
EUROPE
ATMO sphere
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natural refrigerants
19 & 20 April, 2016 – Barcelona

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CO_2 MAC (1988-2016), CO_2 transport refrigeration, and magnetic cooling

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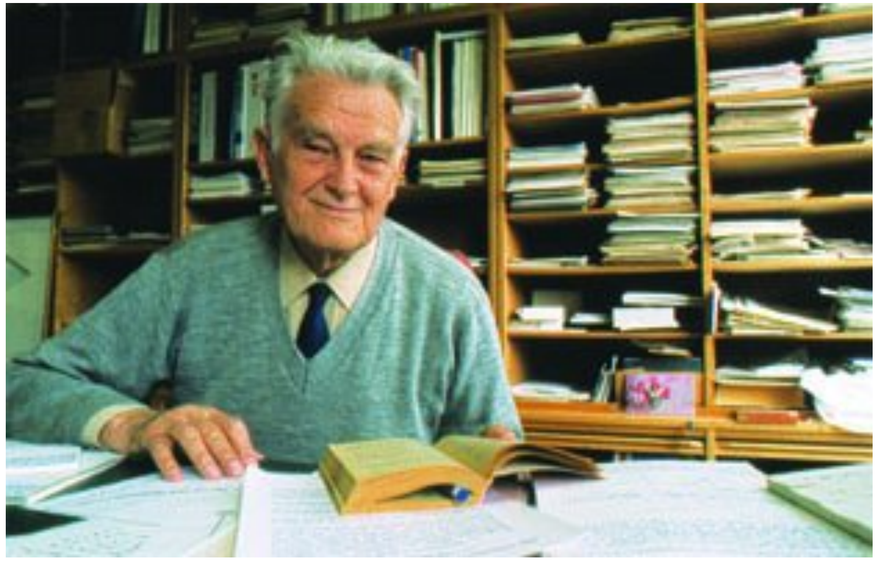
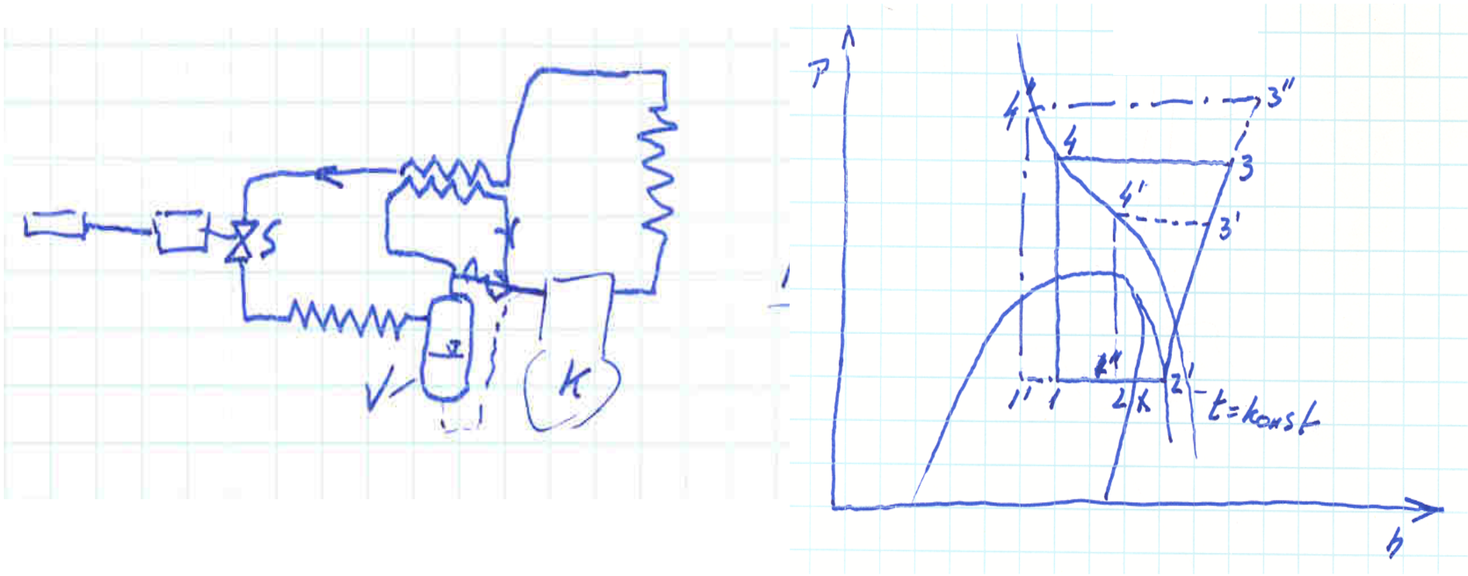
  - ✓ The revival of natural refrigerants
- **Mobile Air Conditioning**
  - ✓ R744 / CO_2 from 1988 → 2016
- **Transport refrigeration options**
  - ✓ Marine
  - ✓ Trains, coaches / bus
  - ✓ Truck&Trailer, containers
- **Magnetic refrigeration**
  - ✓ Challenges
- **Summary / Outlook**

Intro

CO_2 as working fluid – the revival in 1988



Professor Gustav Lorentzen (1915-1995)

