaps, barriers and enabling environments to overcome them, and
- define action items, priorities and timelines.

The introduction of this module will first put the national roadmap in relation to a global roadmap for the RAC&F sector. Next a methodology will be outlined for how to develop a roadmap for the RAC&F sectors in a national context.

1 http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf
2 http://unfccc.int/ttclear/pdf/Call%20for%20Inputs/RM/GIZ_RM.pdf

1. Introduction

The Proklima Programme of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH has submitted a global roadmap for the RAC&F sectors to the Technology Executive Committee under the UNFCCC[3]. This chapter introduces this global roadmap and derives the implications for a national RAC&F roadmap.

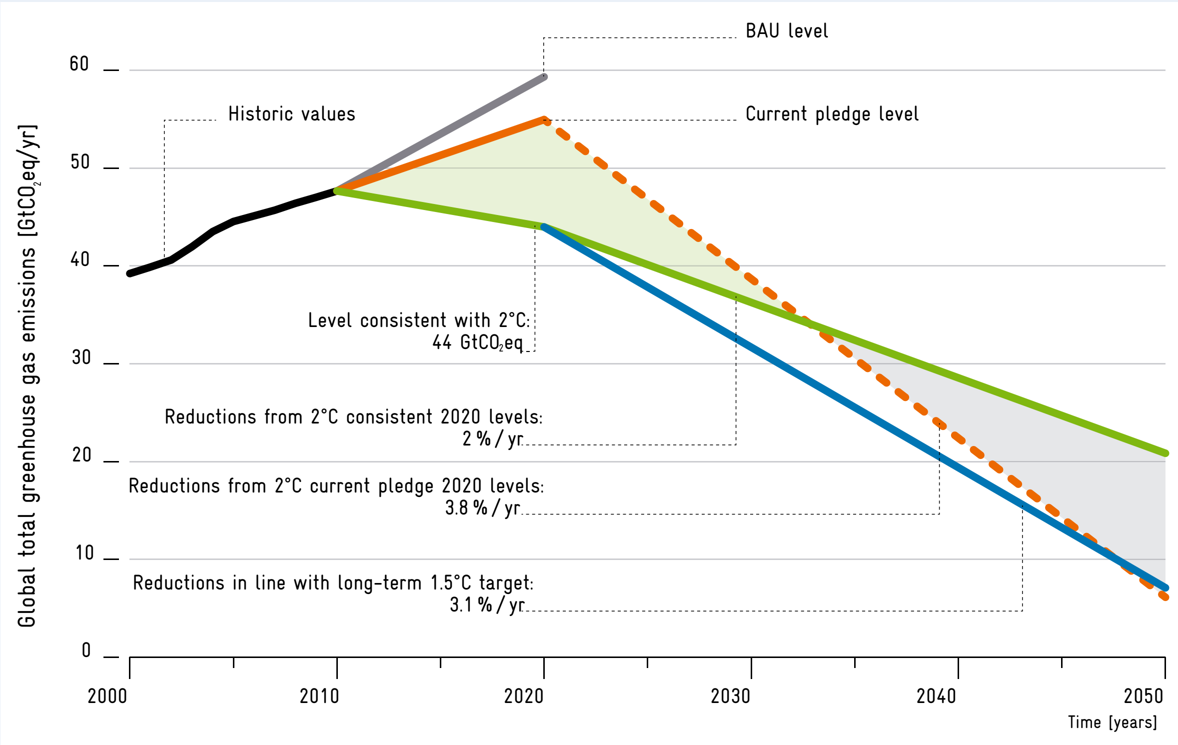
1.1 Global technology roadmap: RAC&F pathways

Globally, unabated direct and indirect emissions in the RAC&F sectors will grow from currently about 4 Gt CO_2eq to 12 Gt CO_2eq by 2030. Key factors for the emissions growth are a growing population, economic development, wealth effects and lifestyle, growing urbanisation and increasing ambient temperatures.

In order to meet the 2°C target, assuming that global emissions are not allowed to peak much later than 2020, it will be necessary to achieve global emission reductions of at least 3.8 % per annum from 2020 to 2050 (cf. Figure 1). The global effort for emission reductions requires the contribution of all countries, including developing countries, and all sectors.

Assuming that all major global sectors contribute in a similar way to the global emission reduction effort, effective mitigation requires capping emissions also in the RAC&F sectors at current emission levels. Such reductions correspond to a pathway where emissions in 2030 will be some 7 Gt CO_2eq below their BAU level. This corresponds approximately to the 60 % reduction target – relative to the BAU scenario - of the BLUE Map scenario, as formulated by the International Energy Agency (IEA) in 2008 for the transport, industry and buildings sector (Taylor, 2008), which is in line with the 2°C target.

FIGURE 1
Global reduction pathway (all sectors) (Ecofys, 2012)



3 http://unfccc.int/ttclear/pdf/Call%20for%20Inputs/RM/GIZ_RM.pdf

Since 1991, ozone-depleting substances (ODS) in the RAC&F sectors are successfully being phased out through the mechanism of the Montreal Protocol. However, the mandate of the Montreal Protocol only covers the phase-out of ODS. It has limited control to interdict the replacement of ODS used as refrigerants and foam blowing agents with substances that have a high GWP. Neither does it prohibit the replacement of systems with new systems that have low energy efficiency. A significant proportion of the ODS phased out under the regime of the Montreal Protocol continues to be replaced in appliances and systems with hydrofluorocarbons (HFC) with a high GWP. There is a substantial risk that the phase-in of HFCs is further accelerated by the on-going phase-out of hydrochlorofluorocarbons (HCFC) under the Montreal Protocol (Velders, 2012). In fact, current emissions of HFCs are strongly increasing (UNEP, 2011). Such a “phase-in” of HFC is inconsistent with the above outlined climate targets.

The global RAC&F roadmap suggests limiting and reducing direct emissions through the replacement of HFC refrigerants with natural, low-GWP refrigerants, and applications and systems supporting these refrigerants. Developing countries are currently in their first phase-down of HCFC consumption with a reduction of 10 % by 2015 versus the baseline year of 2008 (UNIDO, 2009) which will be nearly completed in 2030. The suggested phase-down of HFCs is currently not under the mandate of the Montreal Protocol. Measures to be introduced within a NAMA approach will therefore be additional to ongoing HCFC phase-out management plans (HPMP). The introduction of a combined phase-out of HCFC and HFC until 2030 will potentially lead to a nearly complete elimination of direct emissions from refrigerants and foam blowing agents.

To reach a freeze of greenhouse gas emissions from the RAC&F sectors, in addition to limiting direct emissions, it will be required to take measures to curb indirect emissions. Such measures include the improvement of the energy efficiency of systems and applications as well as the decarbonisation of the energy supply through the increased deployment of renewable energies replacing fossil fuels.

