Refrigeration, air conditioning and foam blowing sectors technology roadmap

GIZ Proklima

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Executive summary

The following technology roadmap and action plan for the refrigeration, air conditioning and foam blowing (RAC&FB) sectors is presented by the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ).

The German government programme Proklima, carried out by GIZ, focuses on the reduction of ozone depleting and greenhouse gas emissions. Since 1996 Proklima has supported more than 40 developing countries with over 250 projects. Proklima assisted mitigation actions of Non-Annex I countries on a national and regional level with capacity building, technology demonstration, sector strategies and policy dialogue. At present, Proklima has been requested by the International Climate Initiative of the German Ministry of Environment to implement the "Green Cooling Initiative", which aims to enhance networking and stakeholder participation under the technology mechanism of the UNFCCC in the field of RAC&FB.

The roadmap developed by Proklima incorporates 15 years of experiences by Proklima and other implementing agencies that have been active in the field, mainly under the Montreal Protocol, but also under the UNFCCC (e.g. CDM). Mitigation strategies for both direct and indirect emissions of the RAC&FB sectors have been utilised to develop low carbon strategies up to 2050. The establishment of an enabling environment is presented as an integral part of the technology roadmap.

<u>Rationale for presenting a RAC&FB technology roadmap:</u>

- Unabated emissions in the RAC&FB sectors will globally grow from currently about 4 Gt CO_2eq to 12 Gt CO_2eq by 2050. The growth of indirect emissions in the RAC&FB sectors are mainly driven by economic development, wealth effects and lifestyle, growing urbanization and increasing ambient temperatures. According to experts, effective mitigation of HFCs needs to cap emissions at least equal or below current emission levels in order to comply with the 2°C target.

- Since 1991, ozone-depleting substances (ODS) in the RAC&FB sectors have been successfully phased out by the Montreal Protocol. However, its mandate does not include the control of refrigerants or blowing agents with zero ozone-depleting potential or indirect emissions resulting from the energy use of appliances. Consequently, in the past a significant part of the ODS has been replaced with HFCs with a high global warming potential and there is a substantial risk that the phase-in of HFCs is further accelerated by the ongoing phase-out of HCFCs under the Montreal Protocol;

<u>Key features of the RAC&FB technology roadmap:</u>

- The technology roadmap will cap emissions at 4 Gt CO_2eq versus the baseline scenario that peaks at 12 Gt CO_2eq in 2030. The reduction of direct emissions of high-GWP HFCs through low carbon alternatives offer the highest potential for immediate and sustainable action in Non-Annex I countries. In combination with technology and policy actions on energy efficiency, this will lead to substantial reductions of indirect emissions;

- The roadmap analyses nine sub-sectors[1] in a comprehensive manner for all major systems and applications. For each of the sub-sectors it evaluates the effect of available low carbon technologies that are market-ready or already placed in the market. In addition, the effects of an enabling environment, such as removing economic and regulatory barriers or providing incentives for the introduction of alternatives and best practices are considered in the roadmap. Based on these analyses, feasible milestones and targets for the global dissemination of alternatives are projected.

- The methodology applied in the roadmap builds on established procedures for emission projection and reporting under the UNFCCC. With regard to national control measures, such as import/export bans, national regulations, policy action and standard development, a proactive approach as historically applied under the Montreal Protocol has been used as a reference. In the analysis of the economic feasibility of mitigation action and its marginal abatement costs, incremental costs of technology investments are considered at the end of economic life of old equipment and its replacement.

The roadmap finally illustrates that depending on the range of support provided to Non-Annex I countries, the replacement of inefficient products and systems by low carbon alternatives and practices could be accelerated even beyond the proposed targets.

[1]Including domestic, commercial, industrial and transport refrigeration and stationary and mobile air conditioning, as well as 3 foam sectors (construction and refrigeration insulation and integral foam)

1. Rationale and scope

The deceleration of climate change is one of the greatest challenges across the world during this century. Despite an international climate regulation (the UNFCCC) to reduce GHG emissions, the global CO_2 emission growth rates have steadily increased in the past decades. The growth rates jumped from 1.1 %/yr in the 1990-2000 period to 3.0 %/yr in the following decade (IEA, 2010) . Thus, more effort is needed to slow down the emissions, which warm up our planet. The major part of the global emissions result from the energy sector (~60%), followed by land use change, agriculture, waste and industrial processes (WRI, 2005). The basket of the top 6 greenhouse gases from these sectors are addressed in the Kyoto Protocol. Important but often neglected chemicals from this list are F-gases (hydrofluorocarbons HFCs, perfluorocarbons PFCs and sulfur hexafluoride SF_6).

Among all F-gas emissions, HFC emissions account for large shares and are expected to increase strongly in absolute figures and their relative weight to other greenhouse gases (Gschrey & Schwarz, 2009). These substances are predominantly used as refrigerants and foam blowing agents in the refrigeration, air conditioning and foam blowing (RAC&FB) sectors. In general, there are two kinds of emissions in the RAC&FB sectors: direct and indirect emissions. The first kind results from the F-gases itself (e.g. leakage of the refrigerant during lifetime or end-of-life), whereas the latter are caused by energy consumption of the appliances during operation or the manufacturing process. Both types of emissions are likely to increase in the future. Direct emissions are expected to increase, because the high-GWP HFCs are replacing ozone-depleting substances, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), which were widely used as refrigerants and blowing agents over the last decades. The chlorine containing chemicals are being phased out under the Montreal Protocol.

Another factor which will boost the direct and indirect emissions is climate change itself. Today, households (in buildings) consume globally about a third of all end-use energy and account for the respective CO_2 emissions. Heating, cooling and the supply of hot water are estimated to account for roughly half of the global energy consumption in buildings (IEA, 2011). In regions with temperate climate, this energy is predominantly used for heating (IEA, 2004). However, space cooling is rapidly growing in high-income countries, hot countries and in emerging economies. A growing (urban) population, increasing wealth and temperatures (due to climate change) will elevate the cooling demand, thus, there will be more AC and refrigeration systems running in future, contributing to higher overall emissions. On top of that, the cooling demand is growing rapidly in countries with very carbon-intensive electricity systems, pointing to the need of low-carbon technologies. Also the global building area is projected to triple by 2050 (IEA, 2011) which will cause a strong increase in the demand for foam for insulation with respective direct emissions from blowing agents.

Consequently, transformations in the RAC&FB sectors can strongly contribute to reach the CO_2 target in 2050, which aims to not exceed atmospheric CO_2 concentrations above 450 ppm (IEA, 2009). The 450 ppm scenario is in line with the 2°C target which is gaining widespread support around the world. It is assumed that a global temperature increase above 2°C will have irreversible and uncontrollable effects in the earth’s system. Today, alternative technology is widely available for most applications in the RAC&FB sectors, however, more effort is needed to spread low-GWP and energy-efficient technologies and overcome existing barriers, in particular in developing countries. The accelerated dissemination of alternative technologies in the RAC&FB sectors promises the prospect of fast and low cost emission reductions to nearly eliminate all direct emissions and further to significantly lower indirect emissions from their business-as-usual (BAU) scenario.

The RAC&FB sectors have been a key area of the Montreal Protocol with its focus to phase out chlorine containing refrigerants and foam blowing agents. As such a broad range of measures, instruments, tools and institutional settings were established under the Montreal Protocol to initiate, execute and control mitigation actions. The global RAC&FB roadmap presented here builds on the experiences established under the Montreal Protocol.