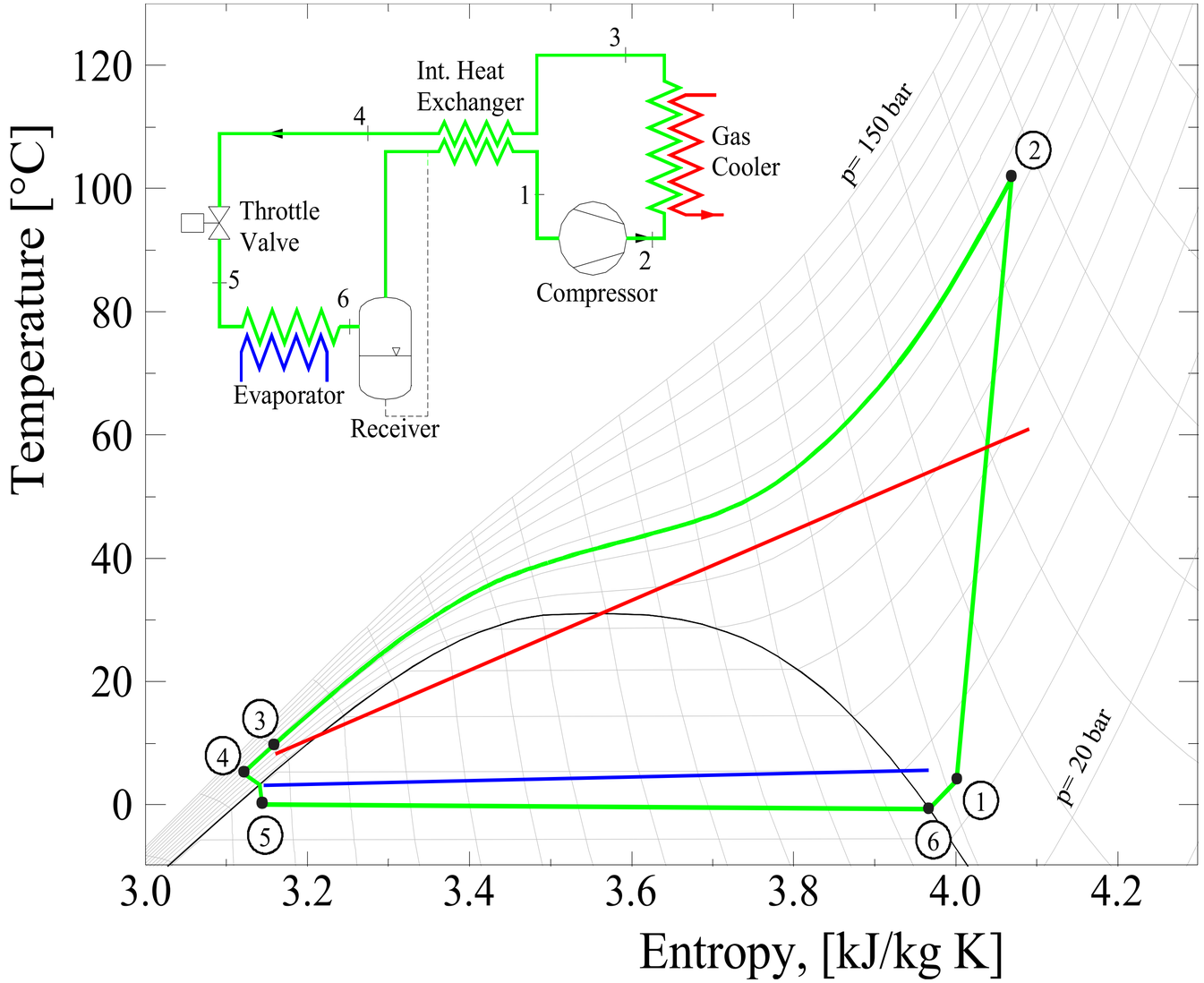


First patent on transcritical CO_2 system in November 1988

The idea was formulated

→ MAC and hot water heat pumps were the first main application areas

Intro



Hot water heatp umps

a perfect application for CO_2

Intro

How could CO_2 refrigeration technology develop?

Despite the massive opposition from the chemical companies.

Start after the Montreal protocol in 1987 → two parties chemical v. natural (old ref.)

<u>Open strategy</u> of the supporters of natural refrigerants:

- ✓ **Choose fluids which are long term environmentally benign (H_2O, air, HC's, NH_3 & CO_2)**
- ✓ **Adapt the components and system architecture (no drop-inn philosophy)**

<u>Support</u> from long-term thinking companies:

Example: Hydro Aluminum; Car-OEM's & TIER1 suppliers,

Key Research projects:

EU funded: RACE (1993-1997);

cohep?Petter….

Meeting platforms:

CDIG, IIR-Gustave Lorentzen Conference

VDA-Wintermeeting

Mobile Air-Conditioning

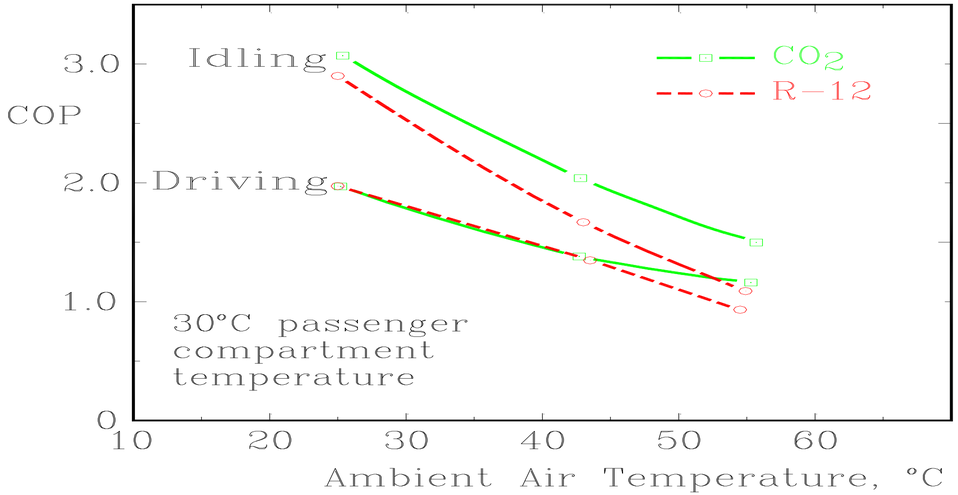
The start: 1989-91 in Trondheim

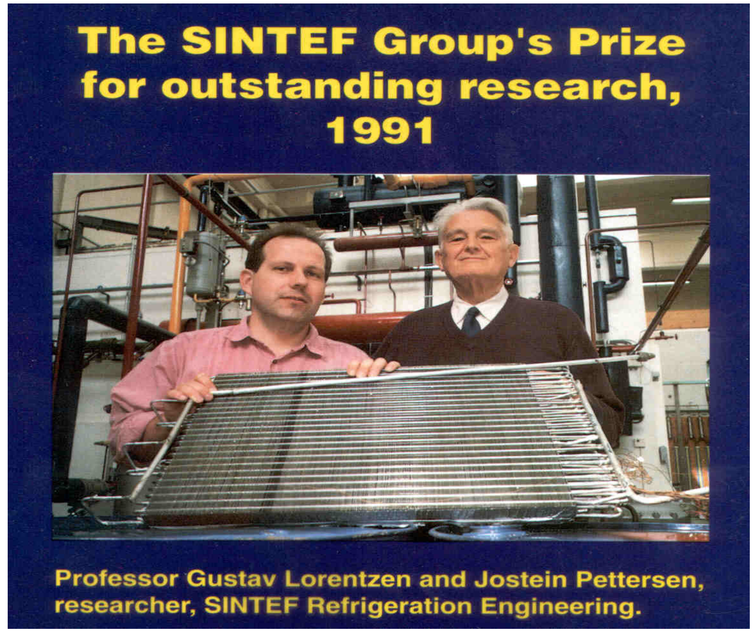
Main issue: Energy efficiency of R744 MAC system

R744 lab. prototype system (left)

BMW 520 CFC-12 system (right)

Measured





18 years ago!

