green cooling initiative

Environmental impact of the refrigeration and air conditioning sectors

Refrigerants

Refrigerants pose a threat to the environment because of their ozone depletion potential (ODP) and global warming potential (GWP). Table 1 gives an overview of the different groups of refrigerants.

Restrictions

The Montreal Protocol on substances that deplete the ozone layer from 1989 is now effectively controlling the use of the ozone depleting refrigerants chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC). There has been a worldwide ban on CFCs since 2010. HCFCs, initially used as substitutes for CFCs, have been forbidden in most non-Article 5 ("developed") countries since 2010 but are still widely used in Article 5 ("developing") countries where they must be phased out by 2030[1].

Figure 1 shows the expected phase-out of CFCs and HCFCs in developing and developed countries and restrictions put on HFCs in the EU.

This factsheet is provided by the Green Cooling Initiative, a project implemented by GIZ Proklima, on behalf of the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and their International Climate Initiative (IKI). Please also visit the website www.green-cooling-initiative.org.

Hydrofluorocarbons (HFC) have no ODP and are currently not controlled under the Montreal Protocol. HFCs are listed under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) from 2005 as substances whose emissions are to be limited or reduced. Some countries and regions have already introduced laws restricting the use of HFCs. In the EU, HFCs will be phased down to 21% of current levels because of the F-Gas Regulation. According to the EU Mobile Air Conditioning Directive, only refrigerants with a GWP of less than 150 are allowed in passenger vehicles.

Table 1: Overview of refrigerant groups

Substance group	Abbreviation	**ODP**	**GWP_{100}**	**GWP_{20}**	**Atmospheric lifetime**	**Example** (refrigerant/ foam blowing agent)
Saturated chloro-fluorocarbons	CFC	0,6-1	4750-14,400	6,730-14,400	45-1,700	R11, R12
Saturated hydrochloro-fluorocarbons	HCFC	0,02-0,11	77-2310	273-5,490	1.3-17.9	R22, R141b
average			*1,502*	*4,299*	*11.4*	
Saturated hydro-fluorocarbons	HFC	-	124-14,800	437-12,000	1.4-270	R32, R134a
average			*2,362*	*4,582*	*21.7*	
Unsaturated hydro-fluorocarbons	u-HFC	-	<1-12		days	R1234yf, R1234ze, R1234yz
Natural refrigerants		-	0-20			R744 (carbon dioxide) R717 (ammonia) R290 (propane)

[1] A residual consumption of HCFCs will be allowed until 2040.

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On behalf of

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

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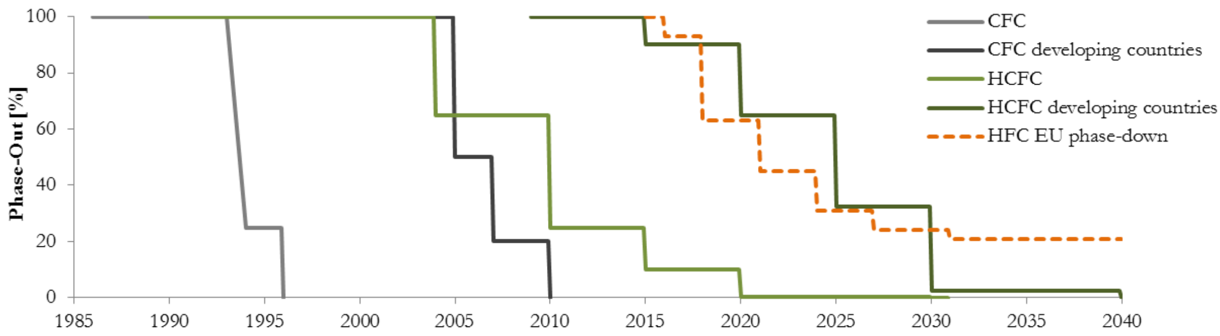

Figure 1: Phase-out plan for CFCs (grey) and HCFCs (green) according to the Montreal Protocol and phase-down of HFCs in the EU (orange).

Unsaturated HFCs (u-HFCs, also marketed as hydrofluoro-olefins, or "HFOs") are synthetically made HFCs with no ODP and low GWP that have been developed specifically to fulfil regulations that prohibit HFCs with higher GWP (e.g. above 150).