GIZ Proklima has been active under the Montreal Protocol and implemented mitigation actions in the RAC&FB sectors since over 15 years. In that context GIZ Proklima, on behalf of Germany, is currently responsible for the implementation of sectoral HCFC Phase-out Management Plans (HPMPs) in more than 15 countries. The work includes the direct conversion of entire sectors from fluorinated, ozone depleting and climate damaging refrigerants to natural refrigerants.

The works carried out by Proklima include international policy consulting, the implementation of sectoral plans on national level, capacity building in developing countries, establishing of demonstration sites and the introduction and penetration of new technologies on the market. Proklima is actively promoting and leading the development of various industrial networks, such as the SolarChill network.

Further, Proklima has been active under the International Climate Initiative of the German Environmental Ministry (BMU) since many years to demonstrate climate mitigation projects in many Non-Annex I countries. As such Proklima is developing a NAMA (Nationally Appropriate Mitigation Action) handbook on mitigation actions in the RAC&FB sectors and is currently supporting NAMAs elaboration and implementation in various Non-Annex I countries.

GIZ Proklima has been awarded by the BMU with a project, the “Green Cooling Initiative” to support the Technology Mechanism of the UNFCCC and the TEC for an accelerated technology transfer in the RAC&FB sectors through

- the establishment of sectoral and regional cooperation networks
- policy recommendations
- support on enabling environments for a supporting regulatory and technology framework (as outlined under chapters 4.1 and 4.2)
- establishment of global, regional and - within the context of NAMAs - national technology roadmaps

Herewith, Proklima presents a global roadmap for the RAC&FB sectors, highlighting the dissemination of alternative technologies. The roadmap builds on the experiences of Proklima in carrying out over 250 projects, including sector mitigation plans on emission mitigation and technology transfer in over 40 developing countries. Proklima demonstrates that significant emission savings can be achieved by sector transformation in the RAC&FB sectors. In particular, it is possible to utterly prevent direct emissions by widely deploying low-GWP refrigerants and blowing agents instead of high-GWP refrigerants such as HFCs. In addition, through energy efficiency gains the emission path of indirect emissions can be altered, substantially below its BAU case.

2. Status of technologies in the RAC&FB

Direct emissions in the refrigeration and air conditioning sector stem from the use of HCFCs and HFCs as refrigerants. These compounds usually have a high global warming potential and thus take to warm the climate once emitted in the atmosphere during production, usage and/or deposition. Natural refrigerants (such as hydrocarbons), which are introduced only in a few subsectors and regions at the moment, are a preferable refrigerant alternative. They are present – as their name implies - in nature, and thus their interaction with the environment (which is usually neutral) is well known in opposite to that of synthetic formed refrigerants. Furthermore, they have a lower GWP than HCFCs or HCFs (see Table 5 in the Appendix). The main refrigerants used for each RAC&FB sub-sector are summarized in Table 1. Indirect emissions from the energy consumption of the units must be added to the direct ones and are usually the dominating emission factors. However, it is relatively easy to reduce direct emissions, which is in some cases done via the substitution of the momentarily applied refrigerant without complete system changes.

HCFCs and HFCs are used in the foam blowing sector as blowing agents in the production process leading to direct emissions. Currently, natural substances are partly applied, for example CO_2 in extruded polystyrene (XPS) insulation boards in China. The indirect emissions are minimal in this sector and are thus disregarded further on.

2,1 Refrigeration

The refrigeration sector can be divided into four sub-sectors:

Domestic refrigeration is used in private households for preserving food, drinks and medicine. Refrigerators, freezers as well as combined systems are covered here. Most of the devices are factory-assembled for an easy set-up and use. In total, around 1 400 million units are globally in stock. Direct emissions were estimated to be 20 Mt CO_2eq, and indirect emissions to be 147 Mt CO_2eq in 2010. (All emissions and stock numbers are taken from Ederberg et al., 2010.)

Commercial refrigeration is needed for cooling of stored or displayed food and beverages. Two temperature levels are applied, food is either kept frozen below 0°C or chilled above. Systems in use are stand-alone units, such as vending machines or beverage coolers, condensing units, which are often used in smaller supermarkets or bakeries, and centralised units. The latter are larger systems, where more cabinets are cooled by one refrigeration system. In 2006, the stock was globally around 90 million units. Direct emissions were estimated to be 314 Mt CO_2eq, and indirect emissions to be 272 Mt CO_2eq in 2010.

Industrial refrigeration implies the food processing, storing and distributing sector and the cooling in industrial processes. Industrial systems differ from others by size and their covered temperature range. Furthermore, they are very often specifically produced to fit a certain application[2]. Direct emissions were estimated at 158 Mt CO_2eq, and indirect emissions at 262 Mt CO_2eq in 2010.

Transport refrigeration covers cooling that is required during the transportation of goods. It is needed on roads within trucks and trailers, but also within trains, ships or airborne containers. The dominating sector is road transport with about 4 million units in stock. Direct emissions were estimated to be 56 Mt CO_2eq, and indirect emissions to be 113 Mt CO_2eq in 2010.

2.2 Air conditioning (AC)

AC is divided into the following two sub-sectors:

Stationary AC implies all applications that are used to cool one or more rooms in residential or commercial places. To achieve cooling, a large variety of systems are available including self-contained AC systems, where all components are built into one housing. Split AC systems consist of two separate elements, the one delivering the cooling is placed inside and the one ejecting the heat is placed outdoors. For multiple rooms, duct split or rooftop ducted AC systems are taken, where a ducting

[2] This is also the reason that no reliable stock number can be given here.

system distributes cold air inside the building. In AC chillers, which are mainly applied for commercial and light industrial purposes, a liquid is cooled and distributed to cooling coils within the building. In total 335 million stationary AC systems are globally in stock. Direct emissions were estimated to be 738 Mt CO_2eq, and indirect emissions to be 1 871 Mt CO_2eq in 2010. These are by far the largest direct as well as indirect emissions from all RAC&FB sub-sectors (see also Figure 2).

Mobile AC systems deliver cooling in vehicles, including passenger cars, trucks or buses and are usually belt driven by the engine. Around 900 million units were in stock in 2006. Direct emissions were estimated at 130 Mt CO_2eq, and indirect emissions at 212 Mt CO_2eq in 2010.

Figure 1 displays the units in stock in the refrigeration and air conditioning sub-sectors, displaying that domestic refrigeration is the most wide-spread sub-sector.

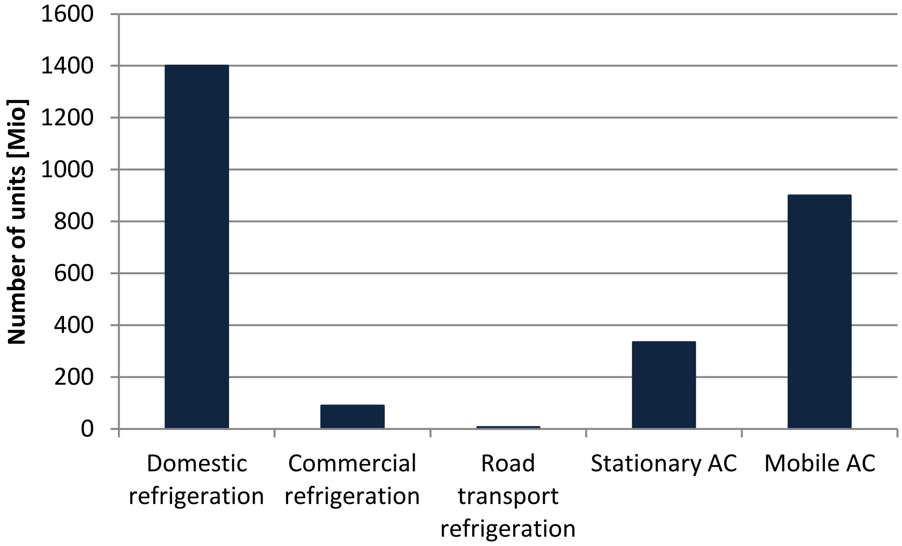


Figure 1: Units in stock in the refrigeration and air conditioning sectors.