Direct and indirect emission reductions will be possible through the phase-out of old technologies and the accelerated deployment of alternative, low-GWP technologies. The replacement of high-GWP with low-GWP refrigerants promises the reduction of direct emissions of up to 3.5 Gt CO_2eq. The increased energy efficiency of the new technologies will reduce indirect emissions by an additional 0.5 Gt CO_2eq, whereas the decarbonisation will contribute with ca. 3 Gt CO_2eq. Indirect emission savings due to improvements of energy efficiency might be much higher than the indicated estimate. The described emission reduction effects are described in Figure 2.

FIGURE 2
The roadmap for the refrigeration, air conditioning and foam blowing sectors estimates possible emission savings of 7.2 Gt CO_2eq. Direct and indirect emission reductions contribute equally to the overall emission savings.

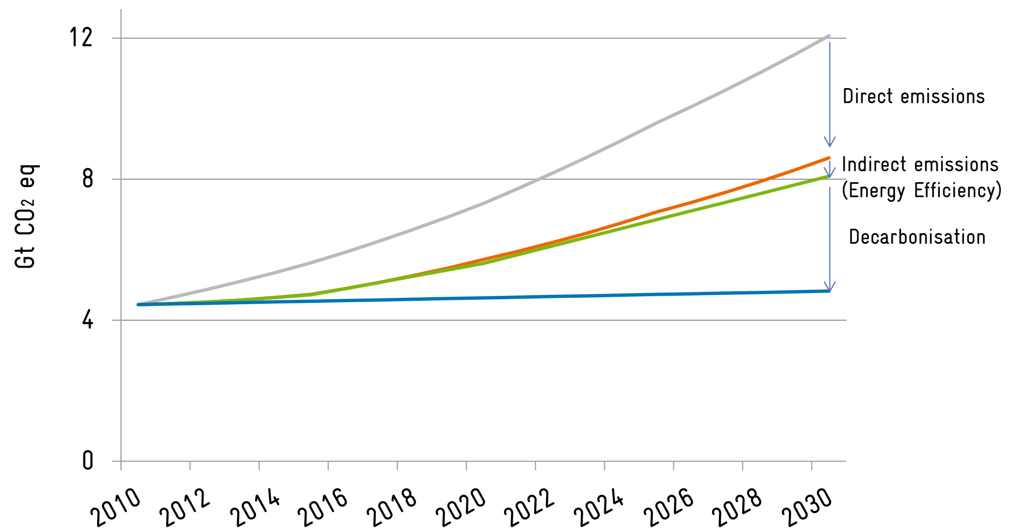
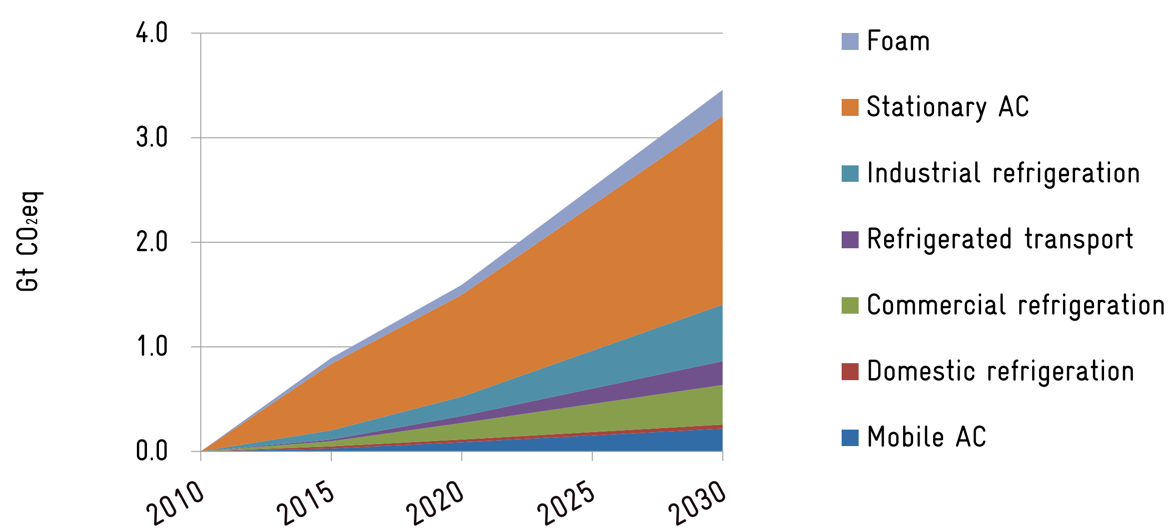


Figure 3 shows the different subsectors' contribution to achieving the direct emission reductions of 3.5 Gt CO_2eq by 2030. Globally, the fastest growing subsectors in terms of demand and emissions are stationary air conditioning and industrial and commercial refrigeration. Accordingly, these sectors reveal the greatest reduction potential. Roughly 50% of direct emissions can be reduced by a transformation of the stationary air conditioning subsector. With air conditioners (AC) being one of the most desirable household appliances in tropical and hot countries, the expected growing prosperity in developing countries will increase the penetration and saturation of this type of equipment. Other subsectors with significant potential reductions are industrial and commercial refrigeration, adding up to ca. 1 Gt CO_2eq.

FIGURE 3
Subsectors' contributions to global potential direct emission reductions



1.2 National technology roadmap: RAC&F emission pathways

Globally, emissions in the RAC&F sectors can only be maintained at or lowered from the current level if the transformation of the sector is initiated and carried out by individual countries. It is suggested that each country describes its individual RAC&F emissions pathway according to the global RAC&F emission pathway described in 2.1., and integrates it with its national climate strategy.

The national emissions pathway for the RAC&F sectors includes
- Tier 2 inventory for the RAC&F subsectors (cf. module 1),
- Stock projections (cf. module 2),
- Identification of alternative technologies and the emission reductions across subsectors (modules 1-3).

Based on these analyses, feasible **milestones and targets** for the global dissemination of alternatives are projected:
- **Freeze RAC&F direct and indirect emissions at current levels**. Establish the target to freeze emissions from the RAC&F subsectors in the long term at current – i.e. 2010 – baseline emission levels.
- **In the longer term direct emissions can be widely avoided through a parallel phase-down of HFCs along the phase-out of HCFCs currently carried out under the Montreal Protocol**. The replacement of HCFCs with HFCs will be avoided. Instead, natural refrigerants are used to replace HCFCs.
- **Indirect emissions are limited through improved energy efficiency and the decarbonisation of the economy**. The latter takes place through the replacement of fossil fuel energy sources with renewable energy sources. The improvement of energy efficiency is achieved through mandatory labelling and energy efficiency standards.
- **Through the mix of measures for curbing direct and indirect emissions only a limited overshooting – both in quantity and time – of peak emissions compared to baseline emissions will take place.**

The roadmap outlines the priority under which emission abatement will take place in the different RAC&F sectors and subsectors. The selection of technologies in each subsector has been described in module 3 and is further outlined within the context of the technology needs assessment in the so-called technology enabling environment in the following chapter of this module.

