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CO_2

A Future Refrigerant

Thematic Report by

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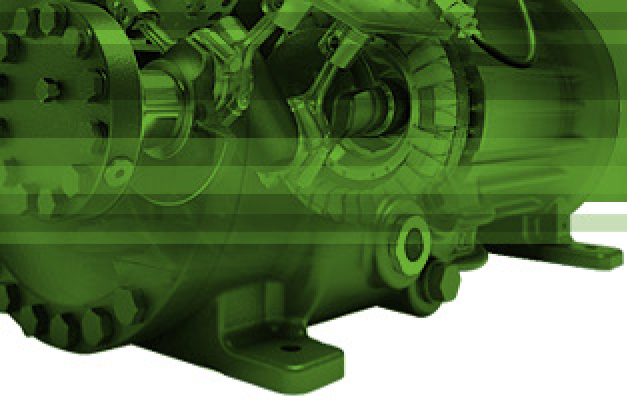


Refrigerants: An Overview

After the commercialization of refrigeration since 1895, various gases have been used as refrigerants. Specific use was decided by a particular refrigerant's performance. It was found that refrigerants with higher masses were capable of carrying more heat, whereas refrigerants of lower mass were easier to compress and required less power to process. CFC's saw extensive applications in the early 1920s, owing to the fact that it's easily compressible and could handle a huge amount of heat.

During the 1970's however, it was discovered that this refrigerant underwent chemical reactions when it came in contact with atmospheric ultraviolet rays. This reaction breaks down the compound's molecular bonds and releases Chlorine, which in turn reacts with atmospheric Ozone molecules (O_3) and breaks them down to Oxygen (O_2) molecules.

The resultant Chlorine is not consumed in the reaction, and so continues damaging the ozone for years to come. After this came to light, governments all over the world signed a treaty to ban the production of CFC. The Montreal protocol was signed to that effect in 1987, heralding a global initiative to phase out the use of CFCs. Later in 1995, the Mobile Air-conditioning industry Systems (MACs) and the stationary refrigeration industry switched to non-ozone depleting refrigerants.

Most cooling systems today use refrigerants based on Hydrochlorofluorocarbon (HCFC) and Hydrofluorocarbon (HFC). These refrigerants are similar to CFCs, with a far reduced impact on the earth's ozone layer. HFC has zero ozone depletion potential. However, these gases contain Fluorine, which has a high Global Warming Potential (GWP). The primary design of a refrigeration system is based on its potential contribution to global warming. Hence even HFCs and HCFCs are to be phased out by 2030.

A new class of fluorocarbon refrigerant called Hydrofluoro-olefin (HFO) has been developed as an alternative to HFCs and HCFCs. The primary advantage apart from its low GWP is that it can be used in existing refrigeration systems. It's still imperative that a low-impact GWP alternative be developed however, a replacement for this fluorinated gas.

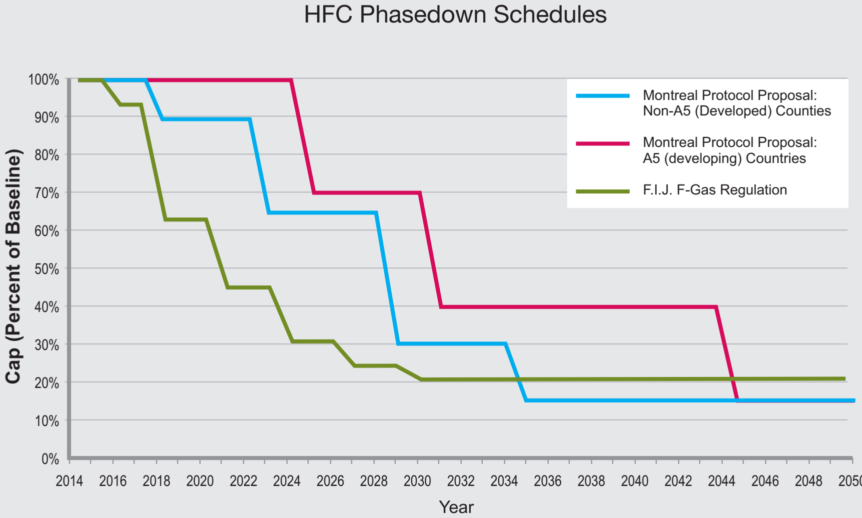
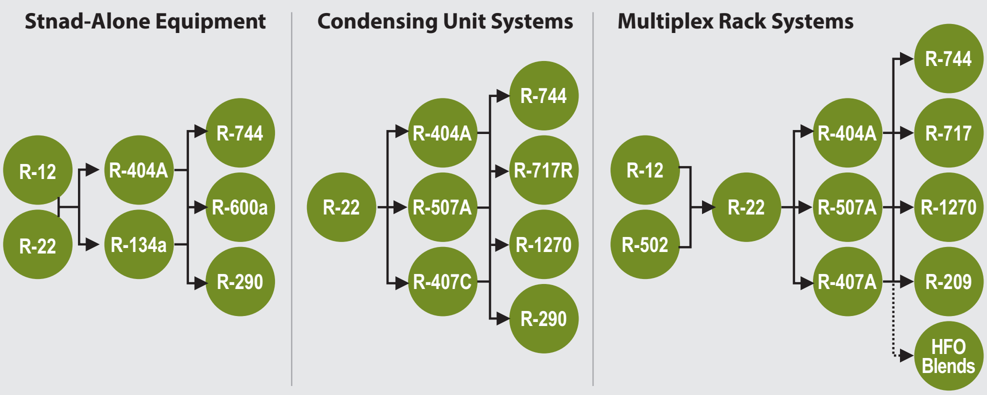


