CO_2 (R744) Systems Technology Update

Speaker:

Armin Hafner	SINTEF/NTNU	Norway
Stephen Memory	Modine	USA

Group members:

Dieter Heinle	Behr	Germany
Kjell Stenstadvold	Hydro	Norway
Michael Sonnekalb	Konvekta	Germany
Willi Parsch	LuK	Germany
Frank Wolf	Obrist Engineering	Austria
Christoph Petitjean	Valeo	France
Jörn Fröhling	Visteon	Germany
Jürgen Köhler	TU Braunschweig	Germany
Pega Hrnjak	University of Illinois	USA
John Manzione	US Army	USA

The speaker speaks for the group.
All 12 group members have achieved a consensus.

Contents

- What is CO_2?
- Who is doing CO_2 development today ?
- Advantages
- Risk assessment
- Service assessment
- Cost
- Timing/ Feasibility
- Technical Summary
- Conclusion
- Discussion

MAC Refrigerants – A Short History

Refrigerant	R12	R134a	R152a	R744 / CO_2
Natural ?	No	No	No	Yes
Flammable ?	No	No	Yes	No
Combustion Product		Toxic	Toxic	-
Relative Price, %	-	100	> 100	3
Volum. Capacity	0.9	(1)	0.9	6.9
Critical Temp. °C (°F)	112 (234)	101(214)	113(236)	31(88)
ODP	1.0	0	0	0
Pres. at 21°C in bar (70°F) (psia)	5.9 (85)	5.9 (86)	5.3 (77)	59 (852)
GWP (100yr)	7100	1300	140	(1)
	Ozone Depletion 1990	Global Warming 2011		

CO_2: Pros and Cons

Pros

- Non-flammable, non-toxic, 'natural' (GWP = 1)
- Lowest LCCP for any climate (direct/indirect)
- Low (neglible) refrigerant cost with global availability
- High volumetric capacity (miniaturization, compact)
- No recovery or recycling required (developing countries)
- Heat pump capability (diesel, hybrid & fuel cell)
- Waste product of the chemical industry

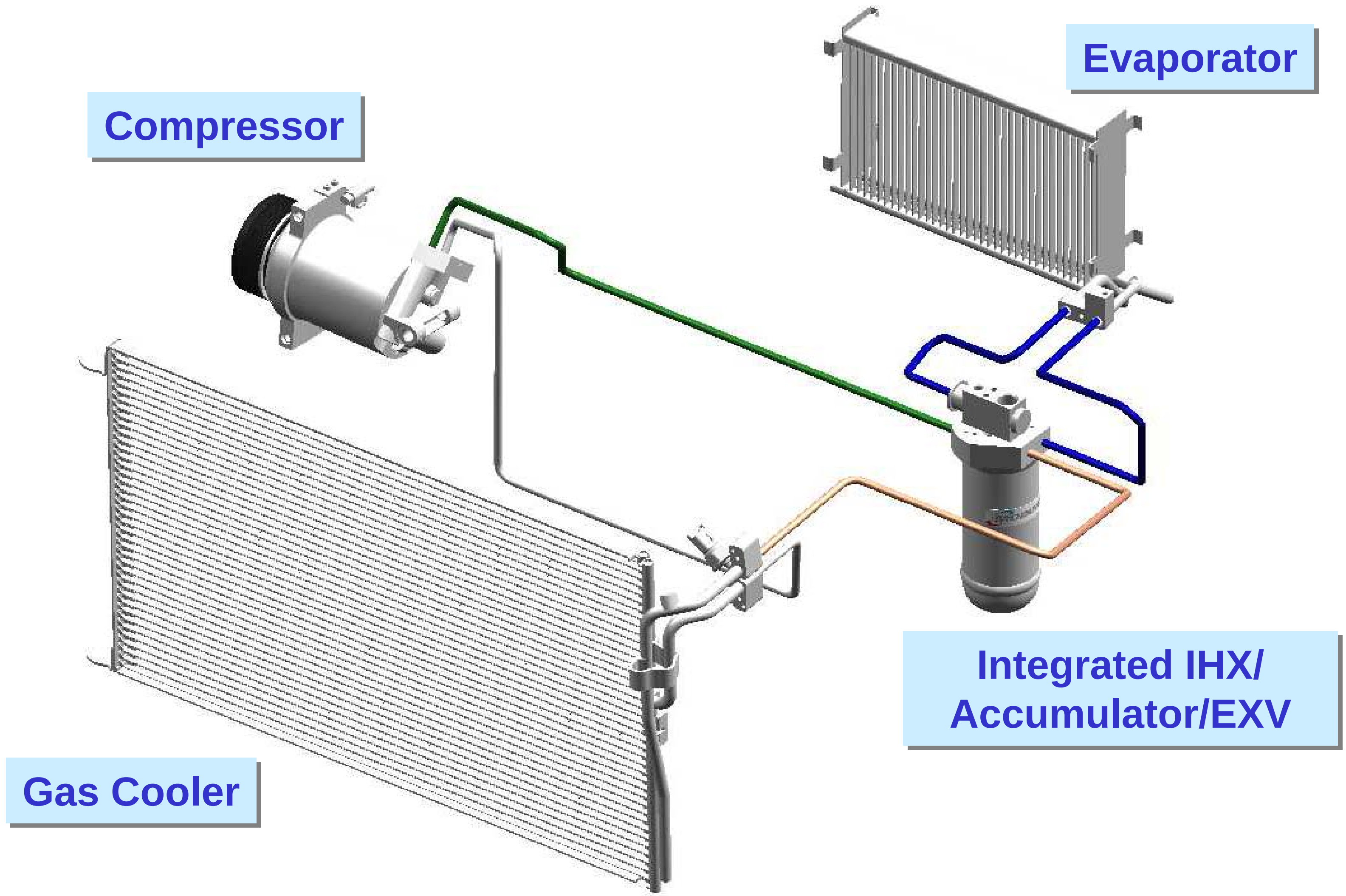
Cons/Potential Barriers

- Highest cost initially
- Training of service personal
- Safety issues (pressure level, 'asphyxiation')
- Some technical hurdles still remain

Who is doing CO_2 – R744 development today ?