Natural refrigerants

The strong advantages of natural refrigerants are that they have zero ODP, a negligible GWP, are part of the natural biogeochemical cycles and do not form persistent substances in the atmosphere, water or biosphere. They include carbon dioxide (CO_2), ammonia (NH_3) and hydrocarbons such as propane (C_3H_8), propene (C_3H_6) and isobutane (C_4H_{12}) and have been used as refrigerants for over 150 years (Calm, 2008). Natural refrigerants are widely used in some RAC applications, for example isobutane in domestic refrigerators and ammonia in large cooling processes.

Refrigerant properties

The following list shows a comparative summary of refrigerant properties, highlighting positive and negative properties of different refrigerants. Table 3 summarises these positive and negative properties of the various refrigerant groups.

- The **ODP** of HCFCs is lower than that of CFCs, but still high enough to justify a complete phase-out.

- Both HCFCs and HFCs have a **high GWP**, up to several thousand times higher than that of CO_2. The GWP of a substance can be determined for different time horizons (usually 20, 100 or 500 years). Because of the different atmospheric lifetimes ranging from a few years to several centuries, usually the GWP_{100} is used. HFCs with an average lifetime of 21.7 years might be better represented by the GWP_{20}.

- All fluorinated refrigerants produce **persistent wastes**. They are persistent in the atmosphere where they destroy the ozone layer or influence the climate. In the atmosphere the decomposition of u-HFCs leads to formation of trifluoroacetic acid (TFA), which is a strong acid with toxicity to some organisms (Key et al., 1997). TFA exists naturally in the oceans in very low concentrations, it is highly persistent and there is no known degradation mechanism (Luecken et al., 2010). There are no studies about the longterm effect on organisms and the food chain. Whilst only 10 to 20% of HFC-134a are transformed into TFA, 100% of u-HFC-1234yf reacts to TFA. Studies modelling future TFA concentrations in rainwater due to u-HFC1234yf predict concentrations that were already reached in extreme events in the 1990, when HFC-134a was first used more widely (Henne et al., 2010; Luecken et al., 2010; Christoph, 2002) and are regularly reached in China today (Wang et al., 2014). These models therefore seem to underestimate future TFA concentrations. Concentrations are expected to be especially high in dry regions with little precipitation or close to industrial centres and high population density. TFA has been shown to accumulate in conifers already (Christoph, 2002). TFA from Europe is expected to precipitate in Asia and Africa in concentrations of up to 2500 ng L^{-1} (Henne et al., 2010). To a small amount, TFA produces tropospheric ozone (Luecken et al., 2010). Natural refrigerants do not produce persistent waste.

- Fluorinated refrigerants are also produced from fluorspar, which is a **depletable resource**. Its global reserves are estimated to be 240 million tonnes, most of which can be found in China, Mexico, Mongolia, South Africa and Namibia (USGS, 2013). European reserves are mainly depleted (CTEF, 2013). Mine production in 2012 was at 6.85 million tonnes (USGS, 2013); making fluorspar available for another 35 years if consumption stays constant. The EU has included fluorspar in its list of the 14 most critical raw materials, defined by supply risk and economic importance (EC Enterprise and Industry, 2010). The reasons are that mining activities are limited to a few countries globally, the recycling rate is smaller than 1 % and substitution possibilities are few (EC Enterprise and Industry, 2010).

- In order to be able to **recycle or dispose** HCFCs, HFCs and u-HFCs, they have to be reclaimed from appliances and cleaned with special equipment. Recycling is mainly possible for pure refrigerants and even more difficult for blends. Cleaned refrigerants can be used again. Refrigerants for disposal have to be rendered environmentally safe by incinerating them at high temperatures and collecting decomposition products such as hydrogen fluoride (HF) and hydrogen chloride (HCl). Dedicated recycling plants are rare in developing countries. Natural refrigerants can easily be recycled after use or vented to the atmosphere without negative impact on the environment.