2.3 Foam

Foam covers the following sub-sectors:

Insulation foam in the construction sector, where foam is used for insulating residential and commercial buildings. This can be achieved by using sandwich panels, XPS boards, spray foams, which are applied directly on surfaces, or one component foams for filling up applications with restricted access.

Insulation for refrigeration applications is needed in all refrigeration applications described above. In domestic refrigeration systems, foam is injected into the space between the outer metal shell and the inner plastic inline, in commercial and transport refrigeration systems, panels of different sizes are implemented.

Integral foams for the automotive and furniture sectors are used for performance and aesthetical purposes in steering wheels, armrests, shoe soles and many other applications. The foam is put into a mould during manufacturing to receive the shape needed for the specific product.

Total direct emissions in the foam sector were estimated to be 149 Mt CO_2eq. The indirect emissions of this sector are minimal, and will be disregarded therefore.

The following table provides an overview of the main refrigerants or blowing agents applied in the sub-sectors described above. More information about the characteristics (category, GWP, flammability, toxicity) of the main refrigerants used and in which sub-sectors they are preferably applied can be found in the Appendix.

Table 1: Summary of the main refrigerants / blowing agents applied in the different sub-sectors.

Sector	*Sub-Sector*	*Main refrigerants[3] / blowing agents used*
Refrigeration	Domestic	HFC-134a, HC-600a (in the majority of European products, also in China and other countries)
	Commercial	HFC-404A, R744, R717, HC-290, HC-600a, HFC-134a; HCFC-22 (Non-Annex I countries),
	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
Foam	Construction sector	HC (N-, iso-pentane, isobutane), HFC-245fa, HFC-235fa, HFC-134a, HFC-152a, CO2, HFC-365mfc/227ea (Annex I countries); HCFC-141b, HCFC-142b, HCFC-22 (Non-Annex I countries)
	Insulation for refrigeration applications	HC (N-, isopentane, cyclopentane), HFC-245fa, HFC-365mfc/227ea (Annex I countries); HCFC-141b (Non-Annex I countries)
	Integral foams for automotive, furniture sectors	HFC-245fa, HFC-365mfc/227ea (Annex I countries); HCFC-141b (Non-Annex I countries)

The global direct and indirect emissions of all sectors are displayed below in Figure 2. It can be seen that with the exception of commercial refrigeration, the indirect

[3] The GWP of each refrigerant is shown in table 5 in the Appendix

emissions are always higher than the direct emissions. However, as discussed above, direct emissions are much easier to reduce than indirect emissions. The by far highest emissions stem from the stationary AC sector.

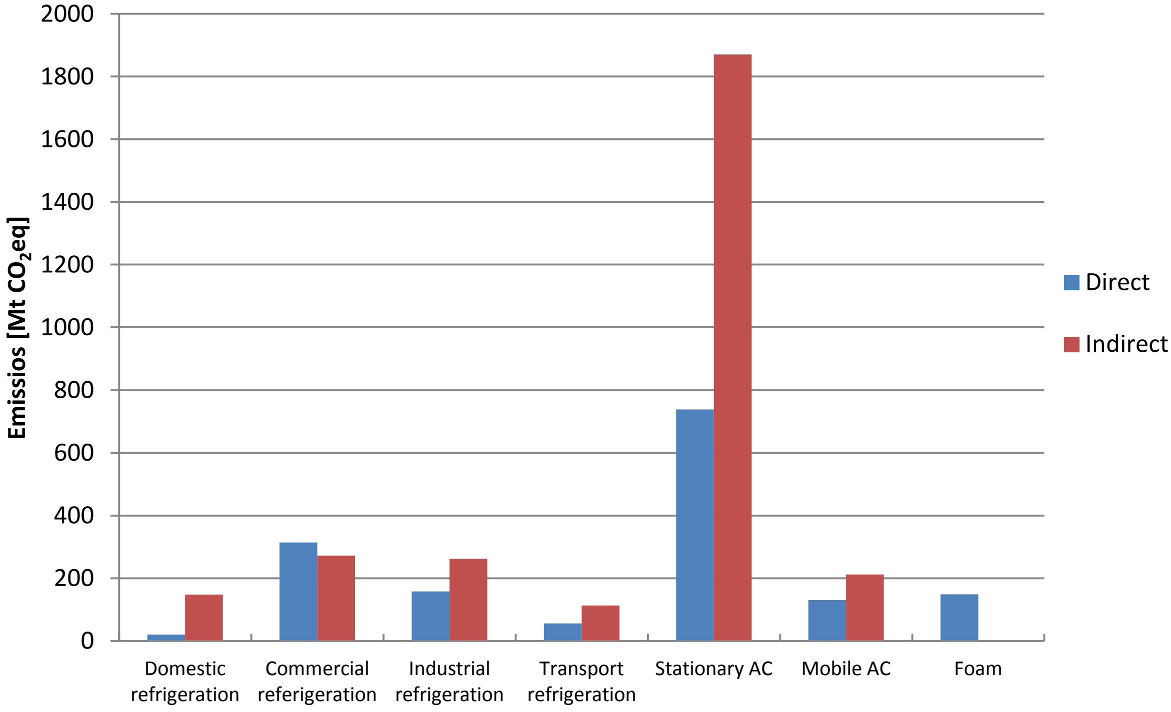


Figure 2: Direct and indirect emissions of the different sub-sectors of the RAC&FB sectors.

3. Vision for a RAC&FB roadmap

If emissions in the RAC&FB sectors just continue under a BAU scenario, they will rise up to 12 Gt CO_2eq in 2030 as illustrated in Figure 3 below. The vision of this roadmap is to show a pathway, where the RAC&FB sectors contribute to emission reductions in the magnitude of 7.2 Gt CO_2eq by 2030. This amount corresponds to the 60% reduction target (relative to the BAU scenario) of the BLUE Map scenario, as formulated by the IEA in 2008 for the transport, industry and buildings sector (Taylor, 2008), which is in line with the 2°C target.

Our roadmap scenario requires an accelerated spread of currently available alternative technologies. The transformation of the RAC&FB sectors will globally reduce direct emissions by 3.5 Gt CO_2eq due to the use of low/zero GWP refrigerants. A higher energy efficiency of the new technologies will reduce indirect emissions by 0.5 Gt CO_2eq, whereas the de-carbonization will contribute with ca. 3 Gt CO_2eq (Figure 3). Indirect emission savings due to improvements of the energy efficiency might be much higher than our conservative estimate. However, this is mainly influenced by measures such as labeling or rationing and also depends on the adopted systems and climate conditions of the considered world's region.

There are also co-benefits stemming from emission reductions, such as benefits for the economy (e.g. labour market, market growth), for technology development in related sectors (e.g. penetration rates, supply infrastructure), for socio-economic development (transport system, income and living situation) for end-users (e.g. customers) or policy impacts on a country level and on international level. Further there are substantial co-benefits from the migration from fluorinated substances to natural substances[4] due to the treatment of the substances at the end of their lifetime. Fluorinated substances are highly toxic and need at the end of the equipment lifetime to be extracted through technical complex processes and destructed through ultra-high temperature procedures with subsequent complicated waste water treatment processes. Most Non-Annex I countries entirely lack the

[4] Natural refrigerants and foam blowing agents are naturally occurring in the environment in contrast to refrigerants/blowing agents from fluorinated substances.

technological ability for the adequate treatment of fluorinated substances and therefore end up with highly toxic waste without suitable solutions for disposal.