2. Methodology

The methodology applied for developing a roadmap specific to the RAC&F sector in the national context refers to the approaches suggested in the *Background paper on Technology Roadmaps* initiated by the TEC (Londo, 2013) and the IEA Energy Technology Roadmaps. *A guide to development and implementation* (IEA, 2010b).

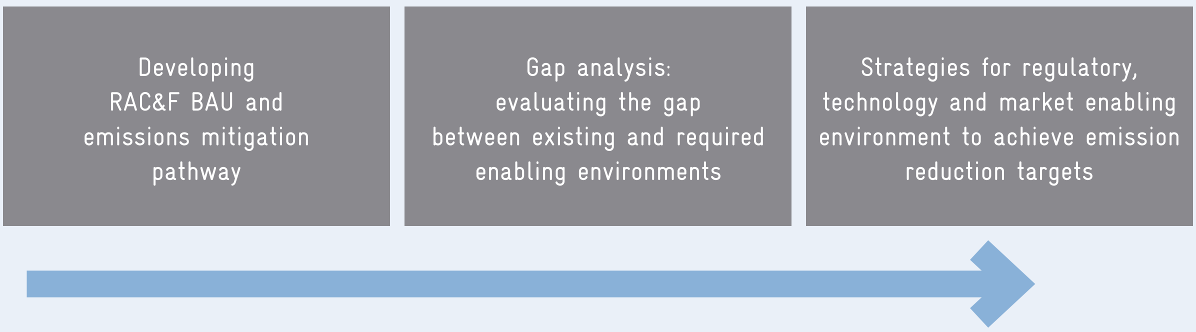
BOX 1
Definition of Technology Roadmap

Common definitions and approaches on the development roadmaps vary considerably. For the purpose of this handbook, and the context of the NAMA and the UNFCCC technology mechanism, the definition provided by the TEC serves as an orientation:

"A Technology Roadmap (TRM) serves as a coherent basis for the specific development and transfer activities, providing a common (preferable quantifiable) objective, time specific milestones and a consistent set of concrete actions; developed jointly with relevant stakeholders, who commit to their roles in the TRM implementation".

The process for developing a roadmap in the RAC&F sectors then includes objective quantifiable, time specific, emission reduction targets on both direct and indirect emissions, setting up enabling environments on regulatory, technology and market aspects with technologies transfer activities, and a consistent set of concrete actions (cf. Figure 4). Enabling environments encompass government policies to create and maintain a legal, regulatory, technological and macroeconomic framework which brings together suppliers and consumers and facilitates the achievement of emission reduction targets[4].

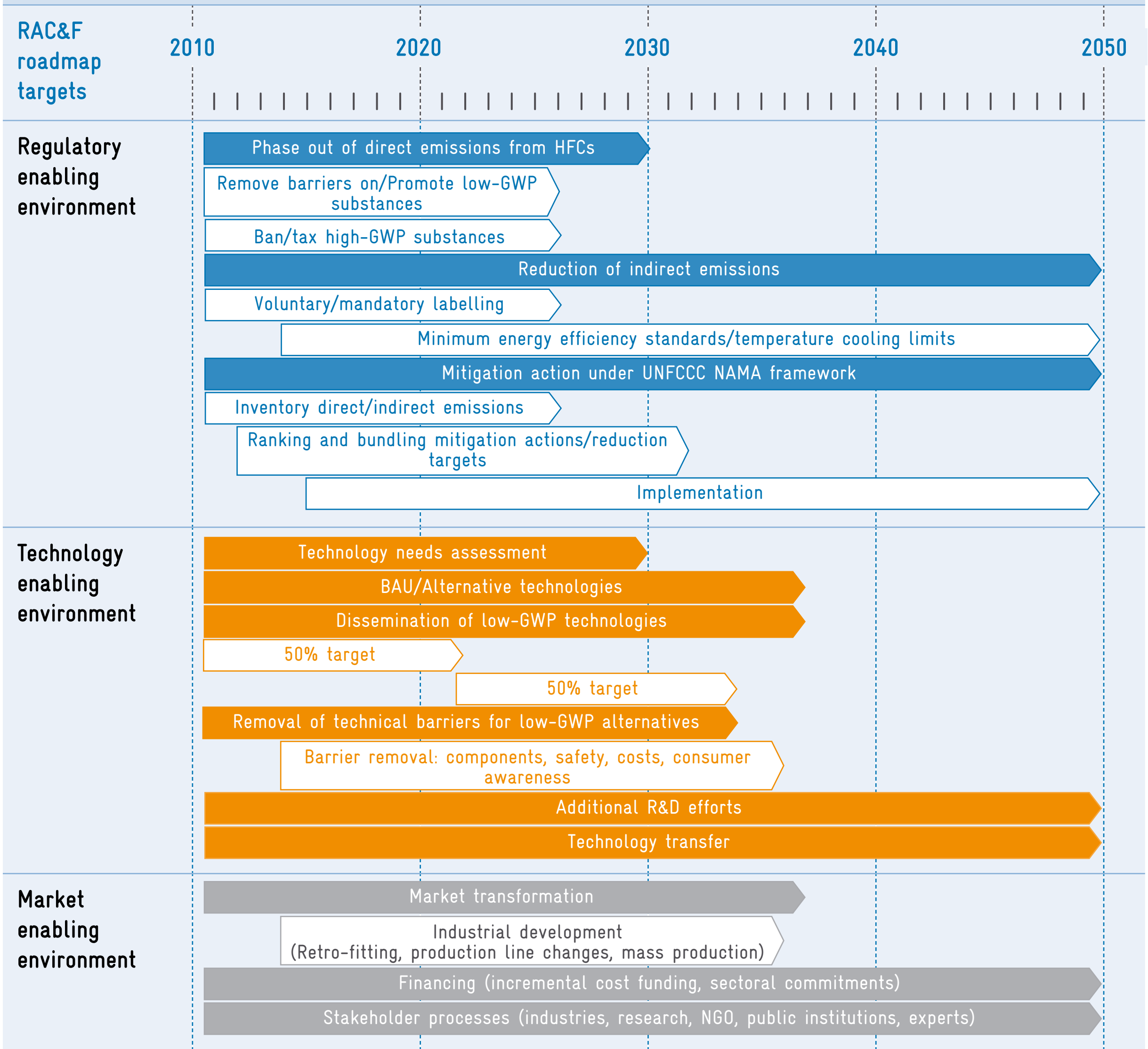
FIGURE 4
Process for establishing the RAC&F roadmap



4 http://unfccc.int/ttclear/jsp/EEnvironment.jsp

The enabling environments are the framework or strategy under which activities and measures are described and bundled in order to achieve the targeted RAC&F emission reduction pathways. Figure 5 illustrates the generic development of the enabling environments in line with the targets and emission reduction pathways outlined in the introduction. Later on, this chapter describes the respective enabling environments in more detail.