CO_2 MAC in 1998: soon ready…

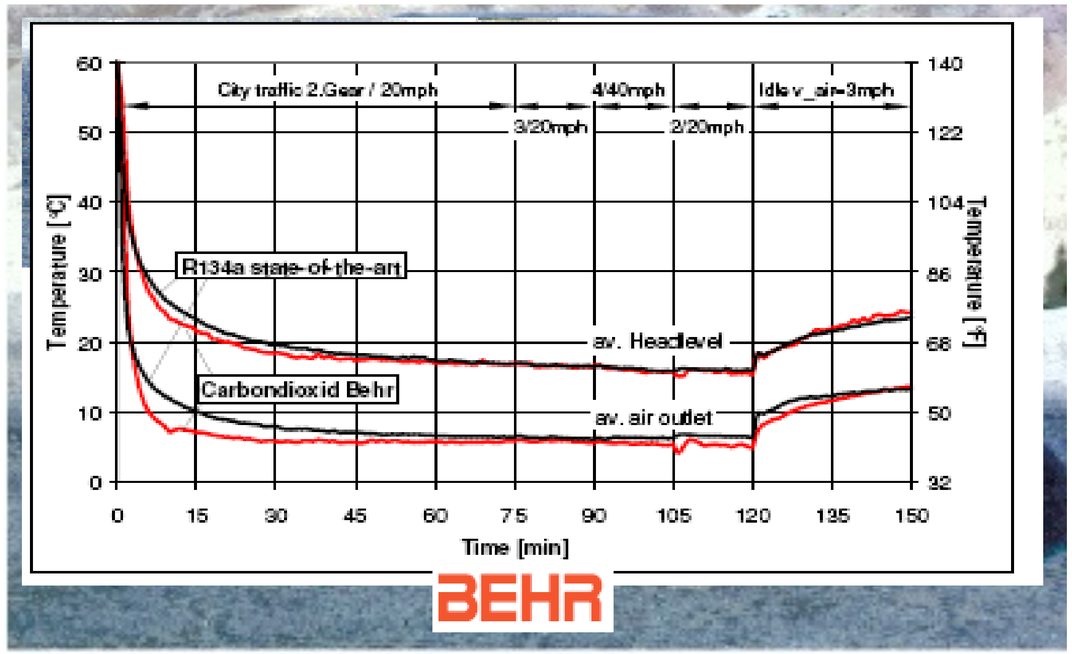
Schwäbische Zeitung 4.April 1998

SCHWÄBISCHE ZEITUNG

Samstag, 4. April 1998 / Nr. 79

Ökologische Klimaanlagen

…the greenhouse gas effect of the car AC system **can be cut by a third** when applying carbon dioxide as a refrigerant



BEHR- Prototype Vehicle with CO_2 – Cycle, Death Valley 1998

http://www.vda-wintermeeting.de/fileadmin/downloads2008/presentations/Christoph_Walter_Behr.pdf

Worlds first CO_2 Car AC system

Made in Japan

JAPAN: Toyota FCEV vehicle will have CO2 air conditioning

21 Jun 2001

Source: just-auto.com editorial team

Toyota's first fuel cell electric vehicle (FCEV) model will include the latest weight reducti and carbon dioxide air conditioning technology when introduced in 2003. And as much the new technology as possible will also be shared with conventional petrol models.

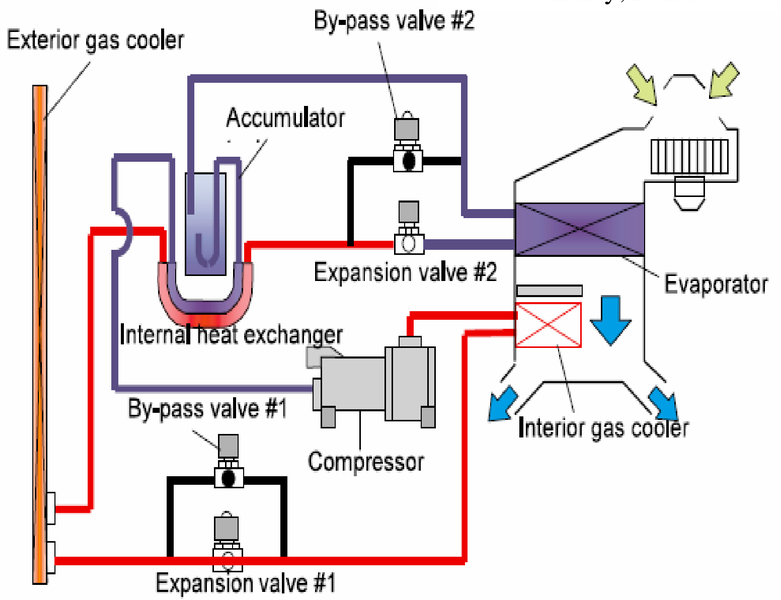
The fuel cell vehicle will have secondary batteries and be built on the same front wheel drive platform as the Toyota Windom (Lexus ES300) and Kluger models sold in Japan. will sell for less than 10 million yen (about $US81,000).

The FCEV will also feature hydrogen fuel tank efficiency improved enough for a petrol-comparable driving range of 300 miles (500km), twice as much as current prototypes.

Toyota has also promised to unveil an air conditioning system jointly developed with its Denso subsidiary that uses carbon dioxide and is 25 per cent more efficient than those currently using CFC replacements such as HFC134A.

Japanese sources say that the 2003 FCEV will be a flagship model attracting a lot of attention, hence the emphasis on its environment-friendliness.

Courtesy, Denso

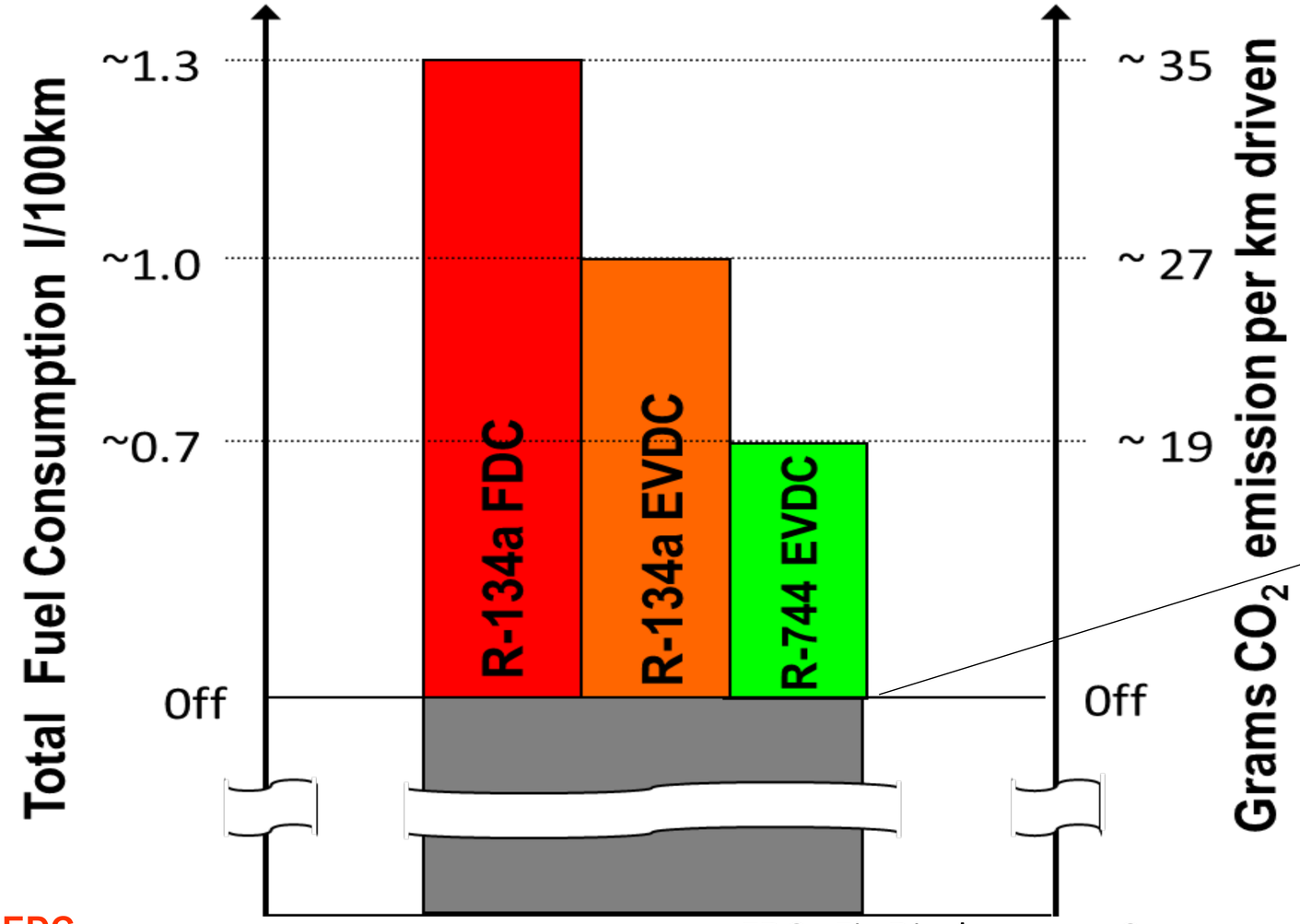


And even with a heat pump option!