Figure 1.1: HFC phasedown schedules for North American Montreal Protocol proposal and European F-gas regulation.

Alternative Refrigerants To HFCs

Alternatives available today include Hydrocarbons — Isobutane (R-600a), Propane (R-290), and Propylene (R-1270), Ammonia (R-717), and Carbon Dioxide (R-744). Other alternatives such as new HFCs/HFOs are also likely to enter the market in the coming years. The Kyoto Protocol (1997) has shifted environmental focus from Ozone depletion to global warming and the emission of carbon dioxide into atmosphere. In Europe, only refrigerants with GWP lower than 150 are permitted in vehicle air-conditioning systems.

The following diagram and tables list a few low-GWP refrigerants and their various properties.



*Solid arrows represent alternatives already available in the market for these systems; dashed arrows indicate those likely to be available in the future.

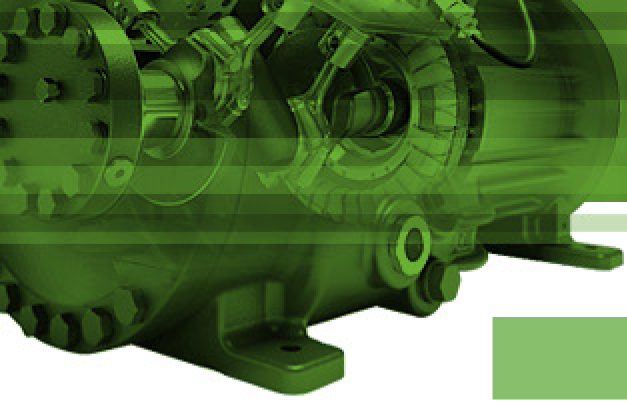
http://energy.gov/sites/prod/files/2014/12/f19/Refrigerants%20Roadmap%20Final%20Report%202014.pdf

https://macsworldwide.wordpress.com/2013/09/20/a-brief-history-of-refrigerant/

Challenges to market entry and potential solutions

Alternative	Challenges To Market Entry	Potential Solutions
Hydrocarbons	Highly flammable Safety code restrictions Liability concerns	Safety devices Standards and service procedures Training and education
R714	Toxic and slightly flammable Building and fire code restrictions	Engineering desig Standard amns safety regulation Revision to existing codes
R744	Safety risks High operating pressure	Engineering desig Training and education
HFO Blends	Market Availability	Research and Development

http://www.epa.gov/ozone/downloads/EPA_HFC_ComRef.pdf

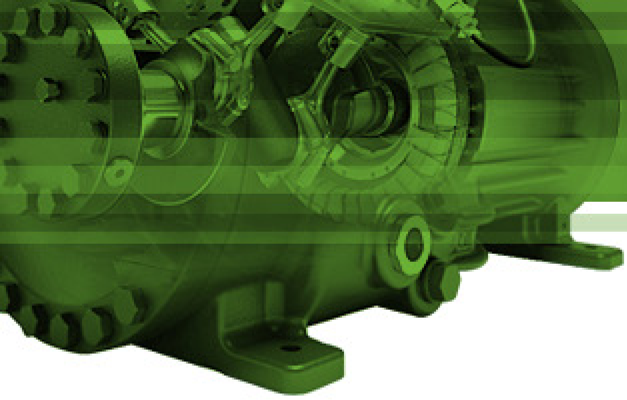


Properties of Low GWP Refrigerants

Property	HFC	Natural			HFO
Refrigerant		HC's	Ammonia	CO_2	1234yf
GWP (100 years)	×× R134a 1300 – R410a 1900	✓ 3-5	✓✓ 0	✓✓ 1	✓ 4
Toxicity	✓✓	✓✓	××	✓	✓✓
Flammability	✓✓	××	×	✓✓	×
Materials	✓	✓	×	✓	✓
Pressure	✓	✓	✓	××	✓
Availability	✓✓	✓	✓	✓	××
Familiarity	✓✓	✓	✓	×	×

