New Technology: CO_2 (R744) as an Alternative Refrigerant

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The speaker speaks for the group.
All 17 group members have achieved a consensus.

Speaker:

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Group members:

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- Who is doing CO_2 development today ?
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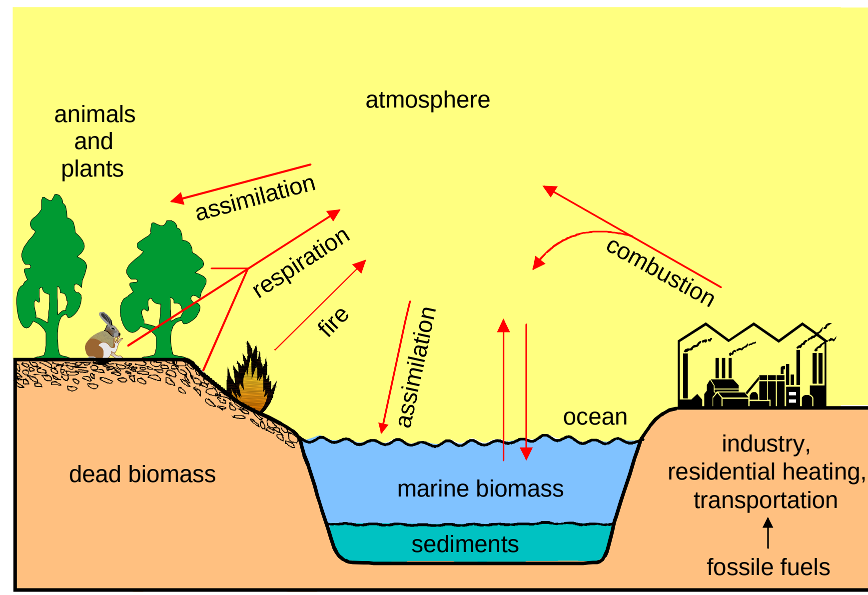
  - Cost
  - Timing/ Feasibility
  - Technical Summary
  - Conclusion
- Discussion

Why consider CO_2 as an alternative refrigerant for mobile applications?

- Natural gas and part of the atmosphere.
- CO_2 is called R744 if used as a refrigerant.
- Product of the metabolism and part of the photosynthesis.
- Well known by science and industry.
- Not flammable and a fire suppressant.
- Classified as non-toxic
- World-wide availability
- Waste product of the chemical industry



CO_2 is a natural refrigerant and

could be a long term solution for mobile and stationary systems.

Who is doing CO_2 development today ?

- Many car manufacturers in Europe, Japan and the US
- The majority of system and component suppliers
- Institutes and universities all over the world
- Related industries are either developing or are already in production with CO_2
  - Commercial and residential hot water systems
    - commercialised in Japan with sales of 20.000 units/year
  - Commercial and industrial refrigeration (stationary, supermarkets)
  - US Army is developing in three fields of stationary, wheeled vehicles and individual soldier applications
  - Helicopter and airplane air conditioning and refrigeration
  - Transport refrigeration
  - Vending machine heating and cooling
  - Bus air conditioning

Questions from the EU answered and arranged in a new order

- Advantages
- Risk assessment
- Service assessment
- Cost
- Timing / Feasibility
- Technical Summary
- Conclusion

What are the main advantages of using CO_2 instead of HFC-134a?