DENSO

Source: CO_2 Air Conditioning System - page 6
Tokyo Motor Show 2003

10 years ago: CO_2 MAC: 30% lower fuel consumption



Off line for 2008 average

Fuel consumption due to drag torque, according to 99 / 100 7 EG

Total l/100km: 5,8

CO_2-Emission: 156 g/km

Values without A/C

R-134a with EVDC

+ 0,1l/100km (off mode)

R-744 with EVDC

+ 0,05l/100km (off mode)

NEDC

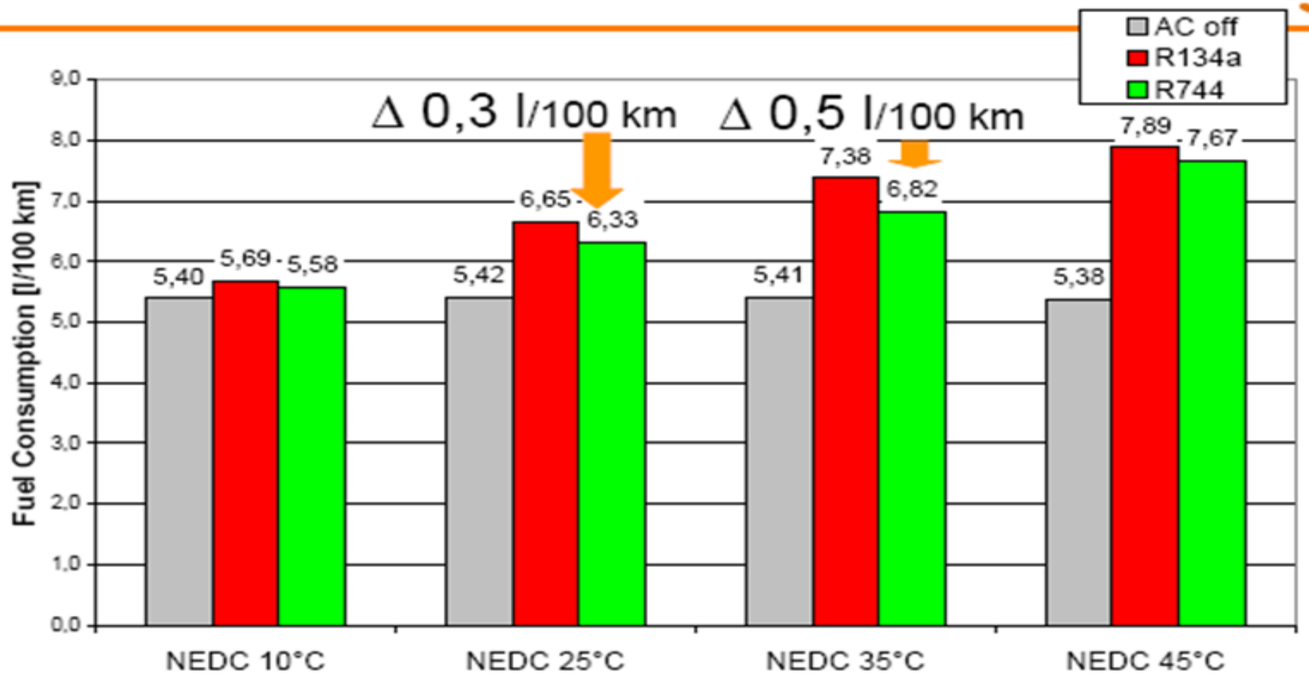
Ambient conditions: 25ºC @ 50% RH
no sun load; Mode: fresh air

FDC - Fix Displacement Compressor

EVDC- Externally controlled Variable Displacement Compressor

Test Results: Fuel Consumption

Visteon



- Engine 3 cylinders, 1,0 l, 51 kW
- Test vehicle with 15.000 km
- TXV system
- Compressor with external control valve (90 cc)

⇒ Significant, absolut fuel reduction of 0,3 and 0,5 l/100 km at ambient temperature of 25°C and 35°C for R744

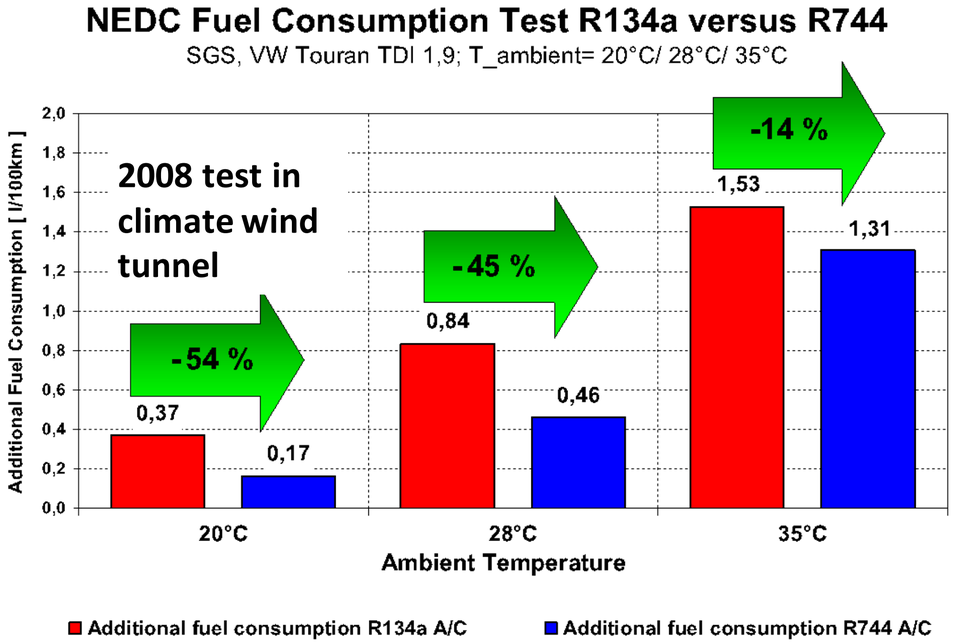
⇒ Add on fuel reduction of 25 % at 25°C and 35°C of R744 in comparison to R134a

Fuel consumption of a Toyota Yaris (MY 2006) with different mobile AC systems when driving a NEDC at various ambient temperatures,

VDA Alternate Refrigerant Winter Meeting 2007, Saalfelden, Austria.

Long term test of CO_2 (R744) MAC in UBA car

May 2009 - April 2015
operation with R744 MAC in daily use over 165.000 km (CO_2) MAC -->
R744-compressor fully functionable and tight



Since May 2015 new long term operation test (planned 1 year) with a new designed mechanical driven R744 – compressor meeting the changed space requirements of car producers
--> April 2016: MAC operation o.k.

-> 2020 ?