FIGURE 5
The development of enabling environments under the RAC&F roadmap



2.1 The regulatory enabling environment

The regulatory enabling environment provides the basis for the reduction of direct and indirect emissions. Key policy targets of the regulatory framework under the RAC&F sectors are

- to avoid direct emissions through a ban of high-GWP refrigerants and foam blowing agents at the latest by 2030,
- to reduce indirect emissions through the introduction of mandatory minimum efficiency standards, labelling and overall performance standards at the latest by 2030.

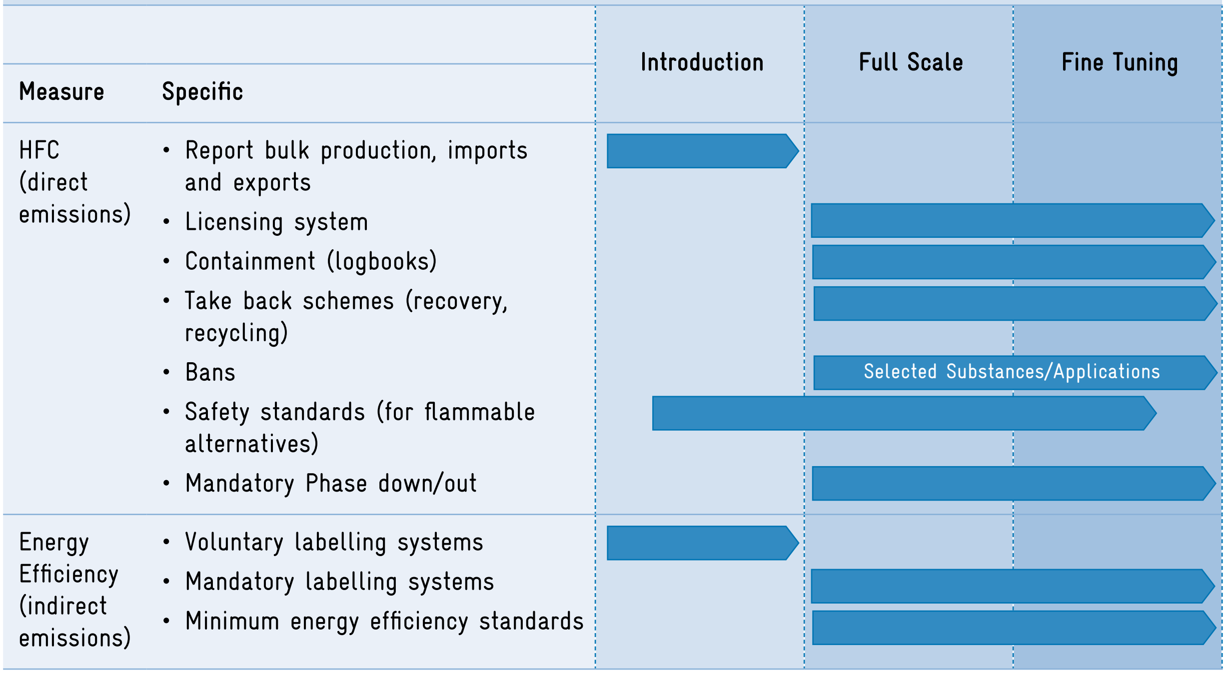
Module 8.1 of this handbook describes in detail the available policy instruments for lower HFC emissions, reduced use of HFC substances and the deployment of appliances and systems with higher efficiency. Chapter 2.1.2 and 2.1.3 describe the strategic framework under which such policies might be introduced in a country in its RAC&F roadmap.

A phased introduction of policies as outlined in Figure 6 may be considered as an appropriate approach. On direct emissions this implies first the introduction of national reporting for the bulk use of HFC substances at production, through imports and exports. The next level would be the transition from a reporting to a licensing system. On the basis of an established licensing system a mandatory phase-down or phase-out of HFCs can be introduced.

Accompanying steps on a national HFC control regime are a measure to lower emissions through better containment of appliances and systems. Outright bans can be imposed on subsectors and appliances where technologies are readily available and deployable with no additional costs to the industry (i.e. ban of HFCs for domestic refrigeration).

The phased approach for energy efficiency usually implies first the introduction of voluntary labelling, followed by a mandatory labelling and, lastly, mandatory and periodically tightening minimum energy efficiency or energy consumption standards.

FIGURE 6
Phased introduction of policies and regulations with a RAC&F roadmap



As a starting point for policy measures it is important to have sufficient capacity building for the personnel and institutional readiness in the country to establish the regulatory enabling environment. For the development of a NAMA in a RAC&F sector, a national focal point and a line ministry should be nominated to oversee the implementation of the NAMA and the mitigation action. The focal point needs to look after Measurement, Reporting and Verification (MRV) of emission reductions, as outlined in module 7. For the establishment of the inventory and the MRV measures it is recommended to nominate a specialised national expert entity, either a governmental, semi-governmental agency or private consulting company, to accompany the development and implementation of the roadmap and its measures.

2.1.1 Framework on direct emissions

The Montreal Protocol has demonstrated the effectiveness of a mandatory, step-wise reduction and phase-out of consumption and production of HCFC and CFC with international support, i.e. funding from the Multilateral Fund (MLF) and implementation assistance from agencies. The Montreal Protocol foresees the phase-out of refrigerants with ozone-depleting potential (ODP), in particular HCFCs, by 2030. Currently, HFCs are still used in most developing countries and sectors as replacement substances. So far, only the European Union (EU) has limited the use of HFCs in legislation through a combination of various measures either limiting the use of HFCs or supporting alternatives. Limiting measures, for example in the EU Mobile Air Conditioning Directive and the F-Gas Regulation, include bans, limitation for placing substances on the market, import/export taxes, GWP limits, and minimum leakage rates.

HFCs are not part of the phase-out activities under the Montreal Protocol. They are among the greenhouse gases under the governance of the UNFCCC. The roadmap suggests that high-GWP alternative refrigerants, such as HFCs, are phased out in a similar time range, i.e. until 2030, as the gases dealt with under the Montreal Protocol. This would avoid that a phase-out of HCFC leads to a phase-in of HFCs. Consequently, HCFCs would be replaced with low-GWP refrigerants and foam blowing agents or technologies not requiring HFCs.

In most cases alternative, low-GWP technologies are based on substances with a higher flammability. In many countries regulatory matters interdict the application of low-GWP substances, which are flammable or toxic. The unqualified prohibition of low-GWP refrigerants represents a major barrier for higher penetration of climate friendly RAC&F applications and systems. Instead of an outright prohibition, the qualified use of low-GWP substances should be allowed and regulated. As an example, this is the case with the European technical standard norms, in particular in the EN378 where the use of flammable substances is regulated in relation to the volume.