The proposed CO_2eq emission reductions stem from a dramatic transformation in the markets which include the deployment of low-GWP and zero-GWP alternative technologies, introduction of appropriate policy measures (such as bans of high-GWP refrigerants as introduced in the EU for certain subsectors) (Schwarz et al., 2011), but also a continued phase-out of HCFCs. HCFC-22 with a GWP of 1 810 (100yr time horizon) is still massively used in developing countries. Direct transformations of sectors to low-GWP alternatives can, thus, strongly contribute to emission reductions. Our baseline consumption accounts for both HCFC and HFC use in the RAC&FB sectors, whereby the baseline is designed upon existing policies. This includes an accelerated phase-out of HCFCs as agreed upon by the Montreal Protocol Parties in September 2007 (UNEP, 2007).

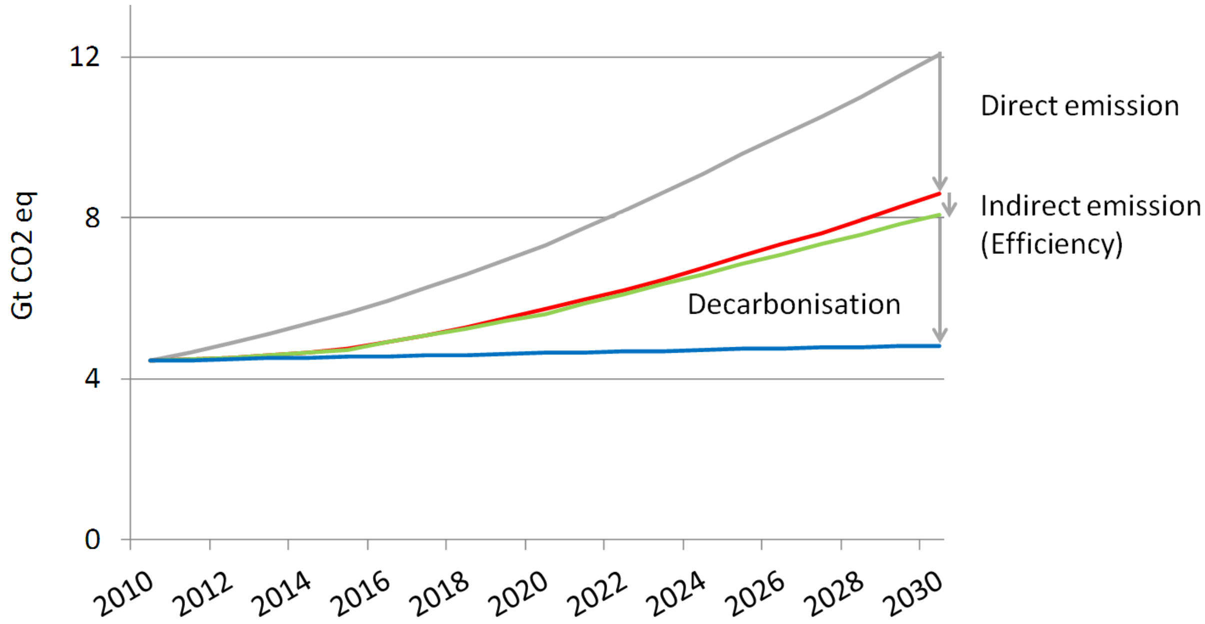


Figure 3: The roadmap for the refrigeration, air conditioning and foam blowing sectors allows emission savings of 7.2 Gt CO_2eq. Direct and indirect emission reductions equally contribute to the overall emission savings.

Figure 4 shows the different sub-sectors´ contribution in achieving the direct emission reductions of 3.5 Gt CO_2eq by 2030. Globally, the fastest growing sub-sectors in terms of demand and emissions are stationary air conditioning, industrial and

commercial refrigeration. Accordingly, these sectors reveal the greatest reduction potential. Roughly 50% of the direct emissions can be reduced by a transformation of the stationary air conditioning sub-sector. Particularly, in developing countries the expected growing prosperity will increase the penetration and saturation of AC units, one of the most desirable household equipment in tropical and hot countries. The stationary AC sub-sector is followed by the industrial and commercial refrigeration sub-sectors in terms of reduction potential (together ~1 Gt CO_2eq).
Achieving these deep cuts in direct emissions is possible with the current available technologies and an appropriate policy framework. To meet the required reductions, also indirect emissions have to be reduced. This can be done via labeling, introducing energy efficiency standards or rationing. It furthermore requires a de-carbonization of the energy generation through a significant shift of the energy mix to low-carbon energy sources (e.g. renewable energy).

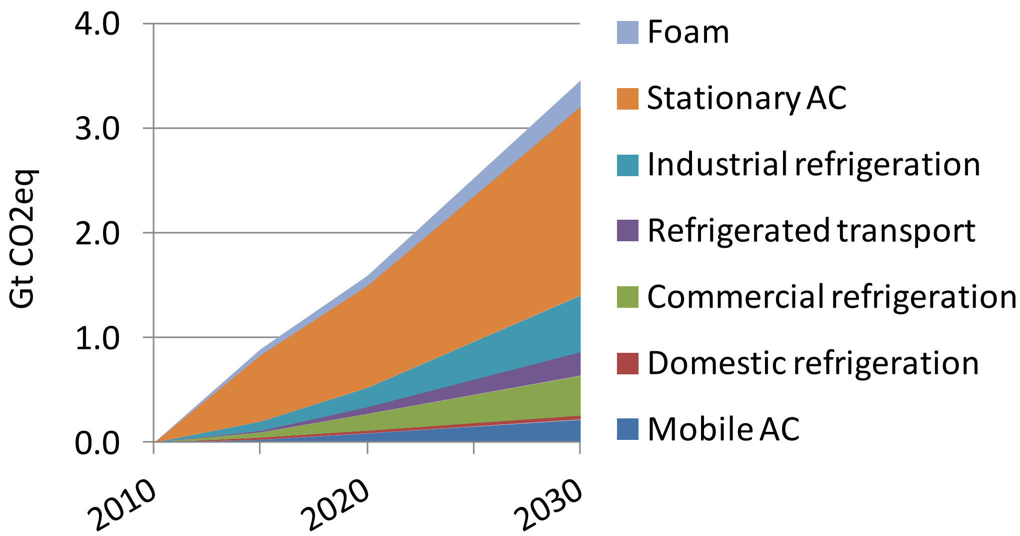


Figure 4: Sub-sectors´ contributions to global direct emission reductions.

Substantial market transformations are more likely to occur at moderate or even negative costs. “Green” technology must become affordable, otherwise it remains unattractive and won’t penetrate the market (as illustrated in chapter 4.2.2. in further detail).