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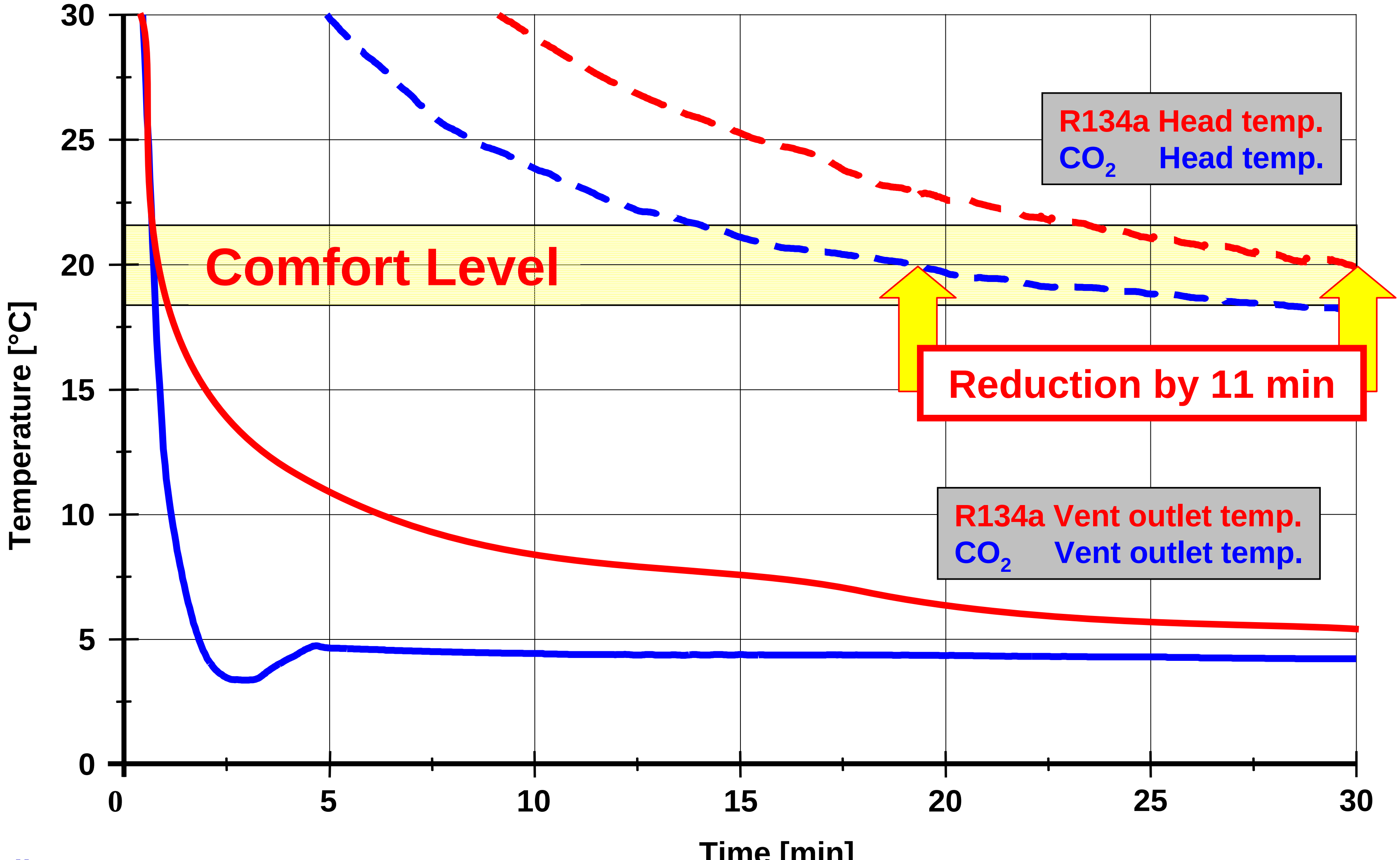
Performance – Cool Down CO_2 vs. R134a



Audi AG

Windtunnel test: t_{amb}.:40°C, sunload:1000W/m², 60km/h, identical system packaging

What are the main advantages of using CO_2 instead of HFC-134a?

Emissions Impact

Direct Emissions (Leakage)

- CO_2 has NO direct emission.
- HFC-134a has an equivalent of 4% of total tailpipe emissions.

Indirect Emissions (Fuel consumption)

- Reduction of the total annual fuel consumption confirmed by investigations on test benches **and** cars

Frankfurt am Main:	-0.7% (average climatic cluster)
NEDC (at 25°C):	-1.4% (potential -2.2%)

⇒ Reduction of total emissions by using a CO_2 system is in the range of 5%.