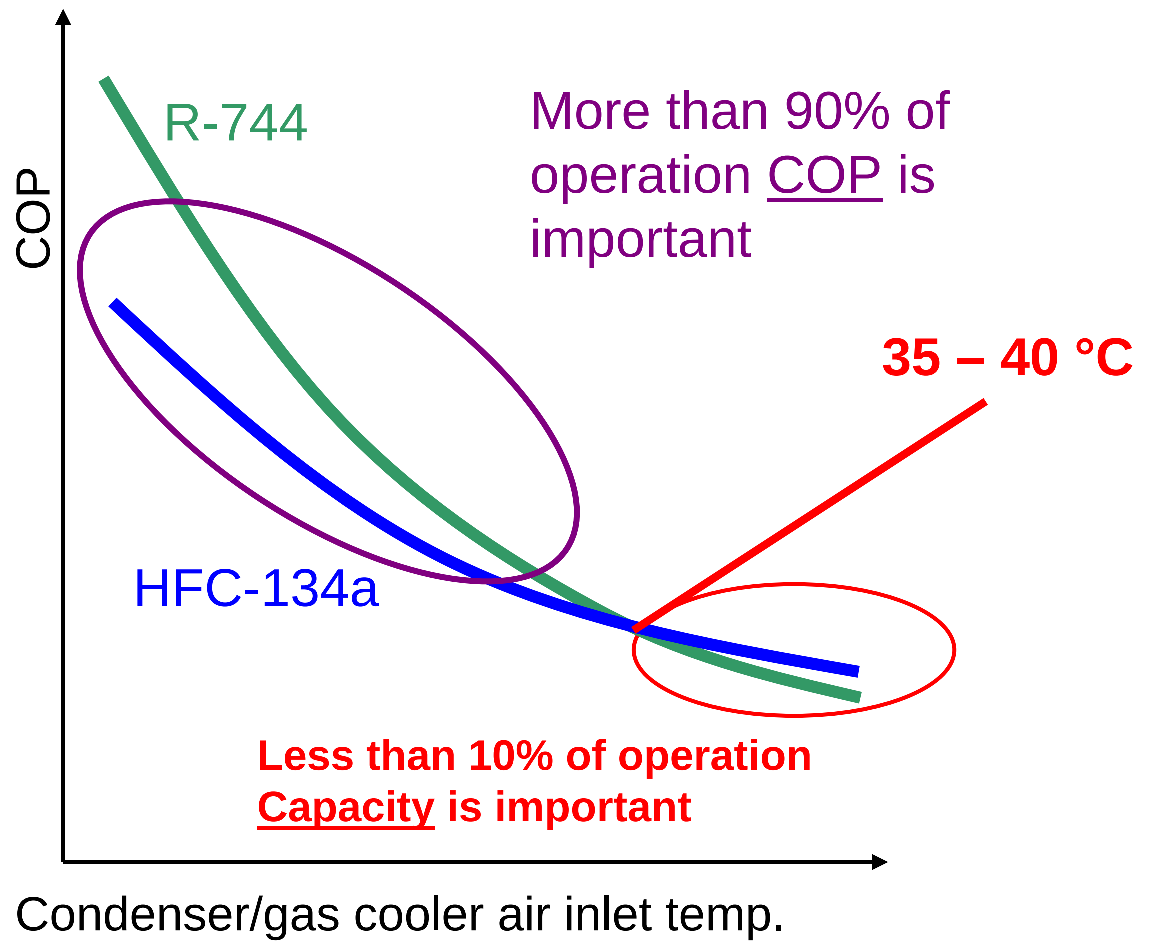
- **Most car manufacturers in Europe, Korea, Japan and the US**
- **All system and component suppliers (Prototypes > 5 years)**
- **Institutes and universities all over the world**
- **Related industries are either developing or are already in production with CO_2**
  - **Residential / commercial hot water systems**
    - commercialized in Japan in 2001
    - sales of ~100.000 units/year in 2004
  - **Commercial and industrial refrigeration (stationary, supermarkets)**
  - **US Army is developing in both stationary and wheeled vehicles**
  - **Helicopter and airplane air conditioning and refrigeration**
  - **Transport refrigeration**
  - **Vending machine cooling (extensive field tests)**
  - **Bus air conditioning has been running field tests since 1997**

CO_2 AC System



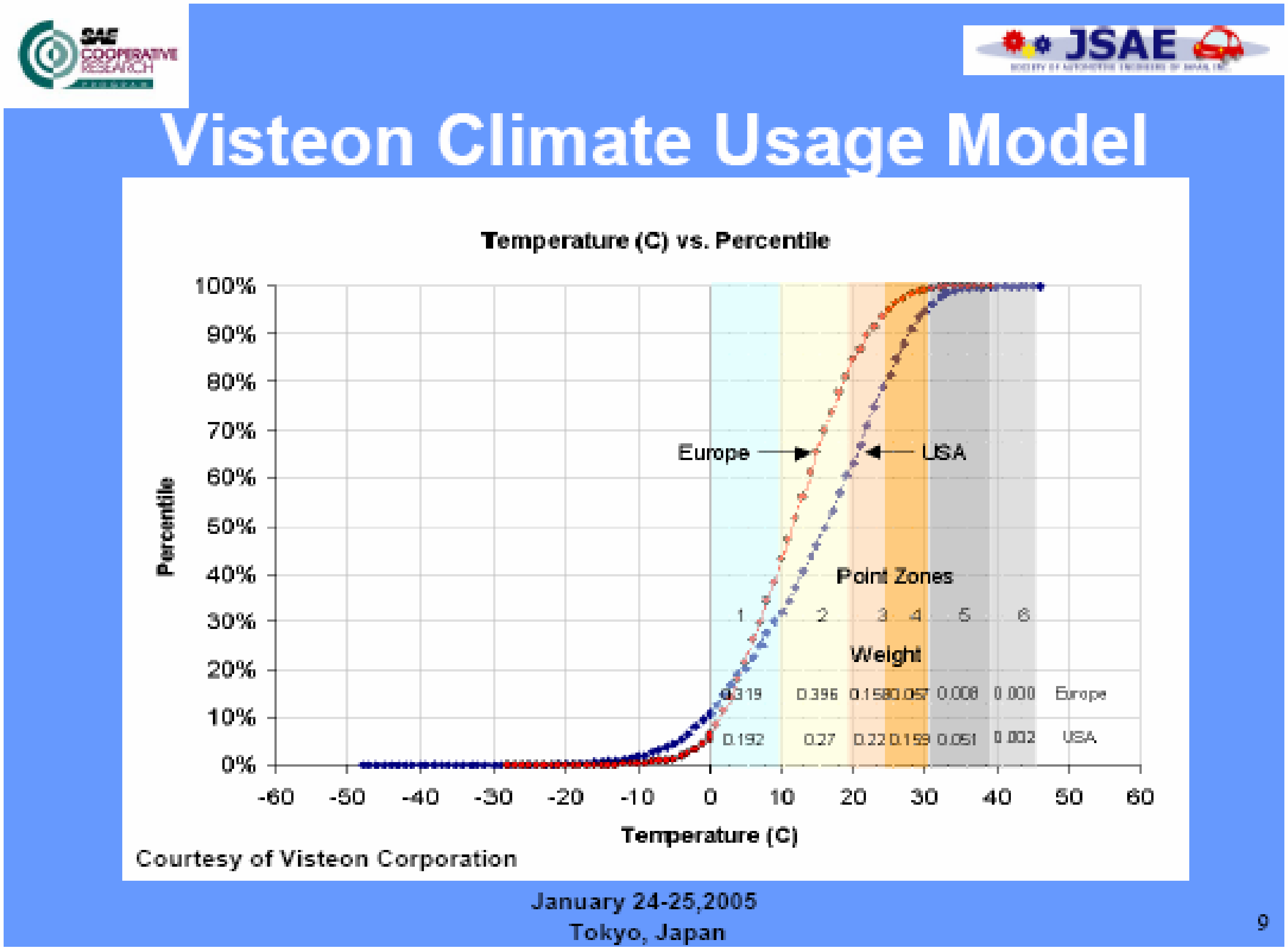
Typical MAC efficiencies

Efficiencies at varying condenser/gascooler air inlet temperature



Climate conditions

California Air Resources Board



The outcome of this climate model is that for Europe only 0,7 % of the vehicle usage is at temperatures above 30°C and less than 0,01 % are above 40°C