Ref: www.daimler.com

“Stuttgart – In order to comply with the legal provisions going into effect in 2017, Mercedes-Benz will equip its vehicles with air conditioning systems that meet all the relevant performance and safety requirements. The Stuttgart-based automobile manufacturer will exceed the EU's climate protection requirements. **From 2017, it will offer in Europe the S- and E-Class as the first production passenger cars equipped with CO_2 air conditioning systems**. ….”

https://www.daimler.com/documents/investors/nachrichten/kapitalmarktmeldungen/daimler-ir-release-en-20151020.pdf

Transport refrigeration vapour compression cycles

Containers

» Leading Danish container handling company -> R290

» *Carrier* has developed R744 refrigeration units placed inside several containers in service.

Application area with a high potential to PHASE-IN natural refrigerants globally.

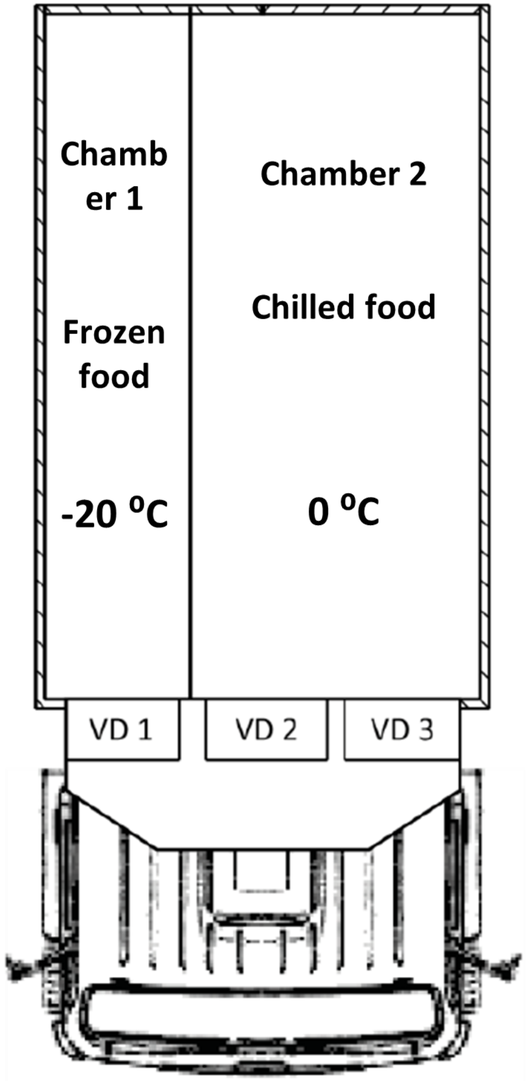
Truck & Trailer units

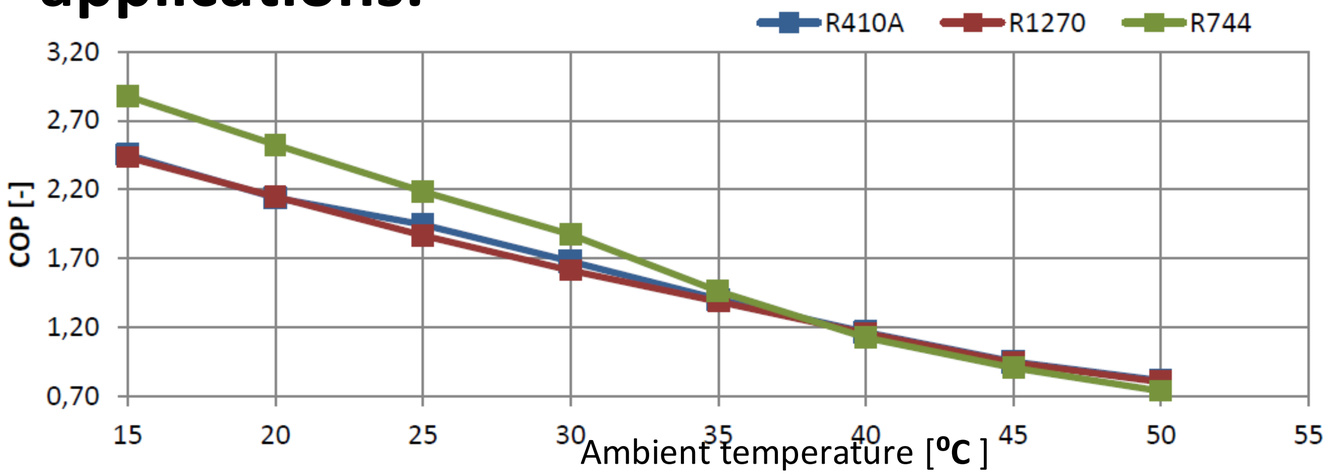
Similar challenges and possibilities as with the container unit.

» *Konvekta* has roof-mounted R744 refrigeration units for transport vehicles.

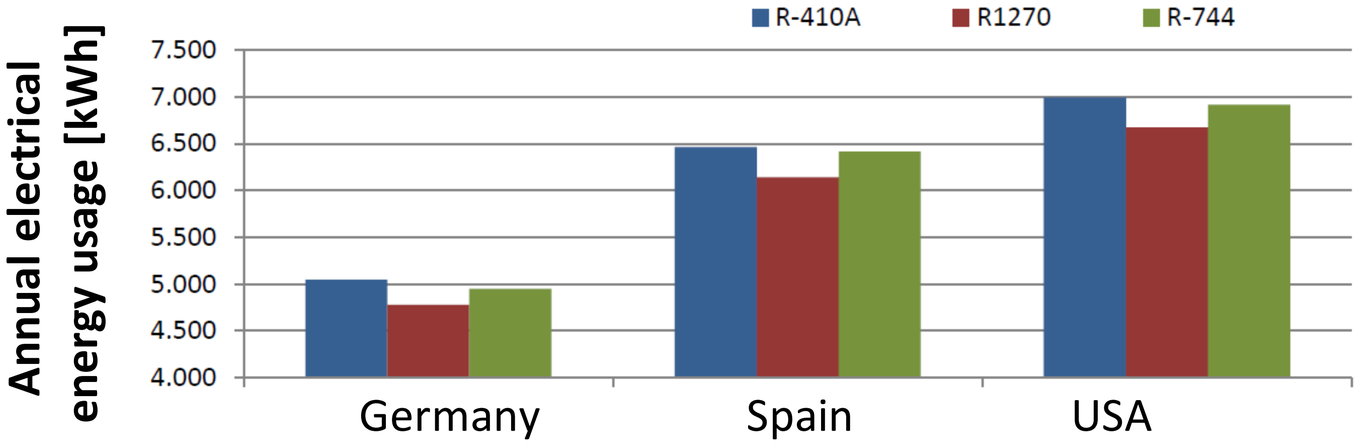
Transport refrigeration

Two stage refrigeration cycles for medium- and low temperature applications.





