Technical Aspects

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Opportunities and challenges per application sector

• **Domestic refrigeration**

  Domestic refrigerators equipped with flammable natural refrigerant (such as hydrocarbons, i.e. R-600a, Isobutane) are widely accepted and are not considered a safety threat.

  Trends indicate that by 2020 around 75% of the domestic refrigerators on the global market will be equipped with R-600a.
Opportunities and challenges per application sector

• Commercial refrigeration

At present, the most promising alternative for the sector is represented by Carbon Dioxide (CO$_2$, R-744).

Its use becomes not energy efficient when the equipment is installed in a hot climate environment (such as in Africa and in most developing countries).

R&D efforts in the last decade have tried to overcome this limit and the most recent achievements have allowed CO$_2$ equipped machines to be as energy efficient as the previous generation, HFC equipped, machines.
Opportunities and challenges per application sector

- Industrial refrigeration

The chance to have at disposal premises where the appropriate safety measures can be deployed and well trained personnel, allow for the use of refrigerants such as Ammonia (R-717), which has very good thermodynamic characteristics but is toxic and flammable, therefore requiring heavy safety measures.
Opportunities and challenges per application sector

• **Room AC**

Leapfrogging from HCFC-22 to low-GWP alternatives, avoiding the high-GWP HFC step, is an option for many developing countries.

Promising alternatives at present seem to be:

• HFC-32 (which is a mildy flammable substance with a medium-GWP)

• HC-290 (Propane, which has good thermodynamic properties but is also highly flammable, being an hydrocarbon).

• A third option can be detected among the many HFC/HFO blends which are currently under test.

All the options presently at stake have drawbacks, so it is impossible to say which one will be the winners.
Natural vs Synthetic Refrigerants

• **Natural refrigerants**

Natural refrigerants (namely Hydrocarbons, Carbon Dioxide, Ammonia, Water and Air) have no environmental impact when used as working fluids for RACHP, as far as Ozone Protection and Climate Change are concerned.

In this sense their application should be promoted as much as possible. Unfortunately there are a lot of technological issues linked to their application and this is the reason why strong R&D efforts are currently deployed to overcome them.

These efforts have solved problems for some sectors and applications, and this is why some natural refrigerants are the most promising in perspective for important applications.
Natural vs Synthetic Refrigerants

- **Synthetic refrigerants**
  Where no natural refrigerants are available, the only possible solutions is via the use of synthetic refrigerants.

- The problem is that synthetic refrigerants with good applicative characteristics and low-GWP are scarce, and very few of them can be used as pure substances.

- They have to be combined to form blends.

- One synthetic pure fluid showing good thermodynamic properties and good environmental characteristic is HFC-32.

- Other synthetic fluids currently being proposed as HFC alternatives are the HFOs, but no single substance seems to be good enough to be used as a pure fluid. And they are also mildly flammable.

- Probably the solution will be a mixture.
Energy related issues

• When the problem to be faced is Climate Change, then energy consumption becomes the most important parameter to be kept under control (energy production is the main factor for the emission of GHG).

• So, for the specific RACHP sector, the impact on climate change is twofold:
  - there is a direct impact, due to the emission of GWP fluids into the atmosphere,
  - and there is an indirect impact, due to the GHG emissions linked to the production of energy consumed by the RACHP equipment to perform its task.

• The goal of any correct implementation of the Kigali Amendment should be the minimization of the total impact (direct plus indirect) more than the simple elimination of high-GWP refrigerant.
Energy related issues

- The impact minimization can be measured using one of the several metrics available in the literature:
  - TEWI, Total Warming Equivalent Impact, or
  - LCCP, Life Cycle Climate Performance
- The LCCP is a more comprehensive and complete but it is also more difficult to calculate and the results it gives do not differ substantially from the results given by TEWI.
Energy related issues

• TEWI is defined as follows:

\[
\text{TEWI} = \text{GWP coming from direct emissions (refrigerant leakage and maintenance plus refrigerant emissions at end of life)} + \text{GWP coming from indirect emissions of } \text{CO}_2 \text{ for the production of energy consumed by the RACHP equipment}
\]
Energy related issues

• The mutual ratio among direct and indirect emissions, substantially depends upon:
  • the GWP of the refrigerant,
  • the Energy Efficiency of the equipment (represented by its seasonal COP, Coefficient Of Performance),
  • the indirect emission factor, which is usually calculated country by country and represents the quantity of GHG emitted by the national power system per unity of electricity produced (generation mix).
Energy related issues

• Generation mix

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| 1  
  heavily dependent on fossil fuels, in particular coal   | China  
  (Libya, Morocco, South Africa)                         | $\beta \approx 0.70 \text{ kg CO}_2/\text{kWh}$ |
| 2  
  balanced mix among fossil fuels, nuclear and renewables | many European Countries  
  (Egypt, Nigeria, Ivory Coast)                         | $\beta \approx 0.40 \text{ kg CO}_2/\text{kWh}$ |
| 3  
  heavily dependent on nuclear or renewables (hydro, solar, wind) | France and Norway  
  (Congo, Ethiopia, Zambia)                          | $\beta < 0.10 \text{ kg CO}_2/\text{kWh}$ |
Emissions of a split system room A/C at different conditions

Direct and indirect emissions and TEWI for a country with an emission factor $\beta=0.70 \text{ kg}_{\text{CO}_2}/\text{kWh}$ (generation mix with heavy dependence on fossil fuels)
Emissions of a split system room A/C at different conditions

Direct and indirect emissions and TEWI for a country with an emission factor $b=0.40 \text{ kg}_{\text{CO}_2}/\text{kWh}$ (generation mix with average dependence on fossil fuels)
Emissions of a split system room A/C at different conditions

Direct and indirect emissions and TEWI for a country with an emission factor $\beta < 0.10 \text{ kg CO}_2/\text{kWh}$ (generation mix with minimal dependence on fossil fuels)
Emissions of a split system room A/C at different conditions

• Analysis of results shows that:
  • The indirect emissions are always prevalent over direct emissions when fuels are used to generate electricity.
  • On the other hand, when renewables (and/or nuclear) are prevalent in the generation mix then direct emissions gain a certain relevance and transiting from high-GWP to low-GWP refrigerant becomes very important.
Emissions of a split system room A/C at different conditions

• to reduce the Climate Change impact of RACHP and to effectively implement the KA, it is important to focus interventions contextually on:
  • the substitution of high-GWP refrigerants with low-GWP refrigerants,
  • the minimization of the impact on GHG emissions due to energy consumption.

• this last goal can be achieved by means of:
  • the increase of the Energy Efficiency of the equipment,
  • the de-carbonisation of the electricity production, through the increased use of electricity produced from Renewables