Considering alternative technologies in the RAC&FB sectors, nearly half of the global direct emission savings can be achieved at negative costs when looking at the full lifecycle of the product (Figure 5). In other words the phase-in of “green” technologies implies a net welfare gain from an overall economy viewpoint. This highlights the particular suitability of the RAC&FB sectors in reducing CO_2eq emissions. However, it must be recognized that the choice of technology is not only based on lifetime costs, but that other factors (mainly high upfront costs) play an important role as well (see chapter 4.2.2). Negative costs are found for chillers, transport, commercial and industrial refrigeration (Figure 5). Taking the emission reduction potential into account, promising sub-sectors for transformation are commercial and industrial refrigeration, where no additional costs are involved. Figure 5 also depicts that the highest reduction potential is given by sub-sector transformations of Non-Annex I countries. With the development and dissemination of alternative technologies, these become more widely available and build up scale, and as a consequence, an increasing share of emissions can be abated at negative costs over time.

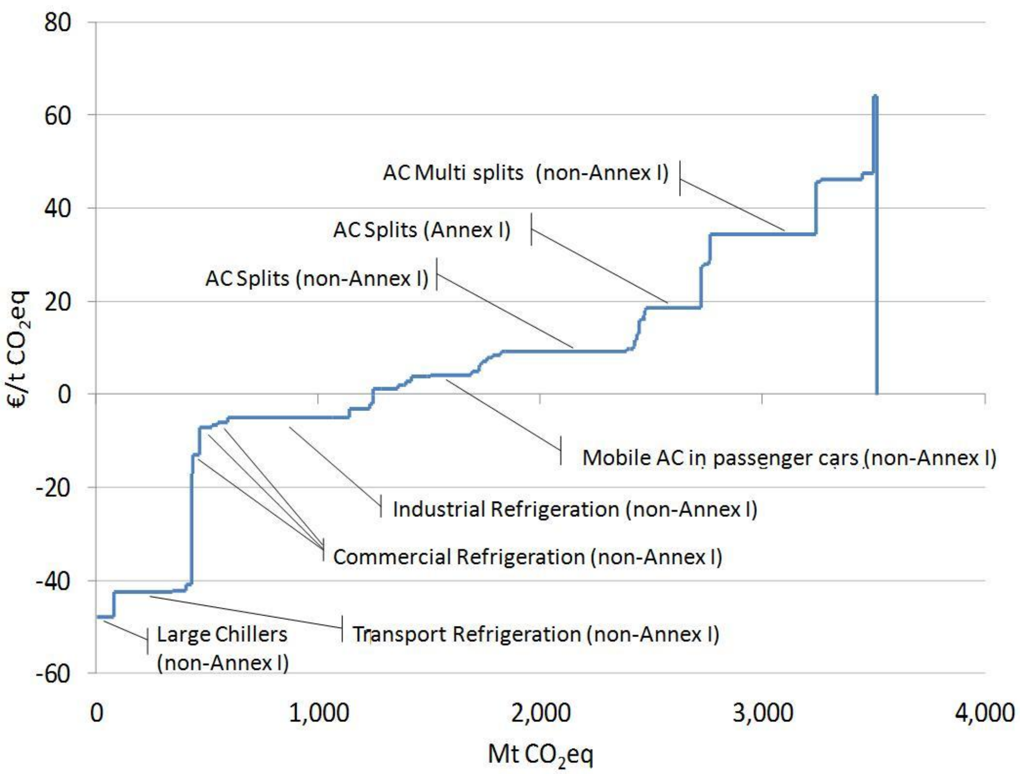


Figure 5: Global Marginal Abatement Cost Curve (MACC). Emission reduction costs associated with the phase-in of alternative technologies by 2030. The y-axis shows the costs (€) that must be spend to reduce one ton of CO_2eq, while the x-axis shows the amount of emissions that can be reduced by the phase-in.

4. Enabling environments for the implementation of the RAC&FB sectors roadmap: regulatory and technology framework

The enabling environments target the promoting of the use of low-GWP alternatives in the RAC&FB sectors and phase-out of high-GWP legacy systems.

The RAC&FB sectors suggested dividing the various promotion measures of low-GWP alternatives and removal of barriers under two categories, being

- **Regulatory framework** and support schemes
- **Technological framework** and market availability of low-GWP alternatives and good practices for their deployment

The enabling environments for the regulatory and technology framework should serve the overall strategic goal of freezing the carbon footprint of the RAC&FB sectors at current levels and reducing emissions from the RAC&FB sectors by two thirds from what they would be under a BAU scenario.

Key policy targets of the r**egulatory framework** under the RAC&FB sectors are

- The avoidance of **direct emissions** through a ban of high-GWP refrigerants and foam blowing agents latest by 2030
- The reduction of **indirect emissions** through the introduction of mandatory minimum efficiency standards, labeling and overall performance standards (including insulation and/or curbing the cooling demand[5]) latest by 2030

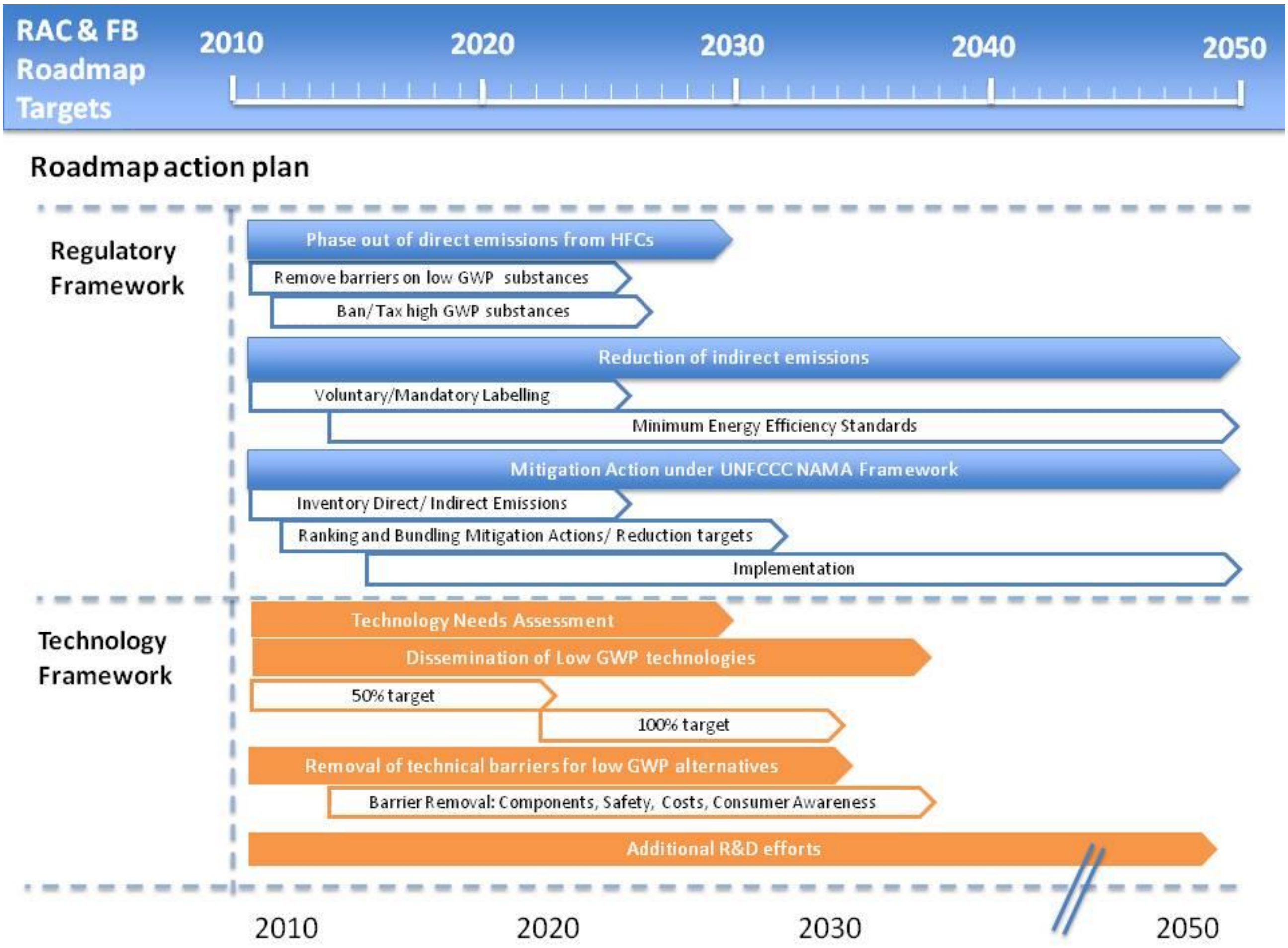
The Montreal Protocol foresees the phase-out of refrigerants with ozone-depleting potential (ODP), in particular HCFCs, by 2030. The roadmap suggests that high-GWP alternative refrigerants such as HFCs (which are part of the greenhouse gases within the basket of gases under the governance of the UNFCCC) are no later