ARCRP II results: Indirect Emissions

SAE Alternate Refrigerant Cooperative Research Program

Phase II Simulation results for energy

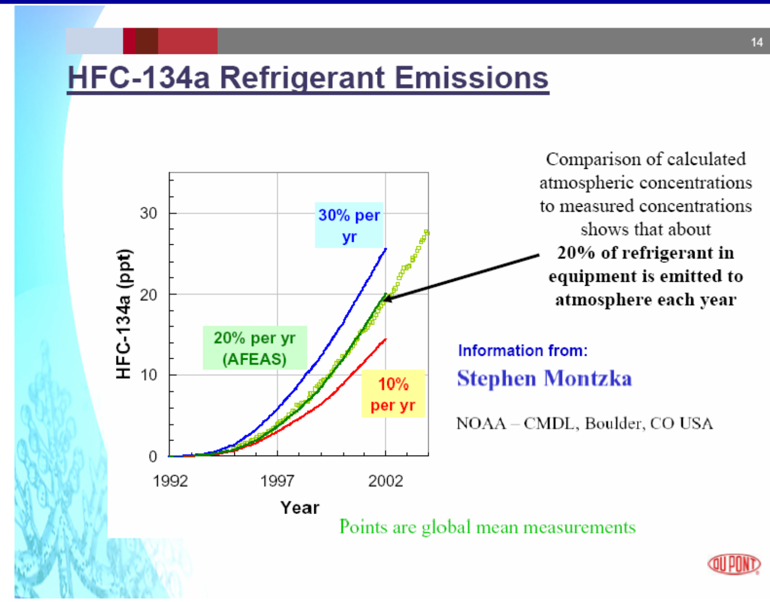
Vehicle	Mid – size	Full Size
Drive cycle	NEDC	US FTP 75
Cycle duration	1180 sec.	2138
System Demand	Energy/ cycle [kJ]	Energy/ cycle [kJ]
R 134a	Base	Base
R 152a	-3%	-7%
R 744* *Optimized Refrigerant Controls	-11%	-9%

Based on analysis of the accuracy and repeatability of the data, it is estimated that these values are within +/- 6%.

Emissions Impact

Direct Emissions (Leakage)

- CO_2 (R744) has <u>NO</u> direct emission.
- ARB: A/C Specific Allowance of
  - ✓ 9 grams/mile CO_2 equiv.



Indirect Emissions (Fuel Consumption)

- Reduction of the total annual fuel consumption confirmed by investigations on test benches and cars
- Most complete is the SAE CRP study at UIUC (see ARCRP Results slide)
- Efficient system design components and air treatment
  - 9 grams/mile CO_2 equiv.

⇒ **Based on ARB, possible to reduce vehicular emissions by 18 grams/mile CO_2 equivalent by using a R744 AC system**

⇒ **Equal to <u>19%</u> of 93gr/mile ARB target (Global ARB target of -30%)**

What are the <u>main advantages</u> of using R744 instead of HFC-134a?

System Mass and Packaging

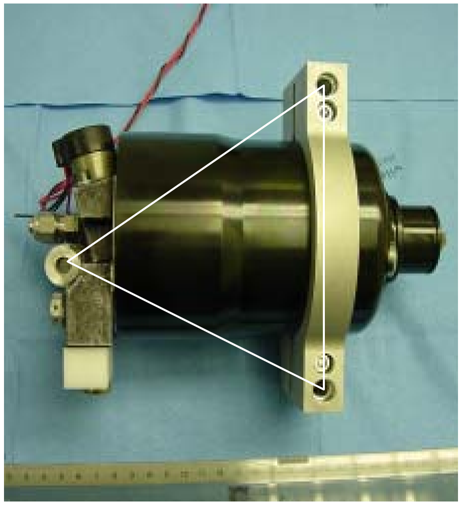
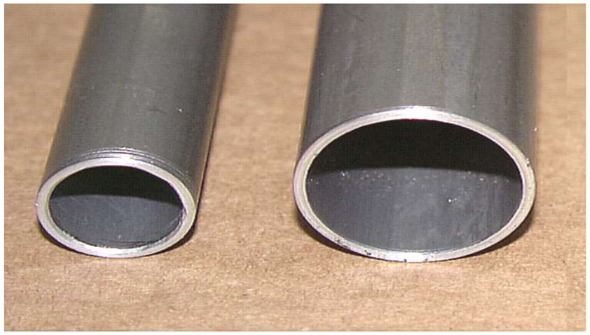
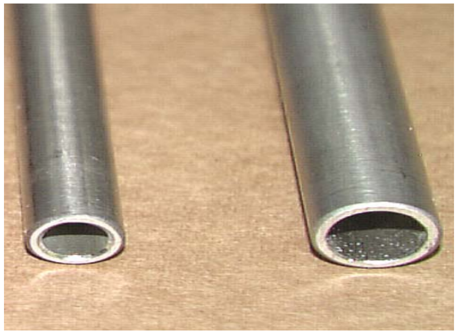
System Mass:

- **Same mass as current HFC-134a systems is achievable**

Packaging:

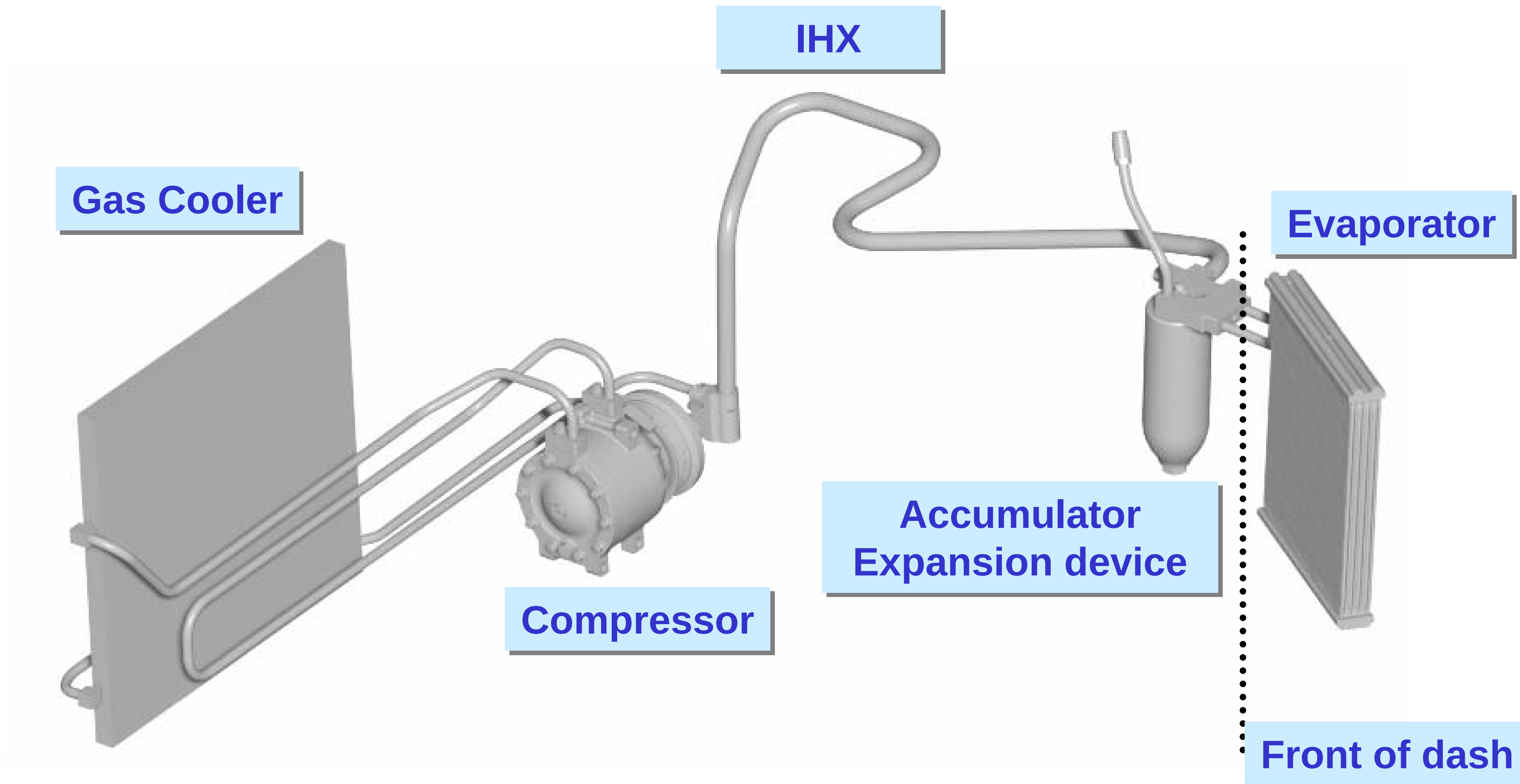
- **Heat exchangers will be smaller at equal performance (capacity).**
- **Compressor and lines will be smaller (higher volumetric capacity)**
- **Integration of accumulator and suction line heat exchanger possible (either stand alone or in place of current Integrated Receiver Dryer)**
- **The packaging of R744 system into space used currently for HFC-134a offers a wide range of introduction scenarios**

Packaging Comparison

	R134a	R744
Compressor		
Lines		

Pictures are same scale

"Low cost and reduced packaging" R744 AC System



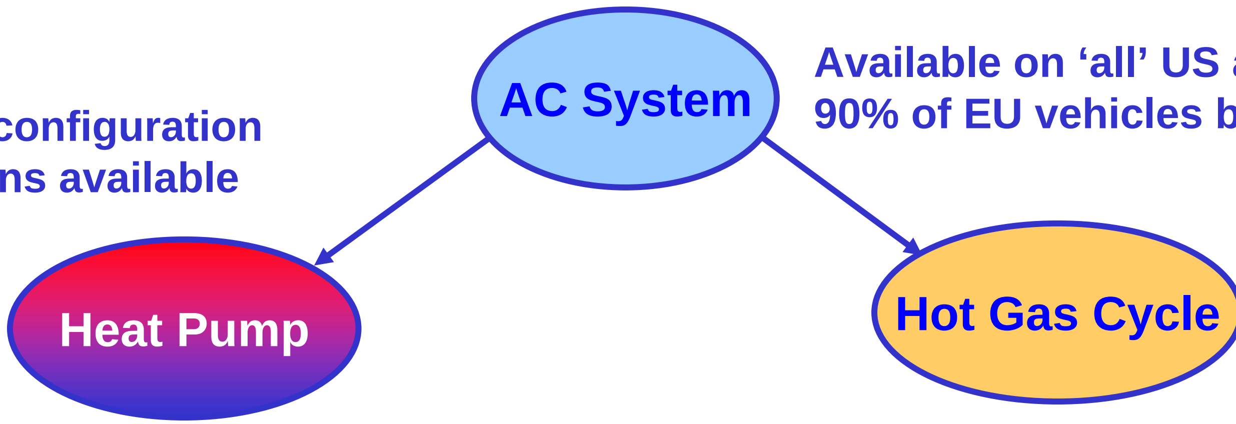
What are the <u>main advantages</u> of using R744 instead of HFC-134a?

<u>Advantages of Heat Pump / Heating Systems</u>

- **Increased heat-up dynamic leads to improved customer comfort, even at very low temperatures**
- **Improved driving safety by faster „de-icing“ and „de-fogging“ of the windshield**
- **HP systems show lower overall energy consumption in comparison to conventional additional heaters**

Available on ‘all’ US and > 90% of EU vehicles by ’07-’08

Many configuration options available



Low cost option (see next page)

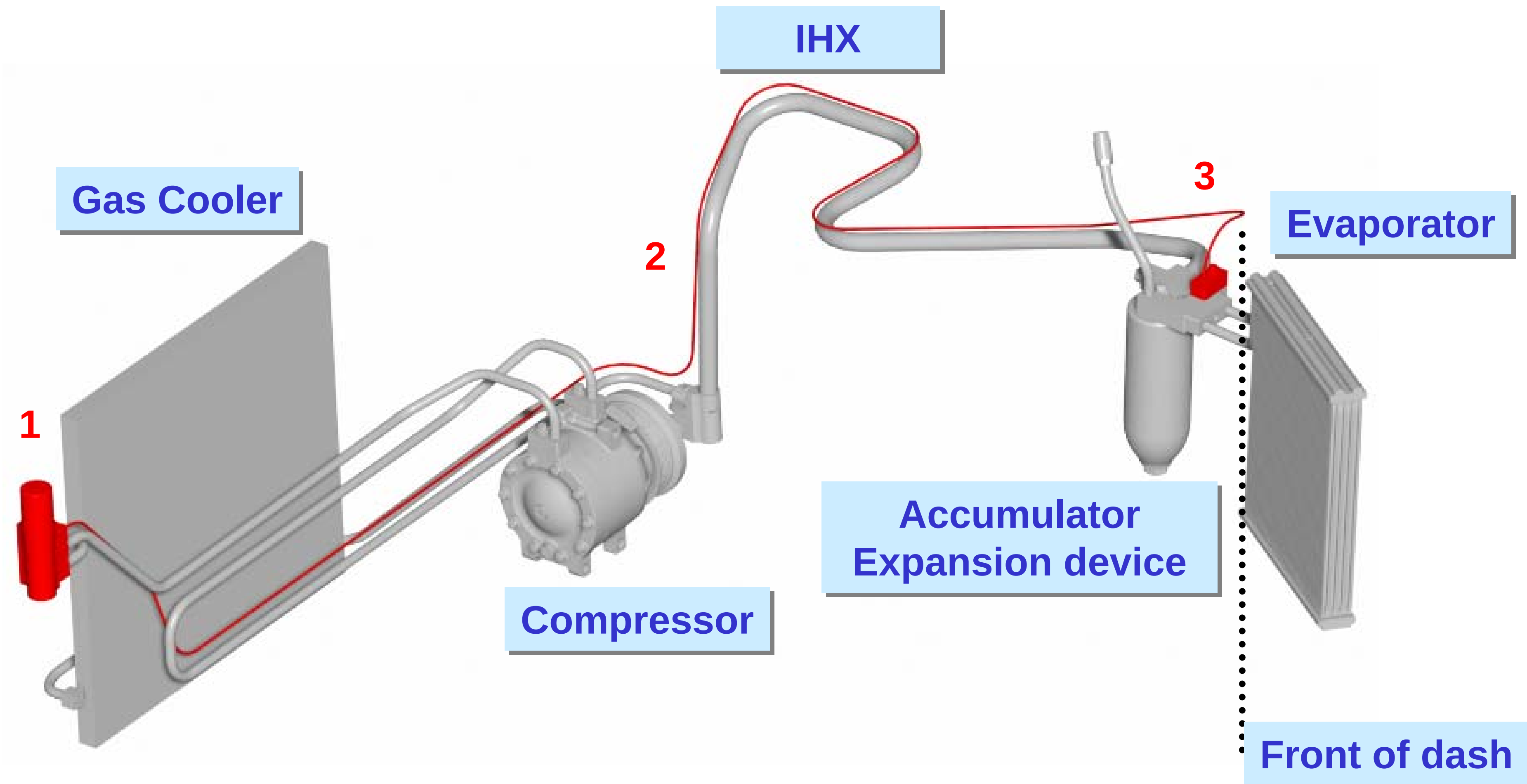
Heat Pump:

- **Source:**
  - **Air/Coolant/Exhaust**
- **Sink:**
  - **Air/Coolant**

Hot Gas Cycle:

- **Source:**
  - **Compressor**
- **Sink:**
  - **Air/Coolant**

Example: "Low cost" R744 AC & Hot Gas System



Additional components for heating:

1 3/2-way valve
2 Capillary tube
3 T-junction

How dangerous is it for passengers and rescue personnel if CO_2 is released into the cabin?

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Risk Assessment

For Passengers:

- Any safety concept has to prevent build-up of dangerous CO_2 concentrations inside the cabin
  - – RISA study
  - – EPA study
- Different risk mitigation options are available
  - Low charge in relation to cabin volume
  - Safe evaporator
- Existing/proposed standards (SAE J639, EN 378) need to be followed

For Rescue Personnel:

- Equivalent risk for rescue personal compared to HFC134a systems

Risk Assessment (cont.)

For Production and Service:

- CO_2 (R744) is widely used today in mass production and can be handled safely.
- R744 systems will have specific charge ports according to SAE J639 to avoid refrigerant mixing.
- R744 systems have an explosion energy level in same range as today's R-134a systems.
- CO_2 – R744 is not flammable.
- Regarding the protection of service personnel, general rules and regulations apply that are already in place for the use and storage of CO_2 in buildings and work places.

Service Assessment

- Service friendly peanut fitting
  - Leak rate << 0.5 g/yr/connection
  - Fits all loop components
- Flexible tubes and corrugated hoses
  - Engine movement compensated
  - Integrated service position
  - Assembly feature device
  - Leak rate << 0.5 gr/y
  - Improved NVH
- Two service valves (leak rate <0.5gr/y)
- p/T sensor (leak rate <0.5 gr/y)
- Suction line heat exchanger and accumulator (leak rate <<0.5 gr/y)
  - Reduced pulsation noise
- Evaporator with orifice and gas cooler (leak rate <<0.5 gr/y)
- Compressor (leak rate ~15-20 gr/y)

Technical solutions are available from different market players giving access to service intervals of 6 years and more

Service Assessment (cont.)

Leak detection and localization

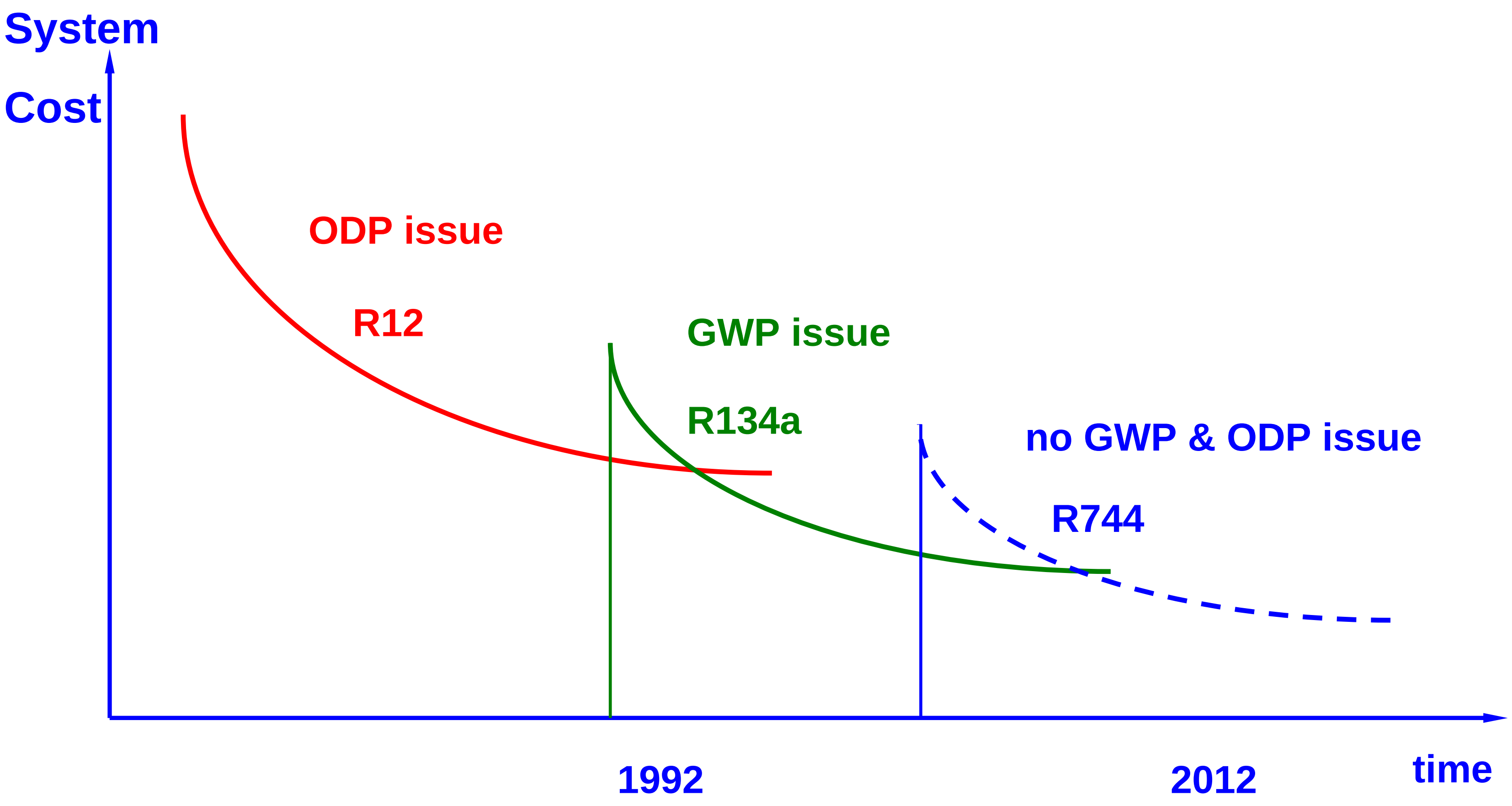
- **Handheld detection devices are available**
  - **should be adaptable to assembly line**

Service Tools

- **According to SAE J639, different service tools are required**
- **A safe service tool has been designed**
- **Interchangeability of service tools is avoided**

Adequate service tools are available from different suppliers, but service personnel will need initial training to handle high pressure R744-systems.