COP Comparison of Temperature inside the freezing chamber -20 °C at 8 kW and inside the chilled food chamber 0 °C at 6.5 kW



Ref.: Möhlenkamp et al. Proceeding of the DKV Meeting 2014

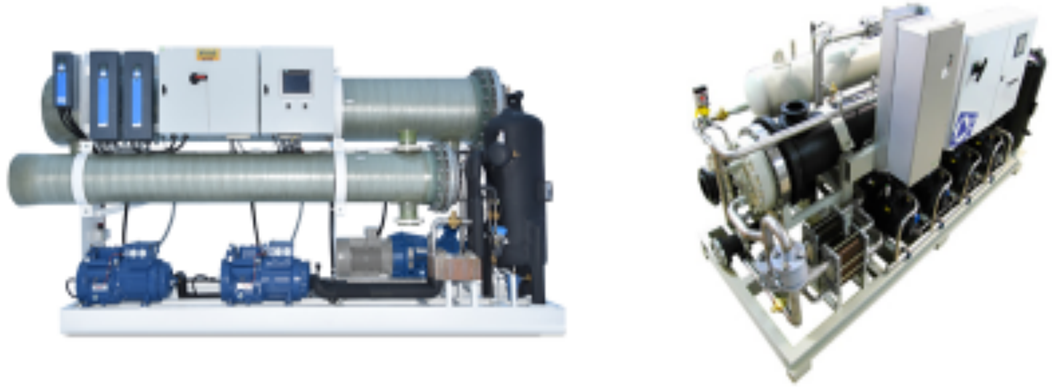
Premium quality fish from R744 equipped vessels

SUMMARY R744 (CO_2) IN MARIN APPLICATION

- deep-freezing time is reduced by 25%
- requires less space onboard
  - + allows to apply smaller tubes / piping
  - + approx. 20% less space for the unit
  - + less freezers required for same freezing capacity
- CO_2 plate freezers achieve better food quality
- in general: service & maintenance becomes better and more easy

KULDE TEKNISK

OTHER CO_2 UNITS FOR FISHING BOATS



Refrigerated Sea Water UNIT

One Vessel equipped with CO_2 – RSW unit was in operation around the Canarian Islands and is now outside Mauretania !

HVAC units for public transport vehicles

Busses / Coaches

» Similar challenges as MAC

» Konvekta developed R744 operated Air Conditioning units for busses since 1997

If MAC goes R744 -> buss AC will follow…

Trains

» Up to **30 % of their total energy consumption** has to be spent to operate the HVAC units of the passenger trains in Germany. (Ref. DB)

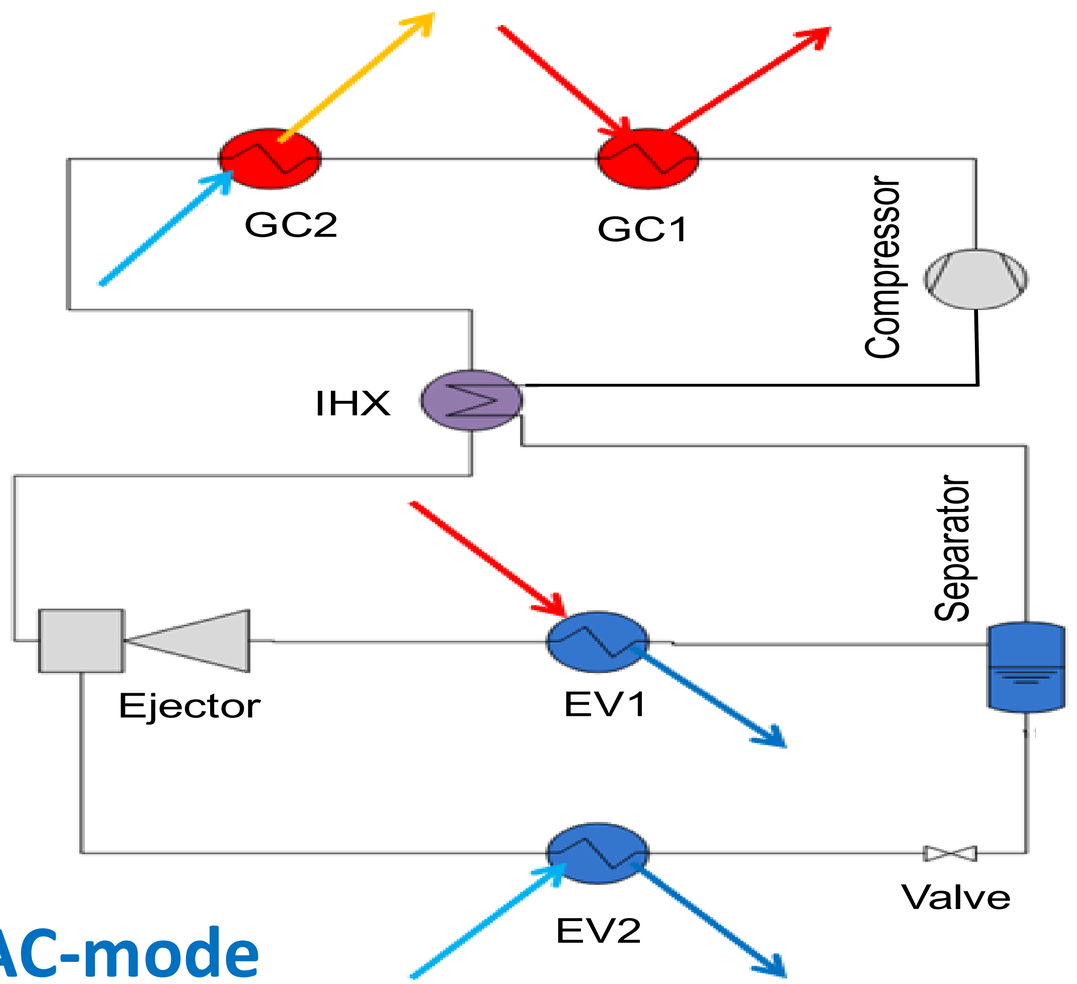
Currently still applied:

Transport AC (train, airplane, etc.)

