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Alternatives to HCFCs/HFCs in developing countries with a focus on high ambient temperatures

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Introduction

The accelerated schedule for the phase-out of production and consumption of HCFCs in developing countries (Article 5 countries) has been agreed at the 19th Meeting of the Parties to the Montreal Protocol on Ozone Depleting Substances (ODS) in 2007 (MOP Decision XIX/6). HCFCs are currently predominantly used for refrigeration, air conditioning, and foam blowing. The refrigerant and blowing agent demand is expected to triple by 2030 in developing countries as a result of economic growth. The choice of alternatives to HCFCs requires particular attention in order to protect both the ozone layer and the climate. In industrialized countries, HFCs have been introduced as ODS replacements in the past that show high global warming potentials (GWP) and therefore contribute to climate change. These substances are today subject to strict regulations in many industrialized countries[1] with the aim to replace high GWP HFCs with alternatives that have a lower GWP. With the exception of car air conditioning, high GWP HFCs are still used to a limited extent in developing countries. These countries have the chance to leapfrog high GWP HFCs and to switch to climate-friendly substances and technologies immediately. This guarantees future-proof solutions for both ODS replacement and growing demand for refrigerants and foam blowing agents. Maintaining high energy efficiency is an integral part of this process, especially at high ambient temperatures frequently occurring in many developing countries during the summer months.

An analysis by sectors shows that a climate-friendly replacement for the current and future of HCFCs and high GWP HFCs is possible in most applications:

- 55% of HCFCs can be replaced by natural refrigerants and foam blowing agents and additional 13% by unsaturated HFCs (i.e. HFOs) in the short term.
- 22% of HCFCs can be replaced in the short term by HFCs with moderate GWP and by HFC-HFO blends in the medium term.
- Alternatives for the remainder are not yet available at the same efficiency level and at feasible cost. Here, low GWP solutions are expected by 2025.

[1] In Europe they are addressed by the Regulation on Fluorinated Greenhouse Gases (EU) No 517/2014 which introduces a phase-down schedule of the HFC supply.

Hydrocarbons and ammonia: 55% replacement potential (kilo tons)

Sector	Savings 2020 (kt)	Savings 2030 (kt)	Alternatives
Commercial stand-alone	25	75	R600a, R290
Condensing units < 5 kW	20	60	R290
Portable/window air conditioner	25	75	R290
Single-split air conditioner < 7kW	100	300	R290
Chillers < 150 kW	5	15	R290
Chillers > 150 kW	15	45	ammonia
Large industrial refrigeration	20	60	ammonia
PU foam blowing excl. spray foam	15	45	pentanes
XPS foam blowing (70%)	25	75	organic solvents

Hydrocarbon refrigerants like R290 (propane) are highly energy efficient R22 replacements at both moderate and high ambient temperatures. The thermodynamic properties are close to R22 so that the current R22 products (e.g. compressors) could be re-engineered to employ R290 instead. Due to its flammability, indoor charges are limited by safety standards to < 1.5 kg R290 (< 1 kg in room air conditioners). If located outdoors or in separate machine rooms, such limits do not exist. Hydrocarbons can therefore be used in high charges for chillers or two-circuit refrigeration systems. This also applies to ammonia (NH_3) which is the most efficient refrigerant overall.

In most industrialized countries hydrocarbons are already dominating the market for equipment with small charges such as domestic refrigerators/freezers, commercial stand-alone equipment, and portable and window-mounted air conditioning devices. Many developing countries use hydrocarbons in these sectors. They are currently also in the process of introducing R290 into the worldwide largest sector of refrigerant application: unitary air conditioning equipment of the split-type. These systems are manufactured predominantly and used in developing countries. Hydrocarbons are the most efficient choice for smaller units (< 7 kW capacity), which account for >80% by number and >50% by refrigerant weight in this sector. Due to charge limits, higher capacities require refrigerants with a lower flammability. The same applies to commercial condensing units which are widely used by food retailers. Units with capacities < 5 kW are charged with less than 1.5 kg hydrocarbons and cover the vast majority of systems by number and > 50% by refrigerant mass.

Charge limits do not exist for chillers (displacement compressor type). In industrialized countries natural refrigerants are already commonly used: hydrocarbons in systems < 150 kW, ammonia for capacities > 150 kW. In Europe, ammonia is the most widespread refrigerant in large industrial refrigeration. These proven technologies are useful options for developing countries, particularly because both R290 and ammonia perform very well at high ambient temperatures, i.e. > 40°C.

In the foam sector, hydrocarbon blowing agents have become standard in industrialized countries, and can replace HCFCs to a large extent in the manufacturing of PU foam and of XPS foam.