System Cost Comparison



Production Lines / Service Personnel Training / Ownership

Cost - Production Lines

OEM:

- Investment for assembly line charging station
- Leak detection facility

Suppliers:

- Investment for compressor production is the highest
- Heat exchanger technology and lines will need investment

Cost - Service Personnel Training

- Service personnel need to be trained for R744 systems.
- Investment for new service stations without recycling function
- No end of life recovery is necessary

Cost – Ownership / Final user

- No recycling cost
- Reduced annual fuel consumption

Expected Cost and Timing

Expected Cost

- Economies of scale and increased performance density can lead to equal or reduced cost for a R744 A/C system
- Different technical options for additional heating give access to high performance and low cost heating systems while having a positive indirect emissions impact
- Direct Injection Engines in the EU and Hybrids in the US will create a trend towards the use of additional heating systems

Expected Timing

- EU Regulation scheduled to phase out HFC134a from 2011
- Some OEM's will move early
- Earliest possible SOPs 2008-2009

Technical Summary

R744(CO_2) shows advantages in comparison with HFC-134a:

- **better cooling performance and efficiency**
- **reduced emissions (lower LCCP than HFC-134a)**
- **possibility of supplemental heating system**

Open issues:

- **equal costs R744 vs. HFC-134a AC system not achieved**
- **limited issues with noise, vibration, harshness**
- **prove reliability and maturity in fleet test**

These open technical issues can be solved within 1-2 years.

There is strong co-operation amongst OEM's and suppliers on non-competitive issues (safety, service, etc)

Conclusion

- Natural refrigerant R744 / CO_2 is the best alternative refrigerant to reduce greenhouse gas emissions.
- CO_2 has excellent cooling and heating properties.
- CO_2 can be handled and serviced safely.

R744 has the potential to become a globally used refrigerant in MAC and other applications

R744 represents the automotive industry technology trend for mass production

Questions?

Thank you for your attention!

Special thanks to all the institutions and companies contributing to this presentation including some OEMs

Sources cited in this presentation

page number / issue / source

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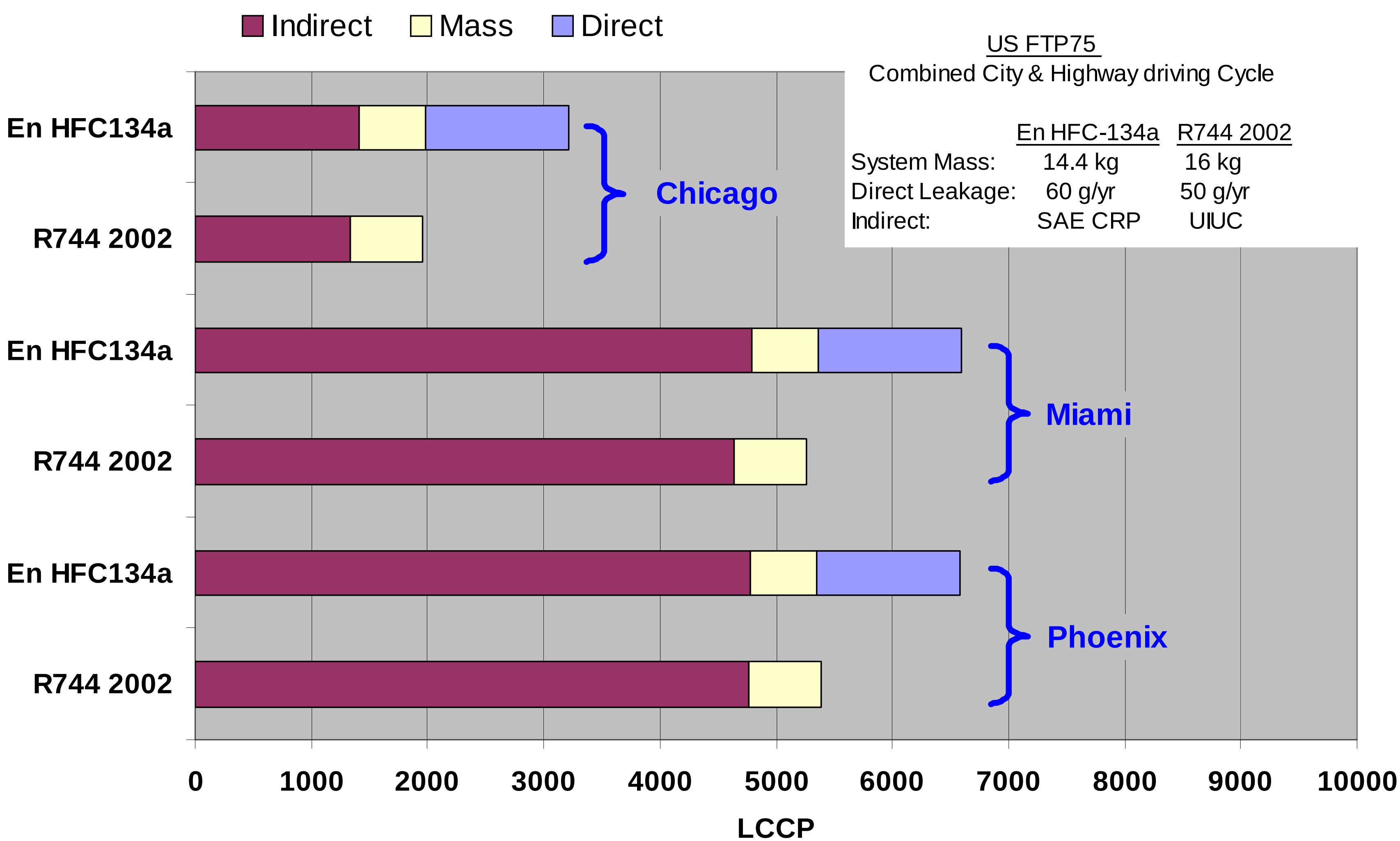
5: Commercial and ff: Danish Technological Institute and the University of Braunschweig (Germany)
5: U.S. Army ff: U.S. Army RDECOM
5: Vending ff: Coca Cola press release
5: Transport ff: Konvekta
5: Bus ff: Konvekta
5: Heat pump letter DoE
6: System Design: Modine
7: Hafner, SINTEF
8: Visteon (Graham Duthie, Shane Harte, and Vijit Jayasheela)
9: SAE Corporate Research: ARCRP Expert Team: Jürgen Wertenbach, William Hill, Steve Lepper, Hans Fernquist
10: Mack McFarland (DuPont), Next Generation Mobile AC Workshop India, New Delhi, March 2005
12: Compressor pictures: LuK, Line pictures: Behr
13: System design: Obrist Engineering
15: System design: Obrist Engineering
16: Rebinger, C., Safety Concept Proposal for R744 AC Systems in Passenger Cars, VDA Winter Meeting, Saalfelden, February 2005
19: Inficon handheld device
19: Picture: Snap-on
27 & 28: Hafner, LCCP analysis Proceedings of the MACSUMMIT Washington, D.C. April 13-15.2004