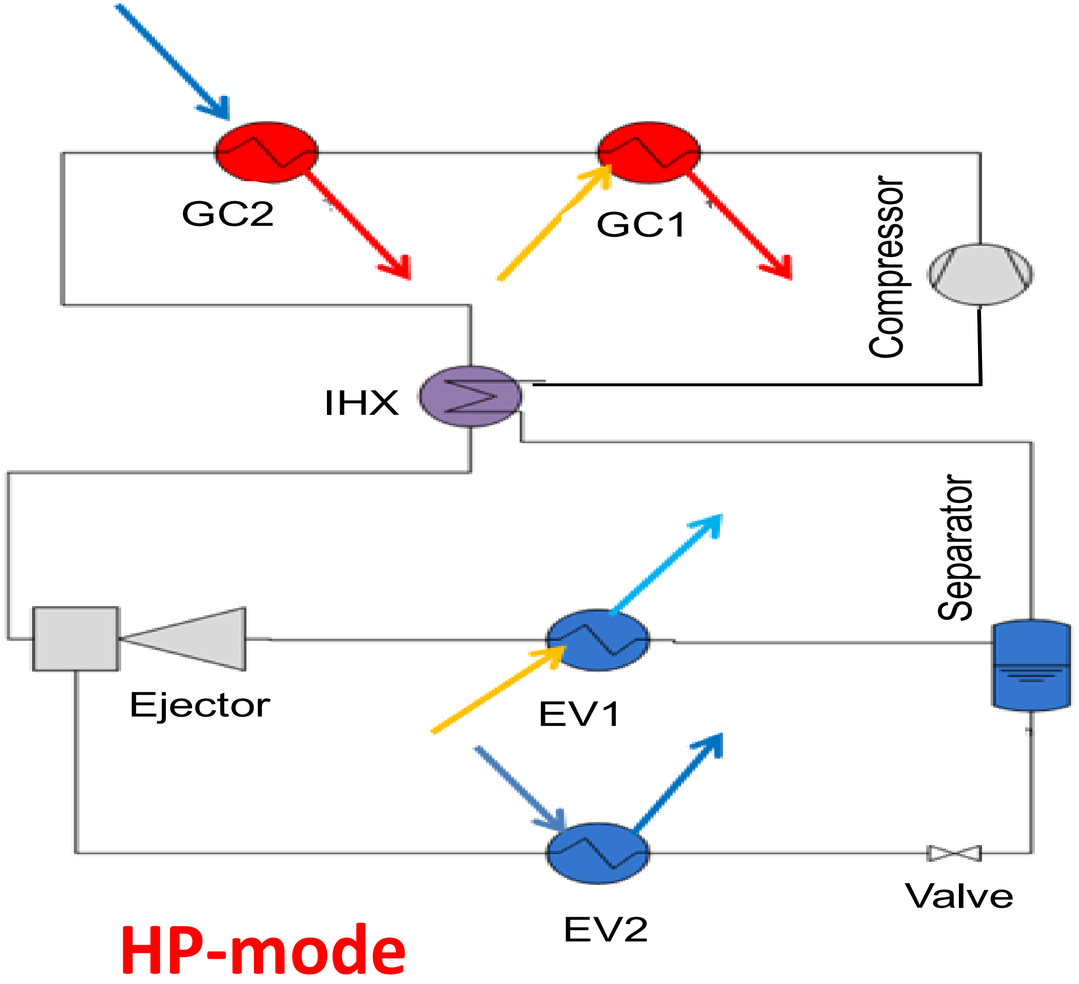
From www.liebherr.com

High performance <u>turbo compressor / expander technology</u> required to achieve acceptable energy efficiency

R744 HVAC units for public transport vehicles



AC-mode

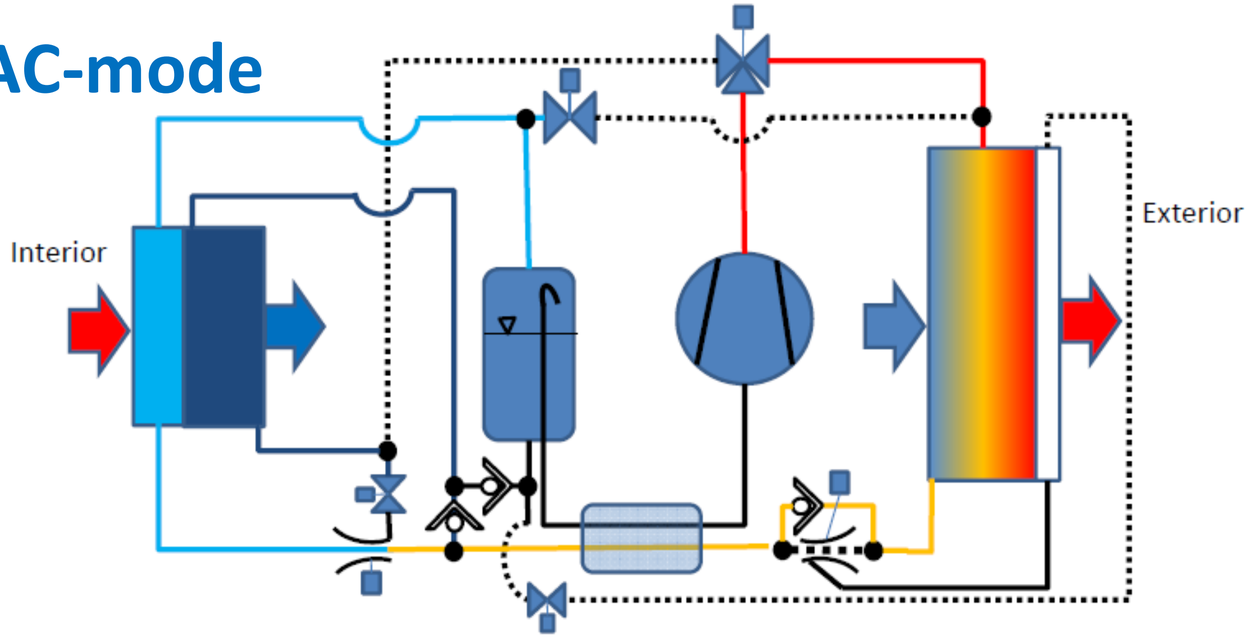


HP-mode

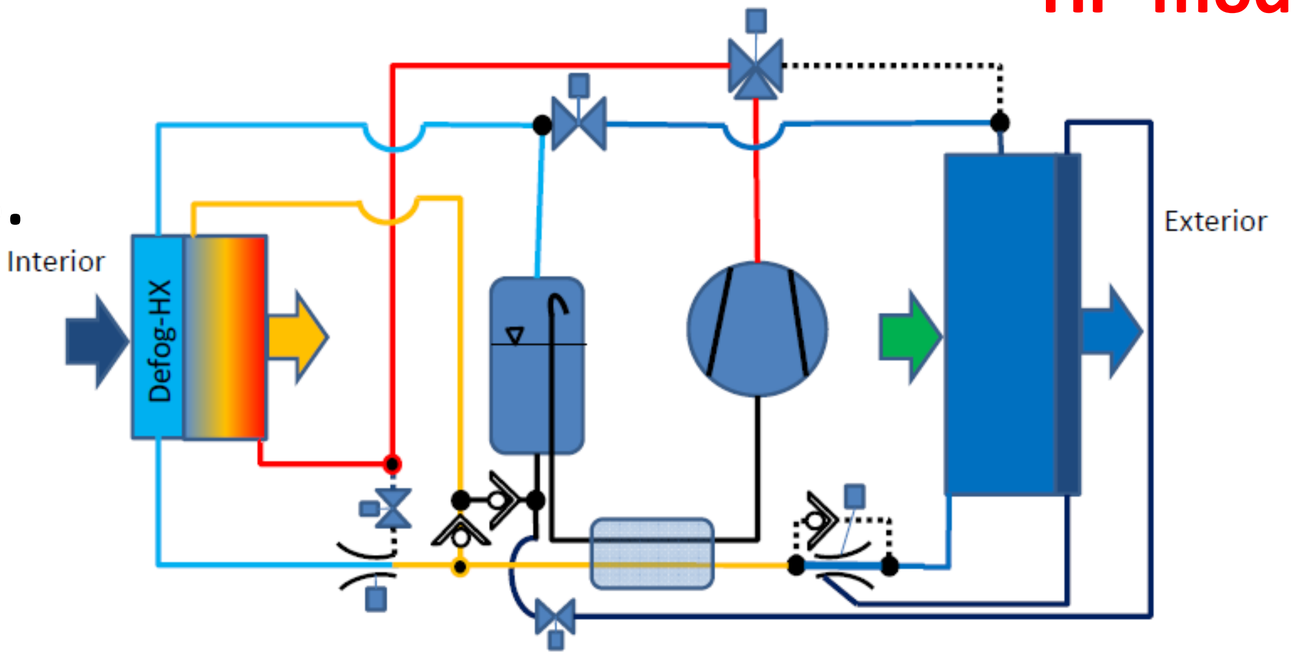
Potential R744 train HVAC unit:

Including fixed nozzle ejectors: Boosting performance at high ambient temperatures.

AC-mode



HP-mode



Transport refrigeration

» Refrigerated transport of valuable food needs sustainable refrigeration technology to preserve the food and limit the environmental footprint.