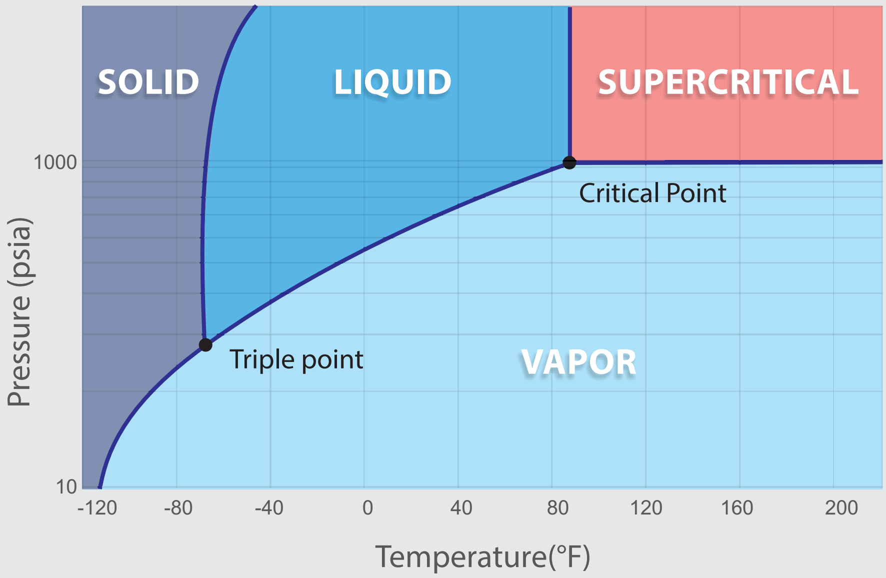
×× Very Poor × Poor ✓ Good ✓✓ Very Good

As evident from the table, hydrocarbons show promise as an alternate refrigerant, with a GWP ranging from 3 to 5. The only downside is that hydrocarbon refrigerants are highly flammable. It has to be handled with extreme care to avoid fire and combustion. Carbon dioxide, with a GWP of 1, is a better alternative to HFCs; albeit falling short in operating pressure limits and familiarity. CO_2 is also non-flammable, and hence, more preferred than hydrocarbons.



CO_2 As A Refrigerant

This phase diagram shows CO_2's critical point, 1067psia (73.56 bar) and 88 degrees F (31.11oc).



Refrigeration systems using CO_2 can be divided into two main processes or cycles:

1 - Subcritical CO_2 Cycle

A subcritical CO_2 cycle refers to a CO_2 refrigeration cycle that takes place above the refrigerant's triple point and below the refrigerant's critical point.

2 - Transcritical Cycle

A transcritical cycle refers to a CO2 refrigeration cycle that spans above the subcritical region and into the supercritical region. It means that its high pressure side is above the critical point.

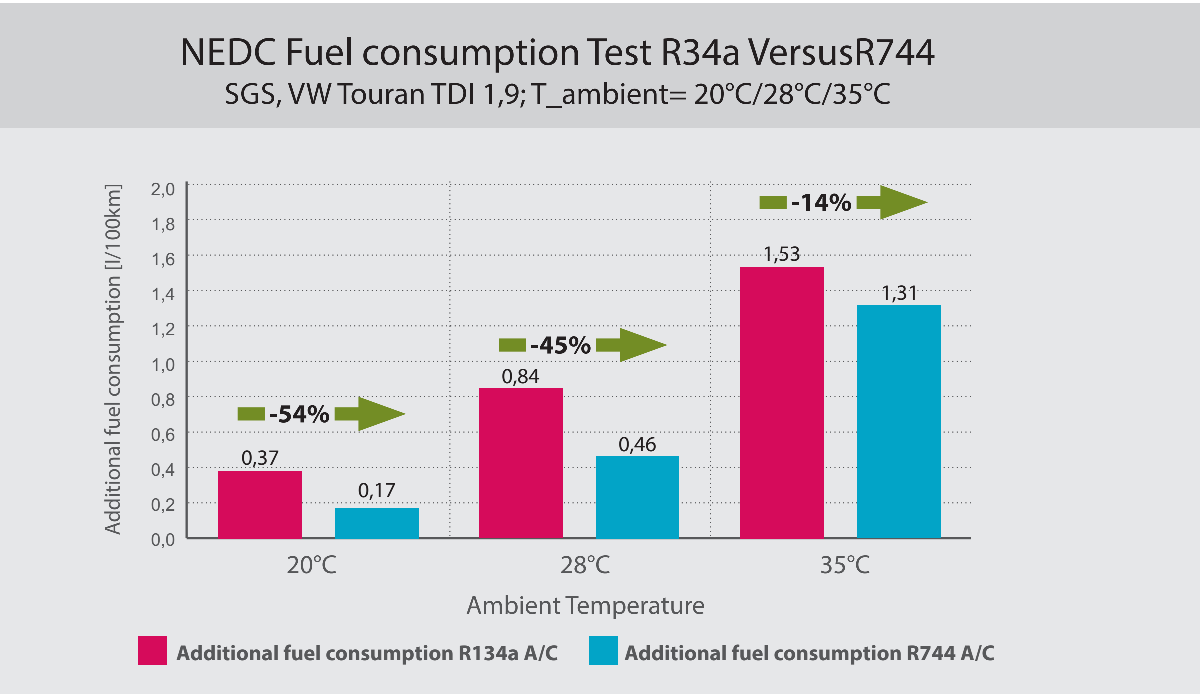
It can be seen that both CO_2 cycles have a high operating pressure. This is a major challenge in using CO_2 as a refrigerant.