What are the main advantages of using CO_2 instead of HFC-134a?

System Mass and Packaging

System mass

- Past: Development target was approx. 2 kg above HFC-134a system
- Present (2003): Actual status shows mass increase of 0.5 to 1 kg
- Future: Development target is same mass as HFC-134a system

Packaging

- Heat exchangers will be smaller at equal performance (capacity).
- Compressor and lines will be smaller (higher volumetric capacity)
- Accumulator and suction line heat exchanger need to be considered

What are the main advantages of using CO_2 instead of HFC-134a?

Heat Pump Systems

Several different vehicular-applied systems have been investigated providing information on different solutions in terms of cost and performance.

Advantages of HP systems vs. supplementary heater

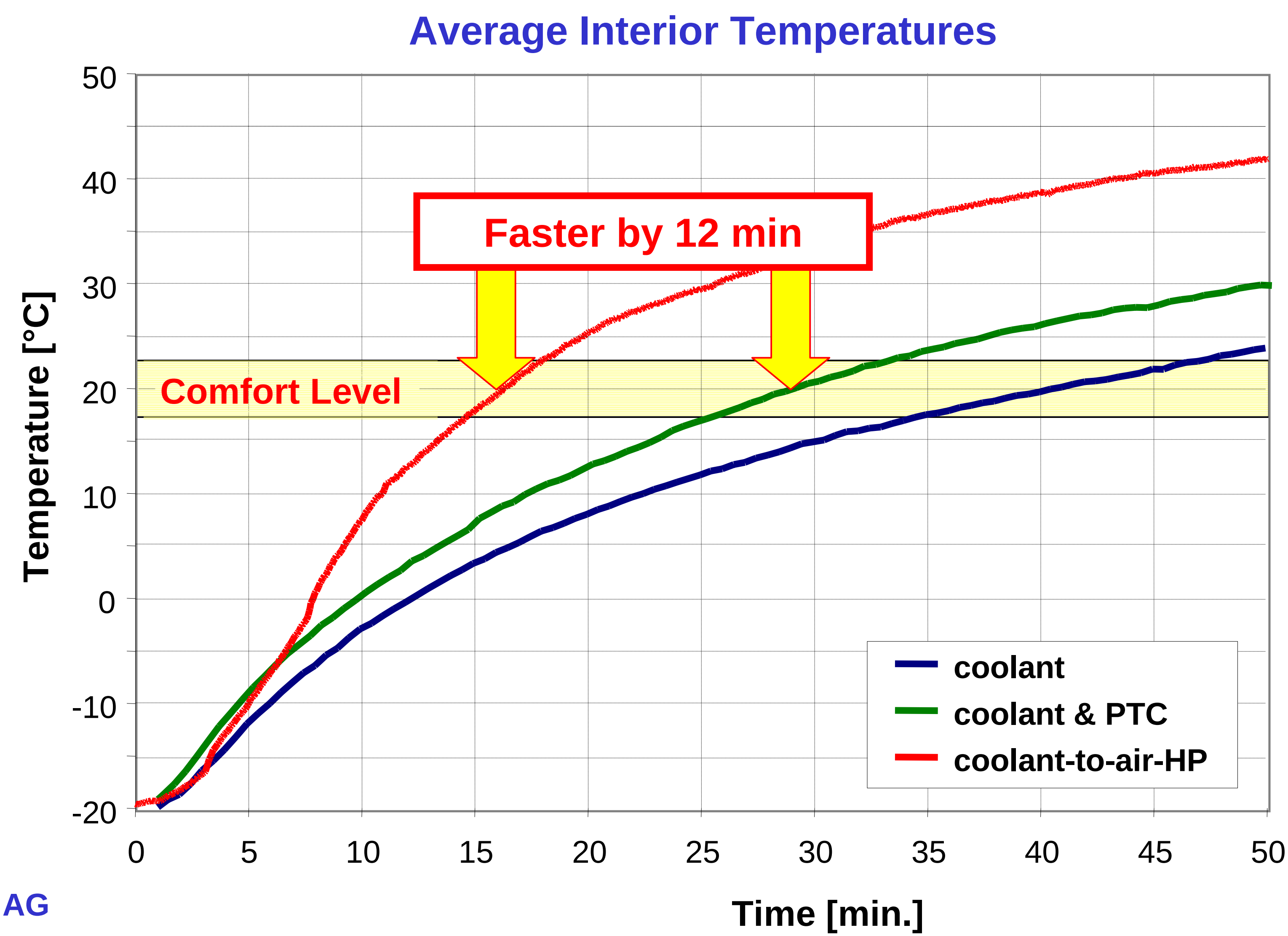
- Increased heat-up dynamic leads to improved customer comfort, even at very low temperatures
- Improved driving safety by faster „de-icing“ and „de-fogging“ of the windshield
- HP systems show lower overall energy consumption in comparison to conventional additional heaters