- Fishing vessels (HCFC 22 → R 744)
- Road transport (HFC xxx → R 744 or HC)
- Containers (HFC xxx → R 744 or HC)

» Public transport:

- Train (HFC xxx -> R 744 or air)
- Cars - MAC (HFC 134a & HFC 123xxxx -> R 744)

Alternative technologies:

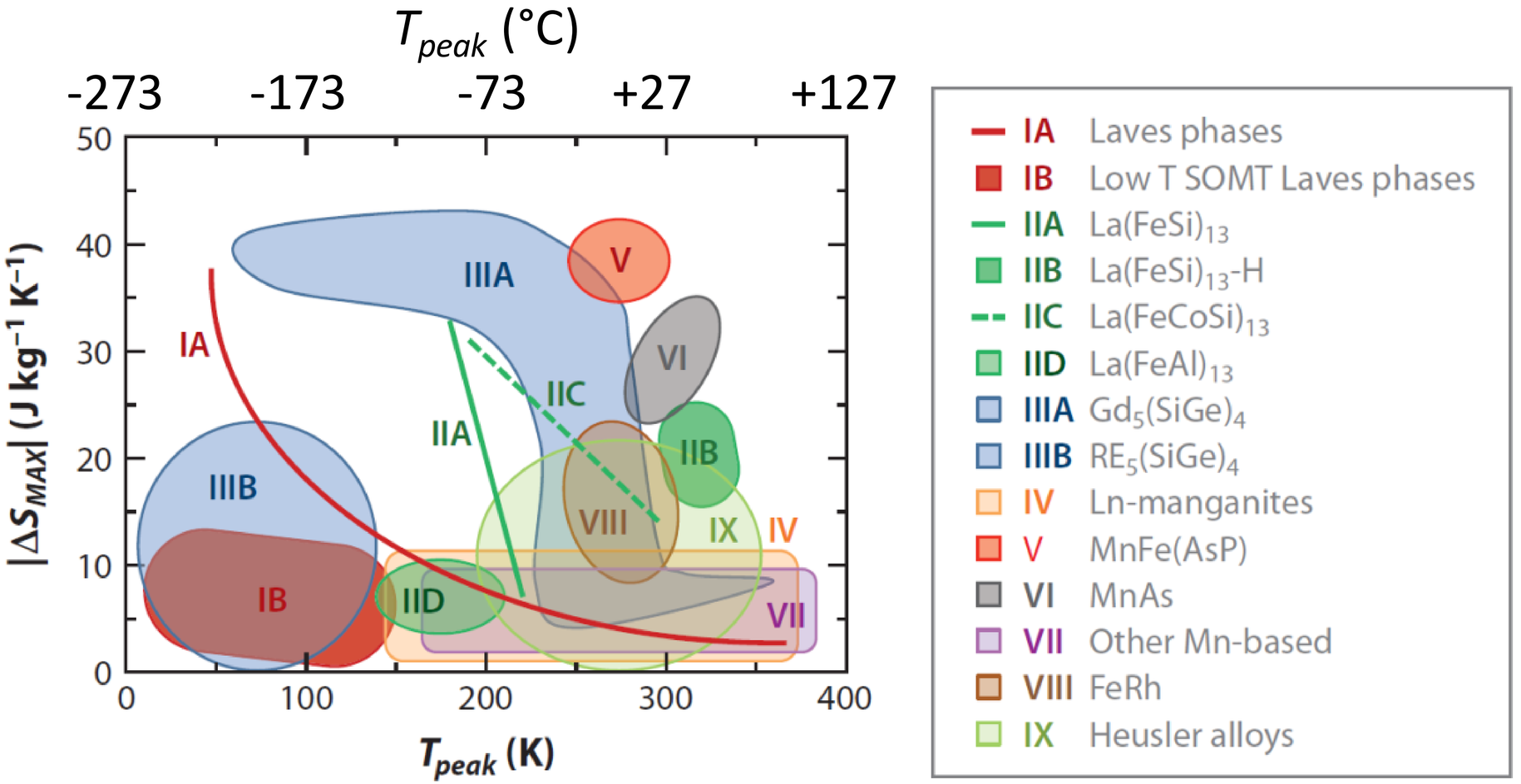
(non vapour compression)

- Technologies successfully applied in other applications e.g. Cryogenic, in spaceshuttles, etc.
- Often theoretical comparisons

  - Not looking into required heat transfer parameters

- Hypes supported by a small enthusiastic community and others *(not)* understanding that this prolongs current turnover…

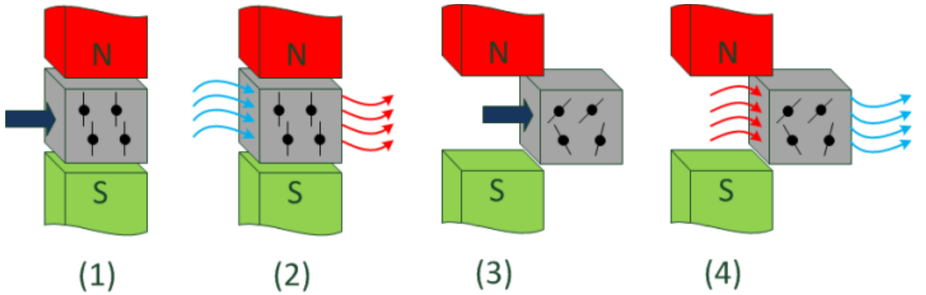
Magnetic cooling: potential materials

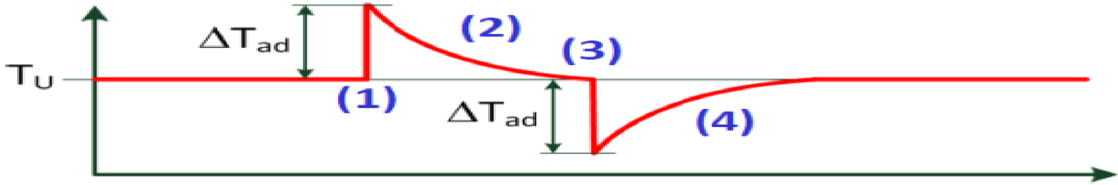


Source: Franco et al.: The Magnetocaloric Effect and Magnetic Refrigeration Near Room Temperature: Materials and Models (2012)

Magnetic cooling:

- Based on magnetocaloric effect (MCE)
- Reversible temperature change when magnetic field is applied adiabatically
- MCE peaks around Curie temperature of the alloy
- max Δt ~ 3 K <u>@ min capacity</u>
  - need to adapt the alloy property





Basic requirements:

- Suitable alloy
- Strong magnetic field

Magnetic cooling; lets find answers to the following questions:

Required cooling capacity is never constant: typically Q_o = 10% to 100%

- Thermal resistance of the magnetic cooling unit?
- Temperature level of the (cold and) hot side may vary at different locations
  - Does it require regenerator with different material configurations to achieve large temperature lifts?
  - Effect of change in temperature gradient?
  - Off design operation?
- Complexity of the unit → relative cost when produced I large quantities?
- Customer acceptance: Strong magnetic field (pacemaker?)
- Benefit in market areas, where hydrocarbons and other natural working fluids are established?

Summary / conclusions / outlook (CO_2 - R744)

- Tremendous development of CO_2 technology since 1988
- Energy efficient CO_2 systems have been introduced in the market
- Adapted ejector technology offer high system performances and COP's, even at high ambient
- CO_2 is a viable natural refrigerant PHASE-IN candidate for many applications, globally

Lets get some answers form the experts in Magnetic cooling now.

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Thank you very much!