HFC based substances are synthetically manufactured; they do not naturally occur in the environment. Applications and systems that contain HFCs, therefore, require careful and costly treatment of recovery, recycling and destruction during their life-cycle, i.e. at production, servicing and the end-of- life. In particular in developing countries such care is often not applied and therefore uncontrolled leakage occurs frequently.

It is recommended that the damage of HFCs to the climate and the environment are properly reflected in the prices of these substances. This can be achieved for example through taxes on the substances.

The RAC&F roadmap suggests phasing out HFCs in line with HCFCs by 2030 to 2040. Module 8.1 describes available policy options for restricting the use of HFCs, such as bans, measures on containment, reporting, licensing and standards. The proposal for an F-Gas Regulation review in the EU, outlined in case study 2 in Module 8.1, could serve as model for developing countries.

2.1.2 Framework on indirect emissions

Indirect emissions are most effectively addressed through mandatory labelling of appliances such as the labelling for domestic refrigerators in the EU, and minimum energy efficiency standards. Labelling and minimum energy efficiency standards regulate the allowed energy consumption related to the cooling capacity of the devices. In some cases, they also set the permissible non-renewable generated cooling demand, as for example in China, where air conditioning of public buildings is only allowed above a certain minimum ambient temperature threshold.

Most important **technical measures on energy efficiency** in the RAC&F sectors are:

- **Optimisation of refrigeration cycle:** Substantial improvements are possible through an overall optimised system balancing, reduction of the refrigerant charge size, larger evaporator and condenser surface areas in combination with new surface textures and the application of alternative cooling cycles, e.g. Lorenz cycle or Stirling cycle.
- **Reduction of parasitic losses:** Energy losses can be avoided through the reduction of required ancillary components or the application of more energy efficient components like fans and pumps.
- **Control of transient effects:** Energy losses within transient effects are mitigated mainly through the application of variable speed compressors optimised electronic controls and the application of expansion valves instead of capillary tubes.

2.1.3 Mitigations under the UNFCCC NAMA framework

The medium to longer term target of the RAC&F roadmap is to cover all RAC&F subsectors in a comprehensive way including direct and indirect emissions. Direct emissions will be reported with the HFC inventory described in module 1. The Tier 2 stock model described in module 1 is the basis for the monitoring of both direct and indirect emissions. The regulatory enabling environment will adjust the legislation in a way to promote low-GWP alternatives and to prohibit high-GWP alternatives. Given the substantial carbon footprint of the RAC&F sectors in most countries, the mitigation actions as outlined in the RAC&F roadmap should be integrated into the national climate action plans and the National Communications (NC) to the UNFCCC (NAMAs including registration, reporting, MRV and consultation).

2.2 The technology enabling environment

The RAC&F roadmap suggests building the required technological capabilities to achieve the emission targets by

- dissemination of available alternative technologies (refrigerants and application systems),
- removal of technology barriers holding back the deployment of low-GWP alternatives,
- additional research and development (R&D) and deployment (pilot and demonstration projects) in new and emerging technologies.

Chapter 2.2.1 provides an overview on the natural refrigerants that are currently available and in actual use for the specific sectors and subsectors and the market penetration of natural refrigerants in the EU and in developing countries.

Chapter 2.2.2 outlines a possible strategy for introducing low carbon alternative RAC&F technologies within a RAC&F roadmap and describes the state of deployment for the main alternative technologies in each of the sectors and subsectors.

2.2.1 Refrigerants

Direct emissions in the refrigeration and air conditioning sectors stem from the use of HCFCs and HFCs as refrigerants. These compounds usually have a high GWP and thus contribute to warm the climate once emitted into the atmosphere during production, usage or disposal. Natural refrigerants such as hydrocarbons (HC), which are introduced only in a few subsectors and regions at the moment, are preferable as alternative refrigerants. They are present in nature, and thus their interaction with the environment, which is usually neutral, is well known in contrast to that of synthetically produced refrigerants. Furthermore, they have a lower GWP than all HCFCs or HCFs. The main and low-GWP refrigerants used for each RAC&F subsector are summarised in Table 1.

TABLE 1
Summary of the main refrigerants/blowing agents applied in the different subsectors

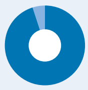
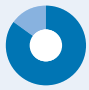
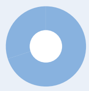
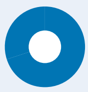
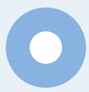
Sector	Subsector	Main refrigerants/blowing agents used (high GWP)	Main refrigerants/blowing agents used (low GWP)
Refrigeration	Domestic	HFC 134a	HC-600a (in the majority of European products, also in China and other countries)
	Commercial	HFC-404A, HFC-134a; HCFC-22 (Non-Annex I countries),	R-744, R-717, HC-290, HC-600a
	Industrial	HFC-404A, HCFC-22 (Non-Annex I countries)	R-717
	Transport	HFC-134a, HFC-404A, HFC-410A, HFC-407C	
Air Conditioning	Stationary	HCFC-22, HFC-410A, HFC-407C, HFC-134a, HFC-404A	HC-290
	Mobile	HFC-134a	
Closed cell type	Construction sector	HFC-245fa, HFC-235fa, HFC-134a, HFC-152a, HFC-365mfc/227ea (Annex I countries); HCFC-141b, HCFC-142b, HCFC-22 (Non-Annex I countries)	HC (N-, isopentane, isobutene CO_2)
	Insulation for refrigeration applications	HFC-245fa, HFC-365mfc/227ea (Annex I countries); HCFC-141b (Non-Annex I countries)	HC (N-, isopentane, cyclopentane)
	Integral foams for automotive, furniture sectors	HFC-245fa, HFC-365mfc/227ea (Annex I countries); HCFC-141b (Non-Annex I countries)	

The starting point of the technology needs assessment is to compile the stock of currently used technologies. With regard to the refrigerant this includes determining the current market share of alternative refrigerants for each subsector. Next, for each of the subsectors, targets need to be set to achieve the emission reduction targets. This target could be the phase-out of HFCs by 2030 to 2040.

The roadmap outlines the current market share and targeted market share of natural refrigerants towards 2030 to 2040. Table 2 illustrates the market penetration of alternative refrigerants in the EU and the average of developing countries. Due to the early phase-out of CFCs and HCFCs, Europe, for example, has used alternative technologies at an earlier stage than most developing countries. Table 2 highlights the difference between the deployment of alternative low-GWP technologies in Europe and in developing countries.

The penetration of low-GWP refrigerants in a country can be used as first benchmark for the current penetration of alternative refrigerants in a particular subsector and country.