- Special **safety measures** have to be taken for hydrocarbons, u-HFCs (flammability) and ammonia (higher toxicity). When u-HFCs combust, hydrogen fluoride (HF), which is extremely dangerous, can form. Measures such as using appropriate materials, selection of safe components and technician training can offset these undesirable characteristics.

- Some CO_2 systems are not as **energy efficient** in warmer climates or need additional cycle adjustments to become as efficient as other systems. Generally, applications using natural refrigerants are as efficient as or more efficient than those using HFCs and HCFCs; HC and ammonia have superior thermodynamic properties with high critical temperatures and low boiling points (Mohanraj, 2009).

- The **costs** can be related to the system, which is typically higher for flammable or higher toxicity refrigerants. However, newly developed u-HFC refrigerants are significantly more expensive (estimates range from 100 US$/kg to 150 £/kg or more in Europe) than HFCs that have been in use for several years where patents have expired (approx. 6US$/kg), and also more expensive than natural refrigerants (e.g. CO_2: <1 US$/kg). Natural refrigerants are relatively cheap because they are mass produced for a wide range of uses and are readily available if distribution structures are present. Natural refrigerants can often be sourced as by-products from other processes

- Because there are no international property rights, natural refrigerants can be **produced or sold by any company in any country locally.** Far more patents are associated with HFCs, u-HFCs and u-HCFCs refrigerants and applications than with natural refrigerant applications. Only natural refrigerant system designs can be patented, not the refrigerants themselves.

	HCFC	HFC	u-HFC	NH_3	CO_2	HC
Ozone depletion	Red	Green	Green	Green	Green	Green
High GWP	Red	Red	Green	Green	Green	Green
Persistent wastes	Red	Red	Red	Green	Green	Green
Depletable resources	Red	Red	Red	Green	Green	Green
Recycling/disposal	Red	Red	Red	Green	Green	Green
Safety issues	Green	Green / Red	Red	Red	Green	Red
Energy efficiency	Green	Green	Green	Green	Green / Red	Green
Costs	Green	Green	Red	Red	Red	Green
Local production	Red	Red	Red	Green	Green	Green

Table 3: Refrigerant characteristics. Green shows positive and red negative properties

Precautionary approach

The term precautionary approach refers to the principle that one should take caution before engaging in an activity that poses a threat to the environment or human health, even if this threat is not fully known or scientifically proven yet. By employing this principle, one means to anticipate and avoid damage as opposed to having to repair damage that could have been prevented. Coined by the Montreal Protocol in 1987 and in the 1992 Rio declaration, the precautionary principle has become internationally recognised: "*Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"

Just like CFCs, HCFCs and HFCs, the newest generation of synthetic refrigerants, u-HFCs will again be responsible for introducing a persistent compound into the environment. Contrary to its predecessors, u-HFCs have no ODP and a low GWP. Their degradation product TFA however, has no known degradation pathway and will accumulate in water bodies, plants and soils. It is phytotoxic and its long term effects are not known yet. This is another case where the precautionary approach should take effect and a more environmentally-friendly technology be introduced.

Energy efficiency

On average, about two-thirds of greenhouse gas (GHG) emissions are caused by energy consumption. Increased energy efficiency of cooling systems and reduced overall cooling needs do not only save the consumer or operator money. They relieve the often strained energy supplies and avoid black-outs which can have negative impacts on the development of competitive industry and services. Energy efficiency also reduces the need for additional investments in energy infrastructure, which can be a huge financial burden to poor countries.

Green cooling technologies

Equipment with both maximised energy efficiency and natural refrigerants, which is therefore minimising its environmental impact, is here termed "green cooling technologies". Green cooling technologies offer long-term solutions for almost all types of systems and appliances in the RAC sectors. The growing use of HFCs in the RAC sectors can be clearly linked to the phase-out of CFCs and HCFCs in these industries, a fact that was specifically noted by the Rio+20 declaration in 2012 and other high level political declarations, such as by the Climate and Clean Air Coalition (CCAC). In the past the phase-out of one group of refrigerants that damaged the environment has always led to the increased use of refrigerants that were only less damaging. This happened in the switch from CFCs to HCFCs (though note that HCFCs were regularly used before the phase-out of CFCs as well) and on to HFCs in developed countries and is currently visible in developing countries where HFCs are replacing HCFCs, and to some extent in developed countries where u-HFCs are introduced.