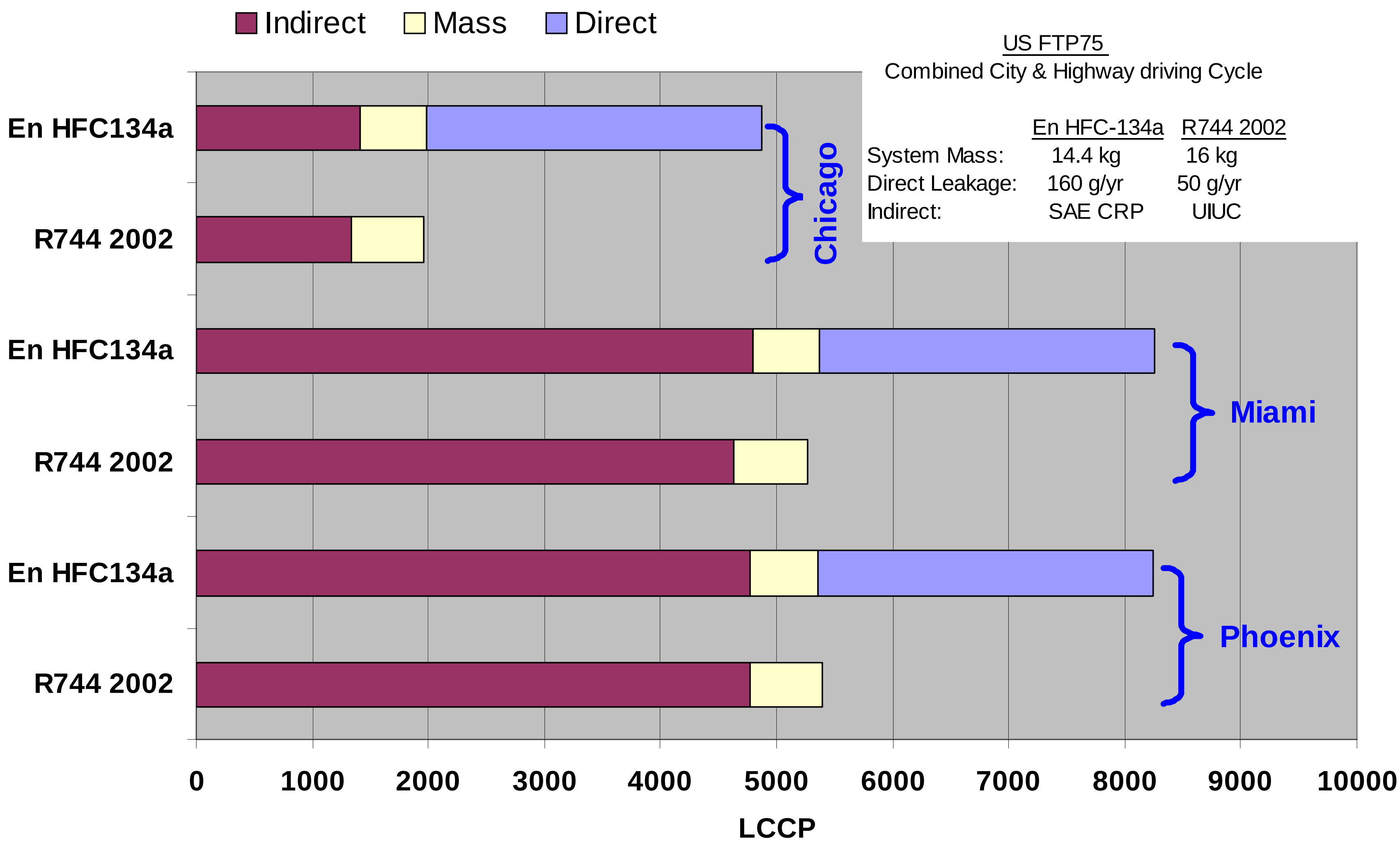
LCCP
Life cycle climate performance



LCCP
Life cycle climate performance

Applying 20% as annual leakage rate:

Ref. Mack McFarland (DuPont), Next Generation Mobile AC Workshop India, New Delhi, March 2005



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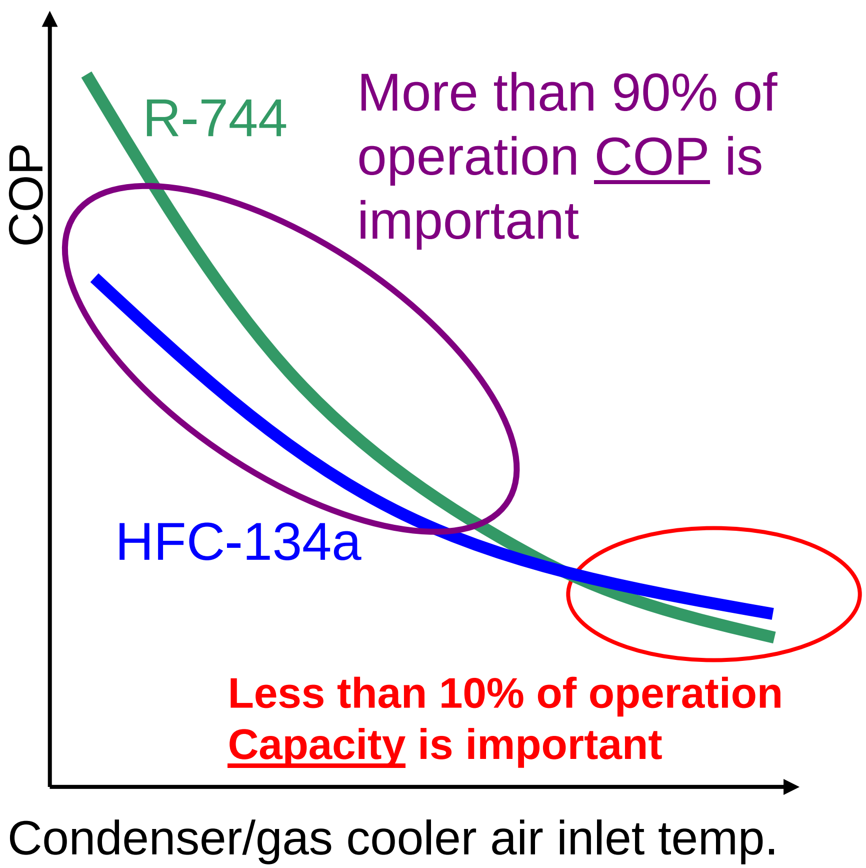
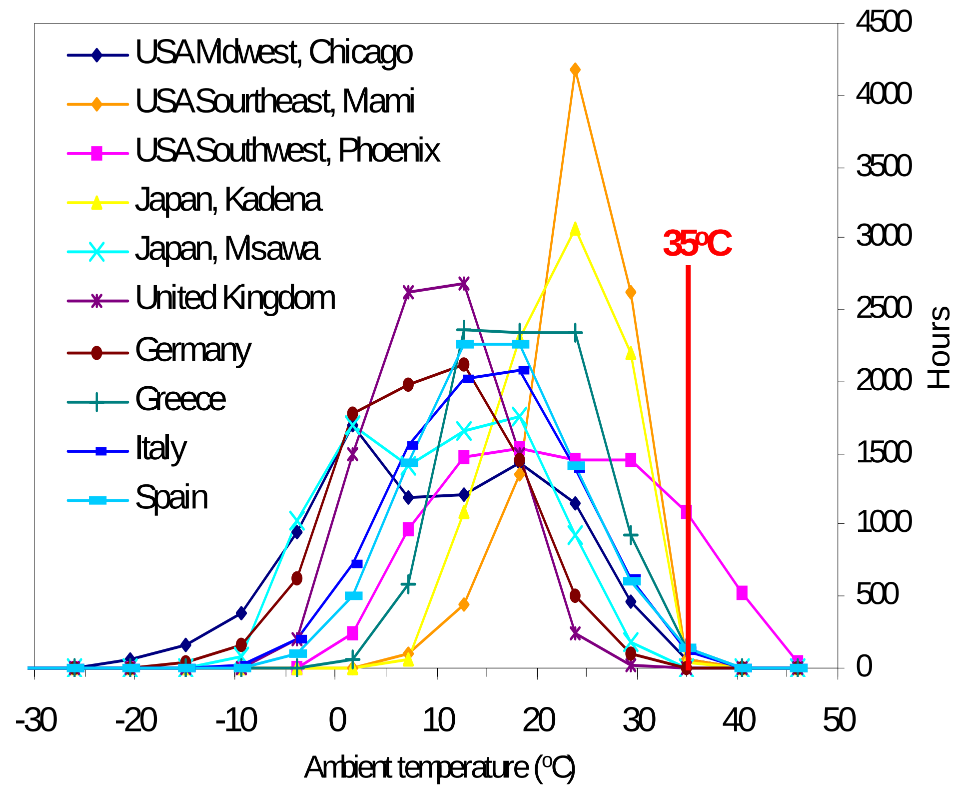
Climate conditions