Unsaturated HFCs (HFOs): 13% replacement potential (kilo tons)

Sector	Savings 2020 (kt)	Savings 2030 (kt)	Alternatives
Mobile air conditioning	30	100	R1234yf
Centrifugal chillers	10	30	R1234ze
PU Spray foam	10	20	R1234ze/1336mzz
XPS foam blowing	10	25	R1234ze

Like hydrocarbons, unsaturated HFCs (HFOs) have a lower GWP. They are flammable, but to a lesser degree than hydrocarbons. The HFO refrigerant R1234yf is currently being introduced by international car-makers for mobile air conditioning. First centrifugal chillers are commercialized with HFO refrigerant R1234ze, which also serves as a blowing agent for special XPS boards. HFOs like 1234ze or 1336mzz can be applied to PU spray foam for which highly flammable hydrocarbons are not safe enough on application. Approximately 13% of the refrigerant/blowing agent demand which is projected for 2030 will not be suitable for replacement by hydrocarbons and could be substituted by HFOs instead.

HFC-32 (R32): 22% replacement potential (kilo tons)

Sector	Savings 2020 (kt)	Savings 2030 (kt)	Alternatives
Split-/Multisplit air conditioning > 7 kW	100	300	R32 -> R32-HFO blends

Hydrocarbon charges < 1 kg cannot provide capacities > 7 kW at high ambient temperatures. As a consequence, air conditioning systems of the split- and multisplit-type with higher capacities require less flammable refrigerants. Current safety standards allow 10-12 times higher charges if HFC-32 or HFC-32/HFO blends (both are of lower flammability) are used instead of hydrocarbons. While newly-developed HFC/HFO blends with moderate GWPs (200-400) will not be commercialized before 2018, R32 is currently available to a sufficiently large degree. Its comparably high GWP of 675 is significantly lower than that of the HFC-blends which replaced R22 in industrialized countries. In terms of energy efficiency at high ambient temperatures, R32 is superior to those blends and almost as good as the hydrocarbon R290 if some technical adaptations are implemented. In order to cover the high refrigerant demand for air conditioning devices > 7 kW, R32 can be accepted as a short term solution for a transitional period.

No short term replacement of remaining demand is difficult

Sector	Savings 2025 (kt)	Savings 2030 (kt)	Medium term alternatives
Centralised Supermarket systems	20	60	R134a or R290 indirect / CO_2
Condensing units > 5 kW	20	60	HFC-HFO blends, R290 indirect
Transport refrigeration	5	20	HFC-HFO blends, R290 indirect

In condensing units > 5 kW and centralized systems for supermarkets, industrial countries have broadly replaced R22 by the HFC-blend R404A which shows an extremely high GWP of almost 4,000. This is more than twice the GWP of R22. In developing countries the refrigerant demand is expected to triple by 2030. As a consequence, the general introduction of R404A in the two sub sectors of commercial refrigeration would jeopardize the efforts to reduce the climate damaging impact from refrigerant applications, the more so as R404A shows poor performance at high ambient temperatures.

Avoiding the use of R404A is a major challenge in R22 replacement.

In the case of centralized supermarket systems, low GWP alternatives are not yet available for the dominating "one-stage" technology, with a single refrigerant for both low and medium temperature levels. For centralized systems, the preferred alternative options in Europe are highly efficient "two-stage" cascade systems with CO_2 as heat transfer fluid for low temperature and R134a for medium temperature cooling. This halves the GWP compared to R22 one-stage systems. It can be further reduced at the upper stage when HFC/HFO blends or indirect hydrocarbon-based systems are commercially available at a feasible cost.

Another challenge for the R22 replacement are condensing units with capacities > 5 kW. For the common technology of direct expansion a short term high efficient alternative to R22 with low or moderate GWP is not yet available. Indirect hydrocarbon systems could be an appropriate option, but only if their efficiency can be increased. The required equipment components for this purpose are currently not yet available in sufficiently large numbers and are still very costly. This option can therefore not yet be considered a general alternative for developing countries.

In transport refrigeration, low GWP solutions to replace R22 or R404A are not yet fully matured.

Conclusion

In developing countries, approx. 90% of HCFCs and high-GWP HFCs can be replaced by substances with low or moderate GWP. This can be done in the short or at least medium term and without reduction in energy efficiency even at high ambient temperatures. It should be emphasized that a successful reduction of the global warming impact relies heavily on a broad application of hydrocarbon refrigerants like R290, wherever it is feasible under the given safety standards. They exhibit performances like R22 at high ambient temperatures and have proven reliable and efficient for many years not only in industrialized countries but also in developing countries.

Immediate action can and must be taken to guarantee future-proof solutions for both ODS replacement and growing demand for refrigerants and foam blowing agents.