TABLE 2
Penetration of alternative low-GWP refrigerants for key RAC&F subsectors in Europe and developing countries

Subsector	Alternative refrigerant	Alternative technology share EU 2015-20	Alternative technology share developing countries 2015-20
Domestic refrigeration	Hydrocarbons		
Commercial refrigeration	CO_2, ammonia, hydrocarbons		
Industrial refrigeration	Ammonia		
Transport refrigeration and air conditioning	CO_2, hydrocarbons		
Stationary air conditioning	Hydrocarbons; solar cooling		
Foams	CO_2, hydrocarbons		

A significant mitigation action both for direct and indirect emissions is achievable with the dissemination and deployment of available technologies. The RAC&F roadmap suggests that a 50 % market share of alternative low-GWP refrigerants and systems is reached by 2020 and a 100 % market share by 2030.

2.2.2 Increased penetration of low-GWP technology options

In the following, the state of technologies and their dissemination in main RAC&F subsectors are described, highlighting major measures for consideration to be implemented within the framework of the RAC&F roadmap.

Figure 7 shows the state of deployment of alternative, low-GWP technologies for the RAC&F subsectors and systems. For the main subsectors and systems detailing descriptions are shown.

FIGURE 7
Strategic deployment of alternative technologies for RAC&F subsectors and systems

Measure	Specific	Fully Deployable	Tested, Full Market Penetration Pending	R&D, Piloting
Unitary air conditioning	• Self-contained air conditioners • 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			
Mobile air conditioning	• Car air conditioning • Large vehicle air conditioning			
Domestic refrigeration	• Domestic refrigeration			
Commercial refrigeration	• Stand-alone equipment • Condensing units • Centralised systems for supermarkets			
Industrial refrigeration	• Stand-alone equipment • Condensing units • Centralised systems			
Transport refrigeration	• Refrigerated trucks/trailers			
Foam sub-sectors				

Within its roadmap the country may choose a similar path, or one adjusted to its specific needs and priorities, within its RAC&F roadmap and technology enabling environment.

Domestic refrigeration: The most effective option is to change the refrigerants to the **hydrocarbon R-600a**, which is a natural refrigerant and already widely established. Over 90 % of this subsector can be converted to R-600a at negative or low costs by 2030. In non-tropical climates, also R-744 (CO_2) can be used, whereas in warmer climates this would lead to lower system efficiency. Hydrocarbons are alternative, low-GWP substances, and are common in Europe and some developing countries, particularly China. Accordingly, alternatives are fully available for this sector. There are no major safety barriers. A near-term phase-out of HFC for this subsector is recommendable. With its Top Runner Programme, the EU has established a strong framework for setting continuously improving energy efficiency standards.

Commercial refrigeration: The most promising options in this subsector include replacing the conventional refrigerants with **R-600a** in stand-alone units or with **R-290/R-1270**, both are hydrocarbons, in stand-alone and condensing units. This can lead to significant emission reductions at negative costs. R-600a and R-290 are already widely available, while R-1270 is more expensive and therefore not as easily available yet. Alternative systems for commercial refrigeration are less common than for domestic refrigeration. However, substantial experience exists with the implementation of the technology in industrialised countries. Similar to the domestic refrigeration subsector, substantial mitigation action may be achieved through the dissemination of existing technologies. Near-term phase out of HFCs for the commercial sector within the RAC&F sector is generally achievable.

For all three subsectors of commercial refrigeration alternative systems are common, predominantly in countries where they are required by law, e.g. Denmark, Sweden or Switzerland. Also, in countries where it is not required companies have started on a voluntary basis to install systems with natural refrigerants due to their superior energy efficiency. Examples are the supermarkets Safeway in South Africa with CO_2 and ammonia systems or Tesco in Thailand with pilot hydrocarbon systems. Hydrocarbon refrigeration systems have become a common product for stand-alone systems in most countries and regions where hydrocarbon refrigerators have become a common standard such as in Europe.

Industrial refrigeration: R-717 (ammonia) is the alternative refrigerant for industrial refrigeration. With the use of R-717, more than 50 % of the baseline emissions can be avoided at negative or zero costs. There is already a wider deployment of ammonia systems in developed countries and in most developing countries. The near to mid-term phase-out of HFC in the industrial refrigeration subsector is generally achievable.

Road transport refrigeration: Here, it is most favourable to replace the conventional refrigerants with **R-290/R-1270**. New systems with R-290/R-1270 will need smaller refrigerant charges and consume less energy than the previous systems. Prototype trucks using R-290/R-1270 have been built, and some systems are already in operation. A significant amount of emissions can be avoided at negative or zero costs. The technology has been successfully introduced in the market but requires additional efforts for wide global dissemination.

Road transport refrigeration systems are not yet common in developing countries. First hydrocarbon systems have been tested and deployed successfully in Europe.

Mobile air conditioning: Current baseline technologies for mobile air conditioning (MAC) systems are systems with the **HFC R-134a** as refrigerant. The EU has theoretically banned the use of R-134a through a GWP limit of 150 in MAC systems in its Mobile Air Conditioning Directive. The car industry is currently searching for the best replacement refrigerant. Potential alternative refrigerants are CO_2, hydrocarbons or unsaturated HFCs. It is expected that the European car industry will identify suitable technology alternatives with the enforcement of the directive in 2016.

As R-134a has a high GWP of 1.430, MAC is the subsector with the highest emissions of HFCs globally. It can be expected that alternative technologies will be available in Europe after 2016. Developing countries can build on these experiences and technology alternatives. For large developing countries with a significant car fleet equipped with MAC systems such as China, India, Brazil, Mexico, the Philippines, Indonesia, Thailand and South Africa, an early cooperation on R&D measures is recommended. That way the technology needs of the particular country can be considered at an early point for the R&D efforts of the alternative systems.

Stationary air conditioning: This subsector covers a variety of systems. Thus also many different technical abatement options exist, covering a broad range of cost-effectiveness. About one quarter of them can be implemented at negative costs. The best option is to focus on chillers, where **R-717** can be used as refrigerant in new systems. **R-290/R-1270** represents another option for chillers, but also for single split and factory sealed systems. Including architectural considerations for single buildings would reduce the amount of air conditioning required. City districts may consider efficient district cooling systems. GIZ Proklima has successfully undertaken R&D and deployment efforts with the largest manufacturers of split-type air conditioners in India and China for the development of R-290 based, low-GWP, split-type air conditioning systems.

Most air conditioning systems today are installed in Asia. Therefore, the migration to low-GWP air conditioning systems should be an essential element of key Asian developing countries' RAC&F roadmaps.

Foams: Foams are mainly used in the construction sector, for insulation of refrigeration applications and in the automotive and furniture sectors. As shown in Table 1, natural foam blowing agents are established alternatives for most foam applications. These alternative technologies are widely used in developed countries and can be readily deployed for most applications in developing countries as well. For example, GIZ Proklima has successfully introduced CO_2 technology for XPS production in China.