[5] i.e. limiting the amount of air conditioning by permitting air conditioners only to operate above a certain ambient temperature level

phased out than 2030 as well (i.e. no later than the phase-out of the HCFCs in order to avoid that a phase-out of HCFC will lead to a phase-in of HFCs).

The **technology framework** addresses the extent of the use of alternative technologies in each of the main sub-sectors of the RAC&FB sectors. The enabling environments for the technology framework address the extent of required research and development (R&D) and deployment efforts to reach a high and significant penetration of low-GWP alternatives.

Table 2: Regulatory and technology framework under the enabling environments of the RAC&FB roadmap.



4.1. Enabling environments: regulatory framework

The regulatory framework in the RAC&FB sectors targets at eliminating direct emissions by 2030 and decreasing indirect emission by at least 10% from BAU emissions through accelerated introduction of energy efficiency measures. Another 40% of indirect emissions are reduced through the de-carbonization of the electricity supply[6].

4.1.1 Regulations on direct emissions: phase-out of high-GWP substances and removal of barriers for low-GWP substances

The RAC&FB roadmap suggests the phase-out of HFC as high-GWP substances in the same time frame as the phase-out of HCFCs as governed under the phase-out plan of the Montreal Protocol.

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 (funding from the multilateral fund and implementation assistance by agencies).

So far HFCs are only limited within the EU through a combination of various measures (bans/limitation of placing them on the market, taxing, import/export tax, GWP limits like the EU mobile air conditioning directive, minimum leakage rates (EU F-Gas regulation) or supportive legislation for alternatives).

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 and/or toxic. Peripheral regulations are sometimes negatively impacting the application of certain abatement options, such as certain requirements for transport and storage of flammable substances. These

[6] The de-carbonization of the electricity supply is assumed as a given external parameter. The analysis of the carbon content of the electricity supply is not further analyzed as part of the RAC&FB roadmap.

barriers are to be reduced through national authorities through the modification of regulation and standardisation which permit the use of flammable refrigerants while safeguarding safety requirements. Similar legislations have been introduced for example in the EU through the EU F-Gas directive and its implementing legislations in EU member states. The use of flammable substances in relation to the volume has further been included in the European technical standard norms, in particular in the EN378.

4.1.2 Regulations on indirect emissions

Indirect emissions are most effectively addressed through mandatory labeling of appliances (like the labeling in the EU for domestic refrigerators) and minimum energy efficiency standards. Labeling and minimum energy efficiency standards regulate the allowed energy consumption related to the cooling capacity of the devices and, in some cases, the permissible non-renewable generated cooling demand (i.e. China allows the air conditioning of public buildings only above a certain minimum ambient temperature threshold).

Most important technical measures within the RAC&FB sectors on energy efficiency are the optimization of the refrigeration cycle, the reduction of parasitic losses and the control of transient effects[7]. Within the refrigeration cycle substantial improvements are possible through i.e. an overall optimized 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, Stirling cycle). Parasitic losses are reduced through the reduction of required ancillary components or the application of more energy efficient components like fans and pumps. Energy losses within transients' effects are mitigated mainly through the application of variable speed compressors, optimized electronic controls and the application of expansion valves instead of capillary tubes.

[7] Colbourne, 2012, NAMA Workshop Thailand, 26.07.2012, RAC&FB NAMA Technical Options and Costs, p. 75.

4.1.3 Mitigation action under the UNFCCC NAMA framework

NAMAs (nationally appropriate mitigation actions) – a set of policies and actions tailored to the circumstances of individual countries – are suggested as an appropriate instrument to implement on a national level the suggested roadmap in the RAC&FB sectors. NAMAs have the potential to address both the baseline emissions (i.e. use of high-GWP substances like certain HFCs) and the migration to low-GWP substances as mitigation action.

An important aspect for the development of NAMAs is the appropriate reporting of HFCs within the National Communication of countries to the UNFCCC. So far only few Non-Annex I countries are reporting HFCs in a comprehensive way. Proklima has developed a comprehensive tool to assist Non-Annex I countries in the development of HFCs inventories and to address mitigation actions for direct and indirect emissions through the application of nationally appropriate low-GWP alternative technology options.

The RAC&FB sectors suggest to implement NAMAs in Non-Annex I countries through supported or unilateral NAMAs within the following steps:

- Capacity building (addressing NAMAs to the relevant national authorities, winning industrial and institutional support, information on alternative technologies)
- Institutional readiness (establishment of RAC&FB inventories and inclusion of HFC reporting into the National Communications; establishment of baseline emissions, BAU scenarios and mitigation pathways)
- Implementation (of pilot projects and roll out)

4.2 Enabling environments: technology framework

The RAC&FB roadmap suggests to build the required technological capabilities for the implementation of the roadmap through

- The dissemination of available alternative technologies
- The removal of technology barriers holding back the deployment of low-GWP alternatives
- Additional R&D in new and emerging technologies

4.2.1 Increased penetration of low-GWP technology options

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

Due to the early phase-out of CFCs and HCFCs, Europe, for example, has used alternative technologies at an early stage compared to other, especially Non-Annex I, countries. The table below highlights the difference of deployment of alternative low-GWP technologies in Europe compared to non-Annex I countries.

Table 3: Dissemination of alternative low-GWP technology options for key sub-sectors in Europe and Non-Annex I countries

Subsector	Alternative Technology	Alternative Technology Share EU 2015-20	Alternative Technology Share Non-Annex I 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	CO2, Hydrocarbons		

In the following, the state of technologies and their dissemination of main subsectors with the RAC&FB are presented highlighting major measures to be implemented within the framework of the RAC&FB roadmap.

Domestic Refrigeration. The most effective option is to change the refrigerants to R-600a (hydrocarbon), which is a natural refrigerant and already widely established. Over 90% of this sub-sector 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 selected Non-Annex I countries (particular China). However, in most Non-Annex I countries the use of HFCs is still dominating.

Commercial Refrigeration. The most promising options are to replace the refrigerants with R-600a in stand-alone units or with R-290/R-1270 (both 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, R-1270 to a fewer extent as it is more expensive. 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 sub-sector there is substantial mitigation action to be achieved through the dissemination of existing technologies.

Industrial Refrigeration. Using R-717 (ammonia) as refrigerant, which is already widely applied, can reduce direct emissions in the industrial refrigeration sector. More than 50% of the baseline emissions can be avoided at negative or zero costs. There is a wider deployment for ammonia systems in Annex I countries compared to Non-Annex I countries.