Switching from ozone depleting and climate harming fluorinated substances to natural refrigerants in energy-efficient systems and applications is often referred to as "leapfrogging". Within the Montreal Protocol, states have always been encouraged to choose alternatives that not only save the ozone layer but that also do not harm the climate. The UN Secretary-General Ban Ki-moon urged "parties and industries to seize the opportunity provided by the HCFC phase-out to leapfrog HFCs wherever possible" in his 2011 Ozone Day message. A phase-down of HFCs is also discussed as an amendment to the Montreal Protocol. Finding opportunities to leapfrog could prevent countries and industries from having to phase new sets of fluorinated gases in and out again with growing concern about future regulations prohibiting the use of HFCs. Figure 2 visualises the leapfrogging scheme.

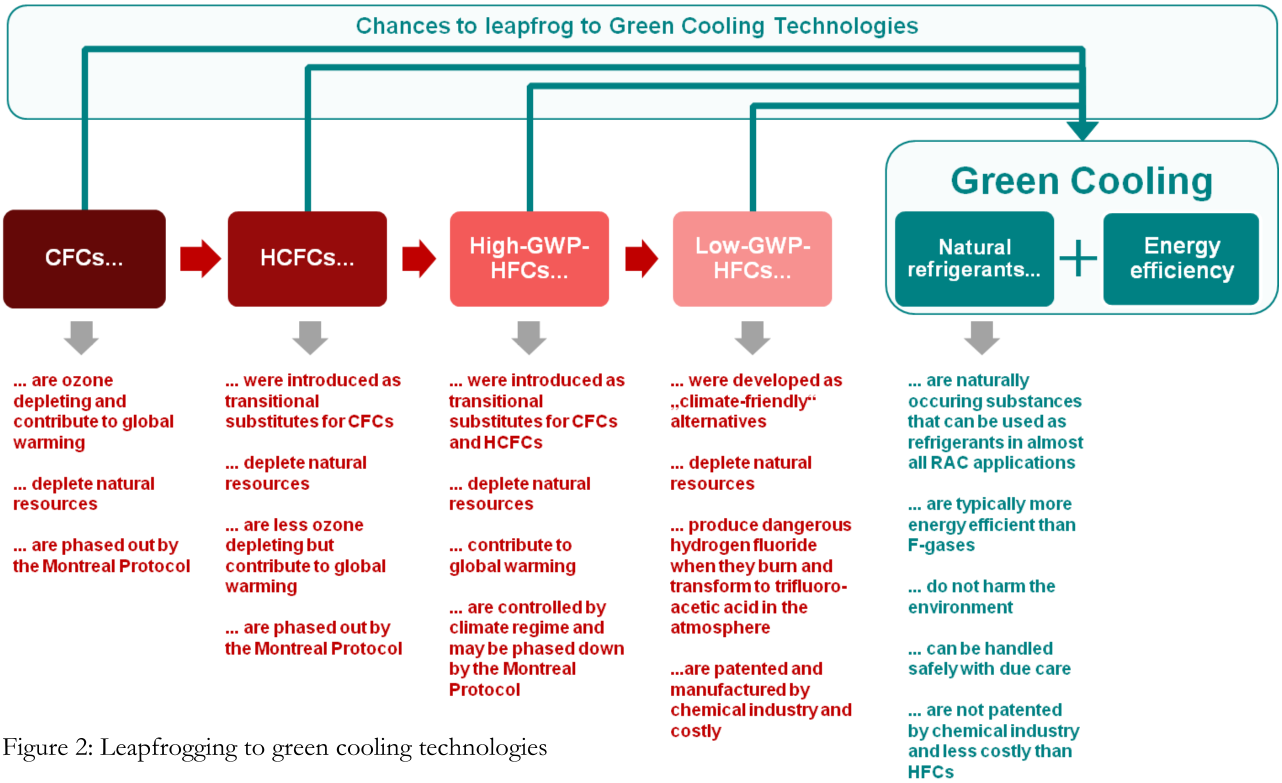

Figure 2: Leapfrogging to green cooling technologies

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