2.2.3 Removal of technical barriers for the application of low-GWP alternatives

Conventional high-GWP fluorinated refrigerants and foam blowing agents such as HCFCs and HFCs are non-flammable. Flammable low-GWP refrigerants such as hydrocarbons require additional safety and related measures. The use of alternative, low-GWP refrigerants therefore requires the removal of barriers. The areas where removal of barriers for the various subsectors is most relevant are illustrated and explained in Table 3. Coloured arrays show the most significant barriers for the different RAC&F subsectors.

TABLE 3
Most significant barriers for the different RAC&F subsectors

Barriers	Domestic refrigeration	Commercial refrigeration	Industrial refrigeration	Road transport refrigeration	Mobile AC	Stationary AC	Foam
Component availability							
Technician competence							
Safety-related restrictions							
Technology implications							

Safety-related restrictions: These restrictions can be a hindrance to the introduction of new technical options, as low-GWP refrigerants are often flammable, and in the case of ammonia also toxic. In some countries, existing safety standards impose restrictions on the allowed amount of these refrigerants or on construction features. The RAC&F roadmap suggests the following measures to overcome this barrier:

- Apply regulations which enable the safe use of flammable natural refrigerants and foam blowing agents.
- Develop alternative national standards, permitting larger quantities or wider applications of the new refrigerants.
- Introduce safety control systems to keep the same level of safety as before.
- Carry out R&D activities to find alternative designs or to enable a lower specific charge.

Component availability: In some regions certain components are not easily available. The RAC&F roadmap suggests overcoming this by working with existing distributors and suppliers to stock the desired components, developing importation channels from overseas producers, and setting up a distribution infrastructure. Furthermore, existing manufacturers could start to develop new components and adapt the production line.

Technician competence: Competence is insufficient in some regions as not enough technicians and engineers have been trained for working with the new technologies, including the handling of flammable and toxic substances. Technician training is essential for the use of hydrocarbons. Possible interventions could include the carrying out of train-the-trainers schemes, widespread training at companies, working with training colleges, universities, etc. Training measures are an important element for the RAC&F roadmap.

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). All GIZ Proklima publications are publically available online at: www.giz.de/proklima

2.2.4 R&D in new technologies

Limited technology development may be another barrier. This covers a fairly broad range of issues, differing with the particular abatement option and the region. Possible interventions include the initiation of collaborative R&D projects at universities and manufacturers, the development of cooperation with enterprises that already have greater experience with the particular technology or the development of design guidelines.

Mitigation action within the RAC&F sectors can be widely achieved with existing technologies and putting the key focus on the dissemination of existing low-GWP technologies.

2.3 The market enabling environment

The wide dissemination of low-GWP alternative systems can be restricted through lack of consumers' awareness or missing acceptance of higher upfront costs. Whilst a system using a new technology may be available, the penetration rate of this technology can be low, because the consumers are not informed about the availability or the advantages. The RAC&F roadmap suggests intervening by rolling out awareness programmes and through the introduction of mandatory labelling schemes together with authorities and non-governmental organisations.

Additionally, the successful market introduction of low carbon RAC&F solutions can be promoted and financed through a so-called "feebate", i.e. fee and rebate scheme, as illustrated in Figure 8. In the feebate scheme fees on high carbon substances and systems are financing the rebates on low carbon alternatives.

FIGURE 8
Feebate system for RAC&F appliances, systems and products

Fees on	No fees, no rebates	Rebates
• Very high GWP HFC substances • Appliances with very low energy efficiency • Products with very low insulation properties (foams)	• Moderately high GWP HFC substances • Appliances with normal energy efficiency • Products with normal insulation properties (foams)	• Natural refrigerants • Natural foam blowing agents • Appliances with high energy efficiency • Products with high insulation properties (foams)

Due to the flammability of some substances, particularly of hydrocarbon based refrigerants and foam blowing agents, the use of natural refrigerants in some cases requires higher upfront costs for additional safety applications. These higher upfront costs can very often be quickly paid back due to energy savings. However, in most developing countries a short term oriented investment behaviour dominates. End users prefer products with lower upfront costs even if this is at the expense of higher energy consumption and running costs. Here a properly designed feebate system can play an important catalytic function.

3. Practical application

The following step-by-step guide shows how to develop a national RAC&F roadmap. It provides policy makers with guiding questions on how to
- set up appropriate goals and emissions targets
- determine appropriate milestones
- identify gaps, barriers and enabling environments to overcome them
- define action items, priority and timelines

Steps for developing a national RAC&F roadmap:

1. Develop national emission pathways
2. Set up milestones
3. Define gaps, barriers and enabling environments
4. Define action items, priorities and timeline
5. Involve stakeholders

Step 1: Develop national emission pathways
The initial step is to set up the national emission pathways for the RAC&F subsectors considering both the business-as-usual (BAU) scenarios and the target mitigation scenarios.
The emission pathways build on the HFC inventory and the BAU emission projection and mitigation scenarios which you have already established with the tools provided with modules 1, 2 and 5.
You should reflect the BAU and mitigation pathways with key stakeholders, such as other government bodies, relevant industry associations and research institutes. The guiding questions for discussing and confirming the pathway are:
- What are the main factors for driving the future demand of appliances (e.g. population, household growth, GDP per capita, urbanisation) and have they been appropriately considered?
- What are the limits of the market (e.g. saturation)?
- What are the existing and planned executed policy measures and their effects (e.g. government restriction to use certain AC appliances in certain buildings or temperature zones)?

Step 2: Set up milestones

Generally, milestones for the development of roadmaps follow the mitigation objectives of the sectors and the national climate action plan, and they are allocated to specific actors such as ministries, universities, or industry. Define milestones following these guiding questions:

- What are appropriate intervals for achieving targets and measuring progress in a specific sector (e.g. 5 to 7 years)? The intervals should be long enough for measures to be implemented and progress to be achieved. But they should not be too long, so that ineffective measures can be critically analysed and corrected or replaced towards the next milestone.
- Can the target set for the milestone be clearly recognised and measured? For example, if you set a target to phase out HFC by 2040, no later than 10 years after the phase out of HFCFs, this is a clearly recognisable and measureable target which provides clear guidance to the relevant stakeholders. The longer term target can be broken down into several intermediate phase milestones, e.g. phase 1 with reduction by 15 % within 5 years, phase 2 with reduction of 50 % within 10 years etc.
- Does the target address specific actors? For example the UN initiative Sustainable Energy for All (SEE4ALL) suggests a doubling of energy efficiency gains by 2030. This can be achieved by setting increasingly high Minimum Energy Efficiency Standards (MEPS) for specific subsectors: For example, assuming a current average Energy Efficiency Ratio (EER) of 3 for unitary air conditioners, this would need to increase by a factor of 0.75 every five years to reach 6 by 2030.