Road transport refrigeration. It is most favourable to replace the refrigerants with R-290/R-1270. This is also the best technical option, which needs less refrigerant charge and has lower energy consumption than existing 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.

Mobile air conditioning (MAC). Introducing systems that use CO_2 and unsaturated HFCs as refrigerants are the best cost-effective options here. Concerning the use of CO_2, R&D still needs to progress further to resolve some technical issues before the systems can be introduced commercially. Once it is introduced on the market, its use will be especially favourable in vehicles with high efficiency (Diesel) engines or in electric cars.

MAC is the subsector with the highest emissions of HFCs globally through the use of R-134a with a GWP of 1 430. The EU has theoretically banned the use of R-134a through a GWP limit of 150 in MAC systems[8]. Still, in the use the deployment of alternative systems has not widely taken place. In some Non-Annex I countries hydrocarbons are used unofficially as alternative refrigerants. Globally additional R&D efforts are required for the development of alternative systems and their deployment.

Stationary air conditioning. Many different systems fall into this sub-sector, and thus also many different technical abatement options, covering a broad range of cost-effectiveness, exist. About one quarter of them can be implemented at negative costs. The best option is to transform the chiller sector using R-717 as refrigerant in new systems. Systems with R-290/R-1270 represent another option for chillers, but also for single split and factory sealed systems. The inclusion of architectural considerations for single buildings would reduce the amount of air conditioning required or for city districts through efficient district cooling systems.

[8] EU Mobile Air Conditioning Directive

Proklima has successfully undertaken R&D and deployment efforts with the largest split-type manufacturers in India and China (Godrej and Gree) for the development of R-290 based, low-GWP, split type air conditioning systems.

Most of the air conditioning systems are today installed in Asia. The migration of key Asian Non-Annex I countries such as China, India, Thailand, Malaysia or Indonesia to low-GWP air conditioning system will be key to a low carbon strategy in the AC sector.

4.2.2 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. The introduction of low-GWP but flammable refrigerants such as hydrocarbons requires additional safety and related measures for their deployment. As such, the use of alternative, low-GWP refrigerants requires the removal of barriers. Below are the most important areas illustrated and explained where removal of barriers for the various subsectors is most relevant.

Table 4: Red-coloured arrays show the most significant barriers for the different sub-sectors of the RAC&FB sectors.

Barriers	**Domestic Refrige-ration**	**Commer-cial Refrige-ration**	**Industrial Refrige-ration**	**Road Transport Refrige-ration**	**Mobile AC**	**Stationary AC**	**Foam**
Component Availability							
Technician Competence							
Safety-related restrictions							
Implemen-tation Costs							
Consumer Awareness							
Technology Implications[9]							

[9] discussed under 4.2.3

Safety-related restrictions can be a hindrance to introduce new technological options, as low-GWP refrigerants are often flammable and in the case of ammonia also toxic. Thus, for those refrigerants, in some countries safety standards may exist that impose restrictions on the allowed amount of refrigerant or on construction features. The RAC&FB roadmap suggests to overcome this by applying regulations which safeguard the use of flammable and natural refrigerants and foam blowing substances:

1) developing alternative national standards, permitting larger quantities or wider applications of the new refrigerants
2) introducing safety control systems to keep the same level of safety as before and
3) carrying out R&D activities to find alternative designs or to enable a lower specific charge.

Component availability is low in some regions for certain components. The RAC&FB roadmap suggests to overcome this by working with existing distributors/supplier to stock the desired components, develop importation channels from overseas producers and by setting up a distribution infrastructure. Furthermore, existing manufacturers could start to develop new components and adapt the production line.

The technician competence is insufficient in some regions as not enough technicians and engineers have been trained for working with the new technologies (and issues of flammability and toxicity). For the use of hydrocarbons technician training is essential. Possible interventions could include the carrying out of train-the-trainers schemes, widespread training at companies, working with training colleges, universities, etc. GIZ Proklima has gathered a fast experience in the training of air conditioning and refrigerant technicians. During the last 10 years more than 35,000 technicians have been trained. The development of codes of practices and national standards for design requirements is another suitable measure.

Implementation costs of alternative systems will be higher than conventional systems especially when alternative systems lack economies of scale both for the production equipment costs and higher system material costs. The first may be caused by the need for new production line equipment, safety systems or refrigerant storage and feed equipment. Funding the purchase of additional equipment and guidance documentation on best practice for its use may help to overcome this barrier. Higher system material costs will include the use of more expensive raw materials, additional components or more expensive refrigerants (although the higher system costs are in many cases offset over time through lower operating costs by reduced energy consumption and lower costs of the natural refrigerants compared with synthetically manufactured refrigerants). The RAC&FB roadmap suggest as possible interventions the funding of additional costs at least during the initial stage of market development.

Consumer issues include lack of awareness or missing acceptance for 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&FB roadmap suggests intervening by rolling out awareness programmes and through the introduction of (mandatory) labelling schemes together with authorities and NGOs. Furthermore, higher upfront costs can be a part of this barrier, especially if the consumer is indifferent to climate change issues. Possible interventions include the work with authorities to develop incentives/disincentives programmes for consumers of abatement/non-abatement systems or legislation to phase out products not using the new abatement technology.

4.2.3 R&D in new technologies

Limited technology development, including poor technological development and refrigerating system efficiency, may be another barrier. The first covers a fairly broad range of issues, differing with the particular abatement option and the region (i.e. the introduction of hydrocarbon technology, which is a widespread technology option with net benefits both in developing and industrialised countries). Poor refrigerating system efficiency can be exhibited by certain abatement options under particular conditions i.e. the provision of tight systems with lower leakage effects. Possible interventions for both barriers include the initiation of collaborative R&D projects at universities and manufacturers, the development of cooperation with enterprises that have already greater experience with the particular technology or the development of design guidelines.

Mitigation action within the RAC&FB sectors can be widely achieved with existing technologies and putting the key focus on the dissemination of existing low-GWP technologies. Still, there are interesting new technologies under development which are highlighted below.

In the RAC sector not-in-kind magnetic systems are widely researched, and a small number of prototype machines has been developed. This is a promising technique that can be applied widely. The cost is likely to be somewhat greater than conventional systems, but efficiency is also found to be potentially very high. Not-in-kind "Stirling" systems are already commercially available in niche applications from a small number of manufacturers. In theory, however, they can also be applied more widely. Efficiency is known to be high, especially for lower temperature levels.

HCFC- and HFC-free options for foam blowing agents are technically available. If their application is further promoted, they provide sufficient options for reducing emissions. The best cost-effective possibility is the introduction of low-GWP blowing agents in the XPS sector, followed by using them for insulation material in domestic refrigerators. Unsaturated HFCs are also researched as possible further abatement option.

5. Suggested near-term actions

GIZ Proklima has supported developing countries in their efforts to mitigate emissions on both ozone depleting and greenhouse gases. The projects were ranging from demonstration projects to entire sector plans, policy advice and supporting enabling environments. Based on these experiences Proklima has developed the global roadmap for the RAC&FB sectors. To implement the roadmap in the near future up to 2030, the following mix of national, regional and sector initiatives are suggested.

5.1 National action plans

Low carbon development strategies in the RAC&FB sectors can be implemented via NAMAs. As more than 50% of global emissions from the RAC&FB sectors are originated in Non-Annex I countries, the inclusion of NAMAs in key countries (in particular the emerging economies like China, Brazil, India, South Africa, Mexico) using RAC&FB equipment will be required for a globally successful strategy. Integrated NAMAs will be instrumental to set up and achieve sector targets. The phase-out of HCFCs could be combined with a supported NAMA to avoid the phase-in of HFCs as alternatives for HCFCs.