Typical efficiency at varying condenser/gascooler air inlet temperature

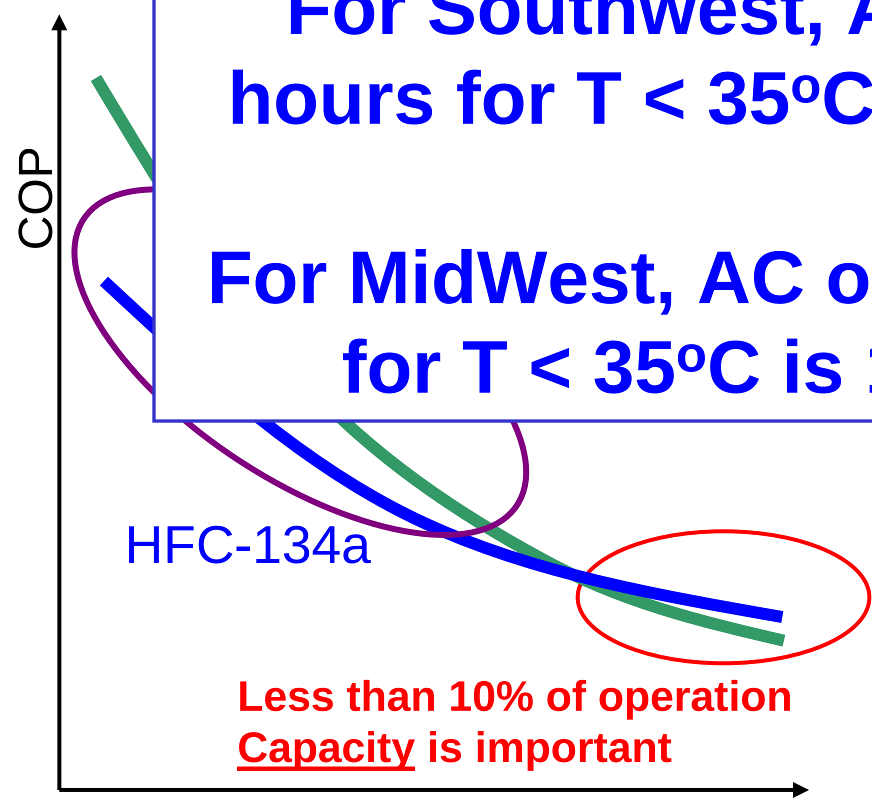


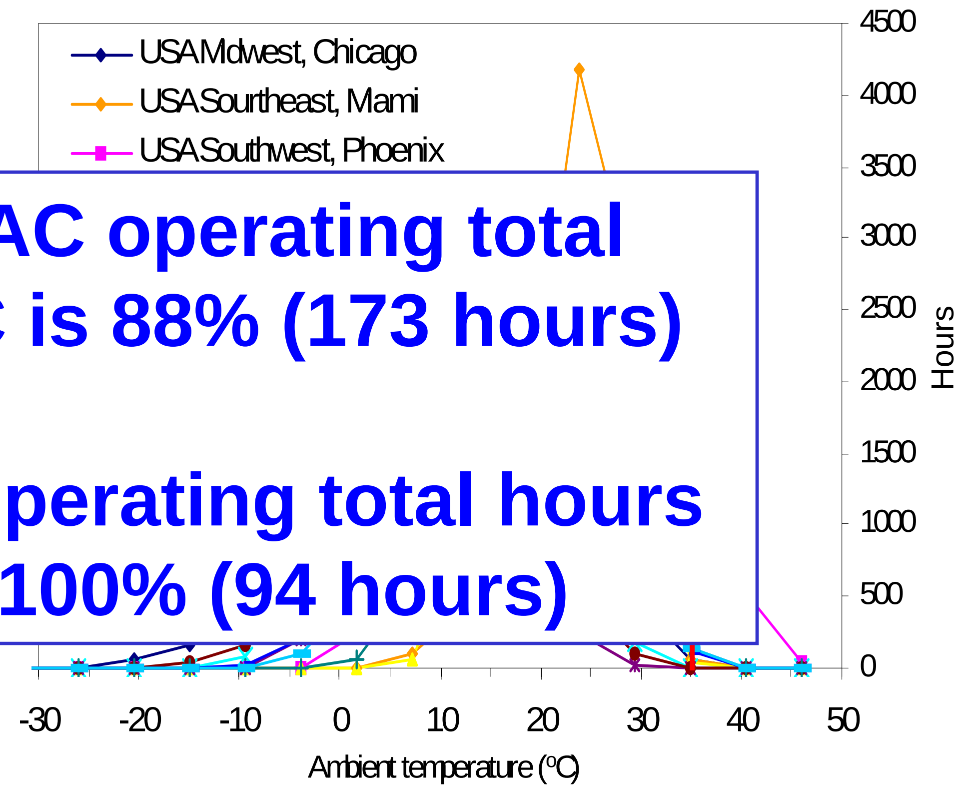


Temperatures above 35ºC hardly ever occur

Climate conditions

Typical efficiency at varying condenser/gascooler air inlet temperature





For Southwest, AC operating total hours for T < 35°C is 88% (173 hours)

For MidWest, AC operating total hours for T < 35°C is 100% (94 hours)

Temperatures above 35°C hardly ever occur