The VDA-Wintermeeting (Saalfelden, Austria) mainly addresses the technical issues of CO_2 heat pump systems.

CO_2 has the best heat pump capability of all refrigerants considered for automotive applications.

What are the main advantages of using CO_2 instead of HFC-134a?

Performance – Heat Pump System



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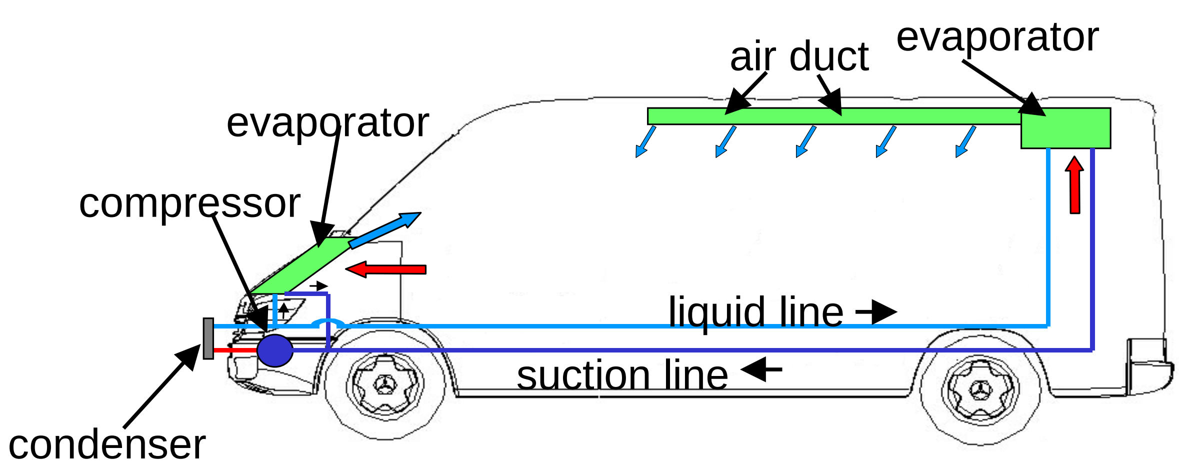
Windtunnel test: t_{amb}.:-20°C, 50km/h

What are the main advantages of using CO_2 instead of HFC-134a?

Dual Evaporator / Direct Exp. vs Secondary Loop

Dual evaporator loops:

- Systems with rear evaporators typically suffer from high losses in the suction line due to increased pressure drop caused by long refrigerant lines.
- CO_2 can improve dual evaporator systems in terms of efficiency and packaging (small diameter of tubes).
- Vehicles with dual evaporator loops have been investigated successfully.



Direct expansion vs. secondary loop

- CO_2-systems can be operated with direct expansion devices.
- There is no need to move to a secondary loop system.

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

Risk Assessment

Risk Assessment for Passengers:

- Any safety concept has to prevent dangerous CO_2 concentrations inside the cabin
- Several different safety concepts are under investigation
- Existing laws and regulations (SAE J639, EN 378) need to be followed
- VDA safety concept will be worked out in 2003 and published
- RISA study

Risk Assessment for Rescue Personnel:

- No excessive risk for rescue personnel

No excessive risk for passenger and rescue personnel !