A project of Proklima with the government of Thailand is exemplary for such national action plans. The NAMA project includes capacity building for setting up capabilities for HFC Tier 2 reporting under the National Communication. It further supports a national needs assessment, the establishment of a baseline, business as usual (BAU) emission pathway and mitigation scenarios for the RAC&FB sectors and sub-sectors. For the establishment of the mitigation scenarios a set of more than 100 alternative low-GWP technology options is analysed. Based on this a selection of sub-sector specific implementation options is suggested.

5.2 Regional action

In addition to national actions under NAMAs, it is suggested to establish **regional initiatives under the TEC and CTCN**. Regional initiatives could be applied in situations, where regions suffer from a specific lack of supplies or infrastructure. For example, Africa has little or no adequate recycling capabilities for products containing toxic fluorinated refrigerants. The regional transition towards natural refrigerants has then significant environmental co-benefits next to emission mitigations. Also many regions in Africa have relatively poor access and use of advanced energy efficient technologies. These regions could particularly benefit from technologies like solar cooling that are specifically tailored to local circumstances.

5.3 Sector Action Plans

Sector action and technology networks are another supplementary way to promote low carbon strategies in the RAC&FB sectors. One outstanding example for such non-profit initiatives in the refrigeration sector is "Refrigerants, Naturally!" which includes several large multinational companies that substitute F-gases used in point-of-sale cooling applications with natural refrigerants. The initiative encourages suppliers and retailers in the commercial sector to follow their example or join the initiative. Based on their experience they offer technical advice and policy recommendations for public and private sector organisations.

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Appendix

In the following table, the categories and some characteristics of the main applied refrigerants are summarized.

Table 5 Table with characteristics about some refrigerants. Adopted from (Proklima International, 2008), Opportunities for the Application of Natural Refrigerants, D. Colbourne.

Type	Refrigerant	GWP	Flammability	Toxicity
HFC	R-407C	1770	None	Low
	R-404A	3920	None	Low
	R-410A	2140	None	Low
HFC-based “drop-in”	R-417A	2350	None	Low
	R-427A	2140	None	Low
	R-434A	3280	None	Low
Natural Refrigerant	R-717 (ammonia)	0	Low	High
	R-744 (carbon dioxide)	1	None	Low
	R-290 (propane)	<3	High	Low
	R-290/R-600a mix	<3	High	Low
	R-1270 (propene)	<3	High	Low

The following table displays several applications and equipment types in the RAC sector, the typical applied refrigerants and the possibilities to apply natural refrigerants.

Table 6 Applications in the RAC&FB sectors, their typical fluorocarbon use and the usable natural refrigerants. Table from (Proklima International, 2008), Opportunities for the Application of Natural Refrigerants, D. Colbourne.

Application	Equipment type	System type	Typical Flouorocarbon	Viable natural refrigerants		
				New refrigerant (retrofit/ retrofill)	New system (circuit and components)	New installation (circuit, components and layout)
Retail Refrigeration	Water coolers	Integral	R134a, R12	HC mix	R600a, R290	R600a, R290
	Chiller cabinets	Integral	R134a, R404A, R502	HC mix, R290	R600a, R290, R744	R600a, R290, R744
	Chiller cabinets	Remote	R22, R404A, R502		R290, R744	R290, R744
	Chiller cabinets	Distributed	R22, R404A, R502			R744, [R290, R1270, R717]*
	Chiller cabinets	Indirect	R22, R404A	R290, R1270	R290, R1270, R717	R290, R1270, R744, R717
	Freezer Cabinets	Integral	R22, R404A,	R290,	R290,	R290, R1270

			R502	R1270	R1270	
	Freezer Cabinets	Remote	R22, R404A, R502		R290, R744	R290, R744
	Freezer Cabinets	Distributed	R22, R404A, R502			R744, [R290, R1270, R717]*
	Freezer Cabinets	Indirect	R22, R404A	R290, R1270	R290, R1270, R717	R290, R1270, R744, R717
Cold Storage and Food Processing	Storage Cabinets	Integral	R22, R404A, R502	R290, R1270	R290, R1270, R744	R290, R1270, R744
	Cold Stores	Remote	R22, R404A, R502		R290, R1270, R744	R290, R1270, R744
	Cold Stores	Distributed	R22, R404A, R502			R744, [R290, R1270, R717]*
	Cold Stores	Indirect	R22, R404A	R290, R1270	R290, R1270	R290, R1270, R744, R717
	Process Cooling/Freezing	Remote	R22, R404A, R502		R290, R1270, R744	R290, R1270, R744, R717
	Process Cooling/Freezing	Distributed	R22, R404A, R502			R744, [R290, R1270, R717]*
	Process Cooling/Freezing	Indirect	R22, R404A	R290, R1270	R290, R1270	R290, R1270, R744, R717
Transport Refrigeration	Road Transport Trucks	Integral	R22, R404A, R502	R290, R1270	R290, R1270, R744	R290, R1270, R744
	Refrigerated Railcars	Integral	R22, R404A, R502		R744	R744
	Marine Refrigeration	Integral	R22, R404A, R502		R744	R744
Domestic Air Conditioners, Dehumidifiers and Heat Pumps	Portable Units	Integral	R22, R407C, R410A	R290, R1270	R290, R1270	R290, R1270
	Window Units	Integral	R22, R407C, R410A	R290, R1270	R290, R1270	R290, R1270
	Through-Wall Units	Integral	R22, R407C, R410A	R290, R1270	R290, R1270	R290, R1270
	Split Units	Remote	R22, R407C, R410A	R290, R1270	R290, R1270, R744	R290, R1270, R744
	Hot Water Heating	Integral	R22, R407C, R410A	R290, R1270	R290, R1270, R744	R290, R1270, R744

	Central Heating	Integral/Indirect	R22, R407C, R410A	R290, R1270	R290, R1270, R744	R290, R1270, R744
Commercial Air Conditioning and Heat Pumps	Split Units	Remote	R22, R407C, R410A	R290, R1270	R290, R1270, R744	R290, R1270, R744
	Mulit-Split/VRV	Distributed	R22, R407C, R410A			R744, [R290, R1270, R717]*
	Packaged Ducted	Remote	R22, R407C, R410A			R744
	Central Packaged	Remote	R22, R407C, R410A			R744
	Positive Displ´t Chillers	Integral/Indirect	R134a, R22, R407C	R290, R1270	R290, R1270, R717	R290, R1270, R717
	Centrifugal Chillers	Integral/Indirect	R123, R134a		R290, R1270, R717	[R290, R1270, R717]*
	Hot Water Heating	Integral	R134a, R22, R407C	R290, R1270	R290, R1270, R744	R290, R1270, R744
	Central Heating	Integral/Indirect	R134a, R22, R407C	R290, R1270	R290, R1270, R744	R290, R1270, R717
*Use of HCs and R-717 require the direct expansion system to be replaced with an indirect (secondary) system						

Table 7 List of Abbreviations

Abbreviation	Meaning
EN	European (industrial standard) norm
F-Gases	Fluorinated Gases
Gt	Gigatons
GWP	Global Warming Potential
HC	Hydrocarbons
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
MAC	Mobile Air Conditioning
NAMA	Nationally Appropriate Mitigation Action
R	Refrigerant
RAC&FB Sectors	Refrigeration Air Conditioning and Foam Blowing Sectors
UNFCCC	United Nation Framework Convention on Climate Change
VRV	Variable Refrigerant Volume