Develop appropriate milestones for main action areas and elements of the roadmap. The addressed areas should be complementary and mutually enforcing. They should include:

- overall emission reduction targets
- targets for the phase out of HFCs
- targets on Minimum Energy Efficiency Standards (MEPS) for RAC appliances
- targets for the development of critical technologies (e.g. readiness of mobile air conditioning (MAC) prototypes for the use of low-GWP refrigerants such as CO_2 or hydrocarbons)
- regulatory, policy, and market frameworks (ie.g. ban of certain high-GWP refrigerants from 2020)

Step 3: Define gaps, barriers and enabling environments

3.1 Prioritise the RAC&F subsectors in your country according to the following criteria:

- Readiness of climate friendly technologies: Are low GWP technologies available to your country and can they be introduced within an achievable timeframe? For example, hydrocarbon technologies for domestic refrigeration have reached a penetration in nearly half of the countries worldwide. So, if your country is still deploying HFCs in refrigerators, the alternative hydrocarbon technology is accessible and it is possible to implement it in your country. You should assess low-GWP technologies regarding both their potential to meet high energy efficiency ratios and the use of low-GWP natural refrigerants.
- Potential to achieve emission reductions through closing regulatory or policy gaps: Has your country introduced MEPS? Many countries have successfully introduced this tool for several RAC&F sectors. If your country has not introduced MEPS, very likely MEPS could be introduced as an effective tool to drive efficiencies.

Once you have identified the technology and policy gaps, assess the ability to overcome the gaps by removing the key barriers. Barriers relevant for the RAC&F sectors are presented in module 3.

Next, develop strategies to overcome the barriers through the development of the appropriate regulatory and technology enabling environments:

3.2 Develop a regulatory enabling environment

A general template for the development of the enabling environments is shown in Figure 5 of this module. Address the regulatory environment through

- Institutional readiness: Identify and appoint the line ministries and focal points for NAMA and MRV reporting to oversee the implementation of the NAMA action and the implementation of the RAC&F roadmap.
- Adapt existing regulation to allow for the reduction of direct emissions and promotion of low-GWP refrigerants and for minimum energy efficiency standards.

3.3 Develop a technology enabling environment

The technology enabling environment facilitates the penetration of alternative, low-GWP technologies. First, assess the current and targeted future penetration of identified low-GWP alternative technologies. Second, define measures (R&D, market introduction incentives) for those technologies.

3.4 Develop a market enabling environment

The market development contains a wider stakeholder process. Governmental and semi-governmental institutions, manufacturers, service industry and consumers are involved. Main topic of concern here is the market competitiveness of alternative systems. This includes funding and financing schemes to bridge higher upfront costs of alternative systems with lower operating costs due to energy savings.

Step 4: Define action items, priorities and timeline

Action items listed in a technology action plan include:

- Establish an inventory of current and target technologies and required R&D, deployment and technology transfer activities
- Formulate recommendations for best practices
- Formulate recommendations for diffusion (support early adopters, nurse niche markets, support SMEs, support public-private partnerships). This can include market introduction programmes where qualified technologies are eligible for first year tax deductable depreciations, interest-free loans, government covered product wear and tear warranties.

Step 5: Involve stakeholders

An important aspect of the road mapping process is to enhance the communication and consensus building between essential stakeholders. Key instrument to involve stakeholders and to promote collaboration between the stakeholders is the organisation of workshops and forums. With regard to the RAC&F sectors essential stakeholders include the following:

- Ministries with functions on environment and climate protection, energy, finance, economics and industry
- Relevant government agencies
- Universities and research institutes with specialisation on RAC&F-related issues
- Industry associations and key companies, in particular, companies willing to act as front runners. Key companies for the RAC&F sectors include equipment producers, operators of equipment and servicing companies. Companies providing refrigerants and blowing agents also play a significant role.
- Industry-specific experts (e.g. national or international consultants or consulting companies)
- Non-governmental organisations

In stakeholders collaboration workshops, may address the following guiding questions:

- Have the key barriers been addressed sufficiently? For example, has the introduction of flammable refrigerants been accompanied with appropriate safety standards which are widely accepted by industry and its customers?
- Are clear actions defined to accelerate innovation, technology transfer and diffusion of low-GWP RAC&F equipment? Are key industry stakeholders involved in the process and have they taken ownership of the process?
- Has the industry accepted the defined milestones? Are key industry players promoting such milestones?

4. References

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 Internationale Zusammenarbeit (GIZ) GmbH (Programme Proklima) and TÜV Süd.

Ederberg, L. et al. (2010). Task 3 Draft Progress Report, (070307), 218.

Ecofys (2012). Why the Durban Outcome is not sufficient for staying below 2C, Policy Update. Issue III. February 2012.

Gschrey, B., Schwarz, W. (2009). Projections of global emissions of fluorinated greenhouse gases in 2050, 43.

Heubes, J., Martin, M., Oppelt, D. (2012). Refrigeration, air conditioning and foam blowing sectors technology roadmap. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (Programme Proklima). http://unfccc.int/ttclear/pdf/Call%20for%20Inputs/RM/GIZ_RM.pdf

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

IEA. (2009). World Energy Outlook 2009.

IEA. (2010a). IEA technology roadmaps – Executive Summary (pp. 45-60).

IEA (2010b). IEA Energy Technology Roadmaps. A guide to development and implementation.

IEA. (2011). Technology Roadmap Energy-efficient Buildings: Heating and Cooling Equipment, 51.

Londo, H.M. (2013). Background paper on Technology Roadmaps (TRMs), Final Draft

Schwarz, W. et al. (2011). Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases, Final, 340.

Taylor, P. (2008). Energy Technology Perspectives 2008 - Scenarios and Strategies to 2050; IEEJ Workshop, Tokyo.

UNDP (2010). Handbook for conducting technology needs assessment for climate change.

UNEP (2007). Report of the 19th Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer, UNEP, Pro 1917 (United National Environmental Programme, Nairobi, Kenya).

UNEP (2011). HFCs: A Critical Link in Protecting Climate and the Ozone Layer. http://www.unep.org/dewa/Portals/67/pdf/HFC_report.pdf

UNIDO (2009). Preparing for HCFC phase-out: Fundamentals of uses, alternatives, implications and funding for Article 5 countries. http://www.unido.org/fileadmin/user_media/Publications/Pub_free/Preparing_for_HCFC_phaseout.pdf

Velders, G. J. M. et al. (2012). Preserving Montreal Protocol Climate Benefits by Limiting HFCs. Science, 335(6071), 922-923, doi:10.1126/science.1216414

WRI (2005). Navigating the Numbers – Greenhouse Gas Data and International Climate Policy.

6

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