Risk Assessment (cont.)

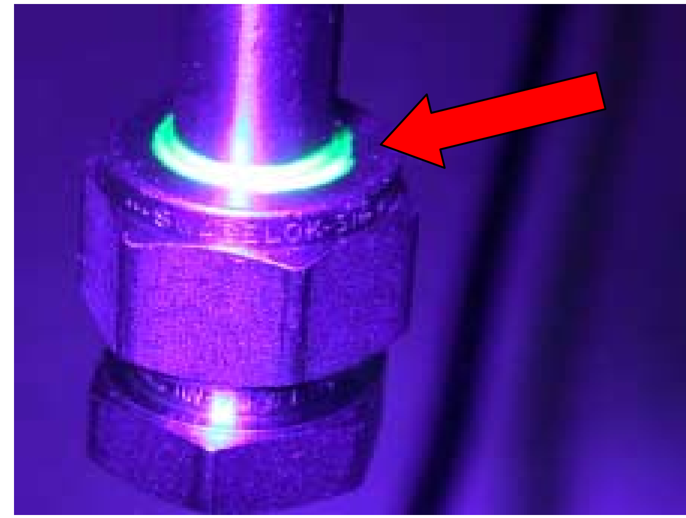
Risk Assessment for Production and Service

- CO_2 is widely used today in mass production and can be handled safely.
- CO_2 will have specific charge ports according to SAE J639 to avoid refrigerant mixing.
- CO_2 systems will have a comparable explosion energy level as today´s systems.
- CO_2 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

Can leaks be identified?

- First testing with leak detection dyes and electric detection show promising results.