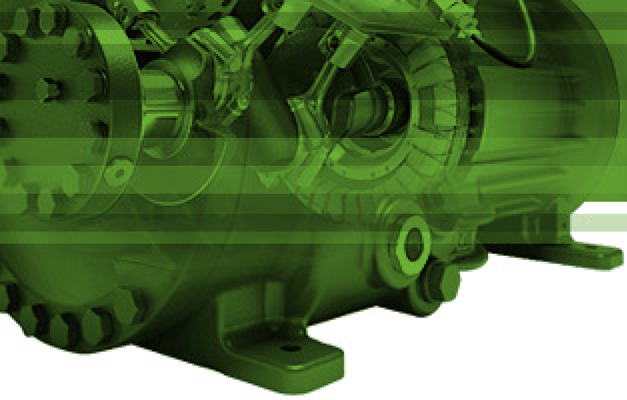
Volkswagen to use CO_2 in air conditioning systems

The Volkswagen Group is continuously working towards sustainability and environmental protection. They are investing about two-thirds of their total investment capital in the development of efficient technologies for drive systems as well as environmentally sustainable production. Moving forward, the group has decided to use CO_2 as a refrigerant for their mobile air-conditioning systems, swapping it for R-1234yf, a compound that was discovered to have flammability issues. In 2012, the whole auto industry in Europe had decided to adopt R-1234yf as its refrigerant of choice.
In September of 2012 however, internal testing carried out by Daimler identified that R-1234yf had safety (flammability) issues under certain conditions. In the discovery's wake, major car makers such as BMW and Volkswagen also followed suit and discontinued use of R-1234yf in their systems. With a GWP value of 1, it is 99.3 per cent below the EU specified GWP limit of 150, an ideal choice for Volkswagen, who decided to use CO_2 in their refrigeration systems.

Fuel consumption tests

Critics of this novel solution have repeatedly claimed that CO_2-based MACs consume more energy than systems with R134a refrigerants. However, experienced MACs developers have demonstrated through tests that CO_2-based systems are, on the contrary, more energy-efficient. A car fitted with CO_2 air conditioning was subjected to measurements on a chassis dynamometer. An R134a system was also subjected to the same test. Under identical conditions the measurements demonstrated that the fuel consumption in a refrigeration system using CO_2 is lower than that of an R-134a air condition system. It was also found that CO_2 refrigeration systems consumed a considerably lower amount of fuel at low ambient temperatures. As the temperature rises, the difference in fuel consumption reduced.
The following graph shows the air conditioning system's fuel consumption in addition to the car's own.





A survey of north European supermarkets by Carrier Commercial Refrigeration found that 65% of respondents had begun to opt for non-HFC refrigerants, with CO_2 the prime choice for 83% of those who had already converted.

Key Players

Danfoss | Carrier | KONVEKTA Technical leadership starts with ideas.

Other applications of CO_2 as a refrigerant

Water Heater Punps

エコキュート ECO CUTE | SANYO | Panasonic | MAYEKAWA

Mobile Air Conditioning

DAIMLER | Volkswagen | BMW

The Future

The political world is bracing itself to decide what’s best for the greater good.

Appeasing numerous constituents at the peril of alienating a small but growing industry is but one of many decisions that need to be ecologically and economically practical. As CO_2 based refrigeration technology grows in both viability and availability, it shows appreciable promise to reduce atmospheric pollution by Ammonia and other often potent greenhouse gases.

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