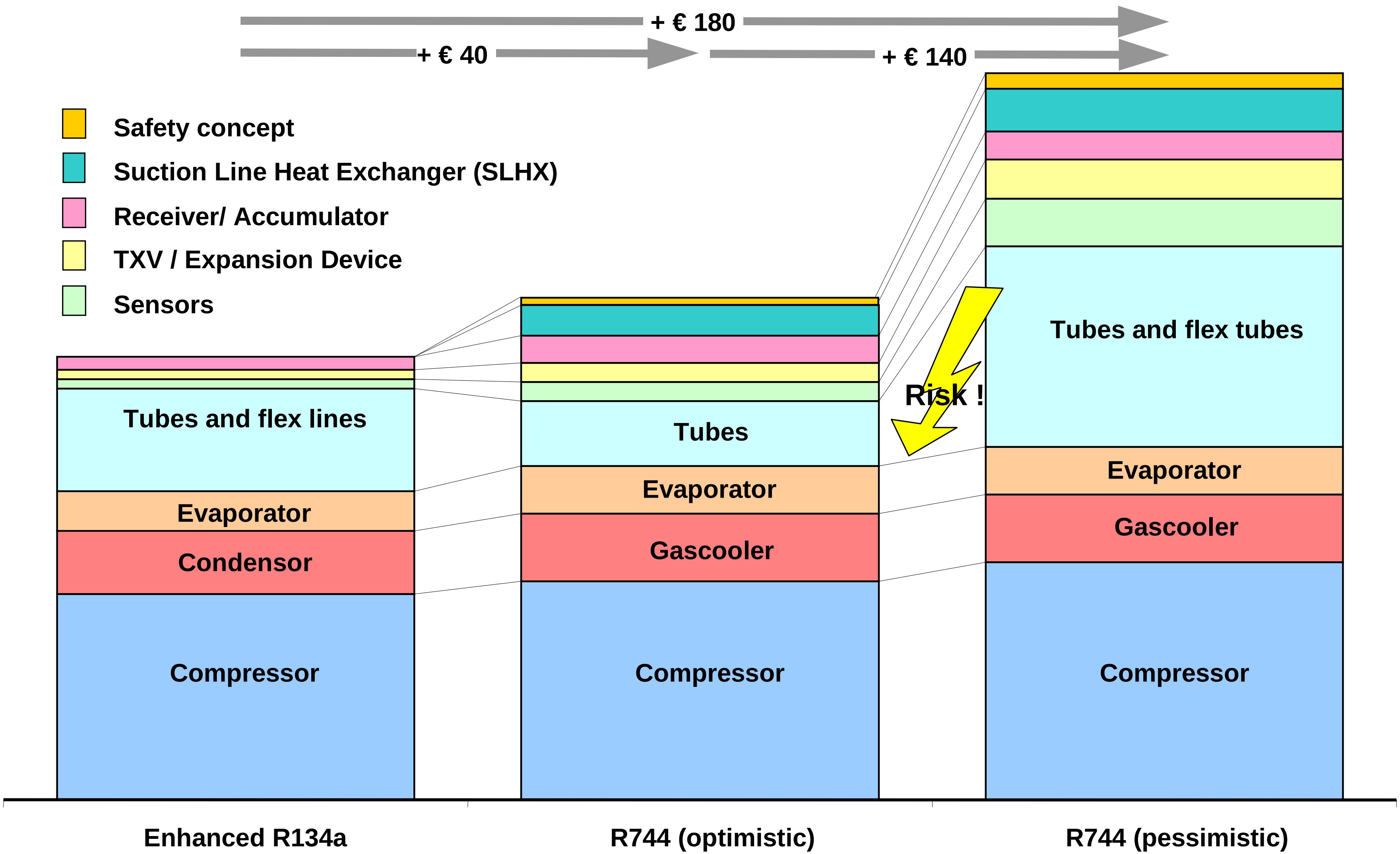
Service

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

In general, adequate service tools are available but service personnel will need special training to handle high pressure CO_2-systems.

Cost (today´s situation)

System Cost: Assumption: 500.000 pieces/yr AC only system



Note: Graph is not to scale.

Cost - Production Lines

OEM:

- Investment for assembly line charging station
- Leak detection facility
- Safety equipment for handling large quantities of CO_2

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 CO_2 systems.
- Investment for new service stations **without** recycling function
- No end of life recovery is necessary

What would be the cost difference assuming that all cars sold in the EU would have a CO_2 based system after a transition time ?

Cost - Expected Situation

- Economies of scale can reduce the cost increase of an A/C system to a lower level.
- On going cost comparison: CO_2-system (AC/HP) vs. R134a AC-system/ additional heater

Direct Injection Engines: trend is towards the use of additional heating systems.

What would be such a reasonable transition period ?

Timing

Oriented towards OEM platform change intervals

Today´s situation

- Platform change intervals are ranging from between 4 to 8 years.
- In some low volume cases, platform intervals can reach 12 years

How mature is the technology itself?

Feasibility for Production

- Function confirmed with prototypes in vehicles and on test benches
- System maturity under investigation
  - Heat exchanger: High
  - Compressor: Medium
  - Flex lines and connectors: Low

To what extent are the problems relating to the introduction of CO_2 systems related to technology itself ?

- Today's delays are mainly driven by unsolved technical problems (60%)
  - Flex lines and connectors
  - Noise, Vibration, Harshness
  - Leakage
- Production Costs (40%)

Open technical issues can be solved within 2-3 years

CO_2 shows advantages in comparison with HFC-134a:

+ better cooling performance and efficiency

+ reduced emissions

+ possibility of a HP system: best heating performance

+ ecology (lower LCCP than HFC-134a)

Open issues:

- flex lines are not yet developed for mass production
- system tightness for production, field and maintenance
- equal costs CO_2 vs. HFC-134a AC system not achieved
- additional cost for heating systems vs. supplementary heating systems
- noise, vibration, harshness

These open technical issues can be solved within 2-3 years

Conclusion

- **Natural refrigerant 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 safely.**

If open technical and monetary issues are solved, CO_2 can be the refrigerant of the future.