

Status of R744 Deployment and Way Forward.



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Status of R744 and Way Forward. Agenda.

- Introduction
- BMW Group Position
- **Technical Status**
- **Functional Status**
- **Global Applicability as Prerequisite:
Ecological Impact & Cost**
- **Summary & Outlook**

Status of R744 and Way Forward.

Introduction.

- BMW Group participated the EU-sponsored RACE-project from 1994 – 98.
- Since 1999 BMW Group is investigating alternate refrigerants theoretically and practically in several system-generations.
- The first EU-commission's proposal for limiting greenhouse-gas-emissions from MACs has been published August 2003.
- BMW Group decided for R744 as alternate refrigerant together with the German carmakers in 2004.
- The present shape of the upcoming EU-regulation is expected by BMW Group as working assumption since mid 2004.
- Assuming the consensus and acceptance for the essential need of a worldwide applicability and regulatory harmonization, BMW Group tried to play its role of constructive support balanced with realism.

Status of R744 and Way Forward. BMW Group Position.

- In its corporate values BMW Group is dedicated to mobility and driving pleasure, but is also committed to ecological and social acceptance.
- BMW Group made its contribution to legal requirements in a constructive manner.
- BMW Group was and is always in full support of the joint position of ACEA for
 - sense of proportion regarding feasibility along the timeline and costs,
 - preferred role of politics to set targets and not technical solutions, that may be counter productive along the timeline or for other purposes,
 - avoidance of a regulatory isolation of Europe.
- BMW Group in principle favors replacement of HC-refrigerants.
- BMW Group decided for R744 for technical reasons and sustainability; for the time being this makes it the only existing alternative for HFC-134a.
- With regard to the timeline of the EU-regulation and lacking alternatives BMW Group sees it as a must to deploy it now.

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Technical Status

Experiences with R744

Time Period	2001 – 2003	2001 - 2004	2004 - 2006
Vehicle	Fleet test 1 3 series Sedan (7 Vehicle)	HP-Systems (7 series/ 3 series)	Fleet test 2 5 series Sedan (17 Vehicle) 7er Sedan (1 Vehicle) with 4 Circuit layouts
Operating experience	~ 3000 h Operating hours	Prototypical investigations	~1.400.000 km continuous running
Investigations	<ul style="list-style-type: none"> • Durability test • Cooling Capacity • Leakage • Fuel consumption • System costs • Package Check • Investigation on <ul style="list-style-type: none"> • maintenance • assembly line 	<ul style="list-style-type: none"> • Investigation of <ul style="list-style-type: none"> • Water-to-Air HP • Air-to-Air HP • Triangle processes HP • Cooling/ Heating capacity • Package Check 	<ul style="list-style-type: none"> • Durability Test • Cooling Capacity • Leakage • System efficiency • System costs • Package Check of different layouts • Investigation on <ul style="list-style-type: none"> • maintenance • assembly line • Analysis of supplier structure • Ability of <ul style="list-style-type: none"> • construction kit • scalability • 2-evaporator system

Technical Status

R744 MAC-Development

- **Specifications on R744-MAC's**
 - Working Group OEM:
Joint set for specifications for MAC-system and its components done
- **Compressor**
 - Decision on compressor oil: PAG
 - Thermo balance: Oil-/body temperature
 - Durability: VDA-continuous running, "Raffertest", ~1.400.000 km
 - Acoustics level comparable to Todays-HFC-134a-MAC
 - Off-power consumption slightly lower than HFC-134a-compressor
→ Working draft of specifications confirmed
- **Connection technology and leakage:**
 - Fleet test 2: no leakage reported
 - Metal axial sealed connectors confirmed (coordination with plant, quality and development took place)
→ Working draft of specifications confirmed



Technical Status

R744 MAC-Development

- **Safety analysis**
 - Coordination in VDA WG “Safety”
 - Coordination with EPA
 - **Process and Method** of safety proof, which is presently being derived from IEC61508 and ISO WD26262 (see VDA-Wintermeeting 2006)
 - **Refrigerant R744 with Odorization**
 - **Open Issue:** Int’l acceptance of the process and method
- **Process “Assembly line”:** Integration, filling and leakage verified
- **Process in maintenance** described, Cooperation with SAE started
- Further examination to
 - 2-Evaporator-Systems
 - Various system layouts for the integration into the vehicle (package and thermal dynamic check)



Technical Status

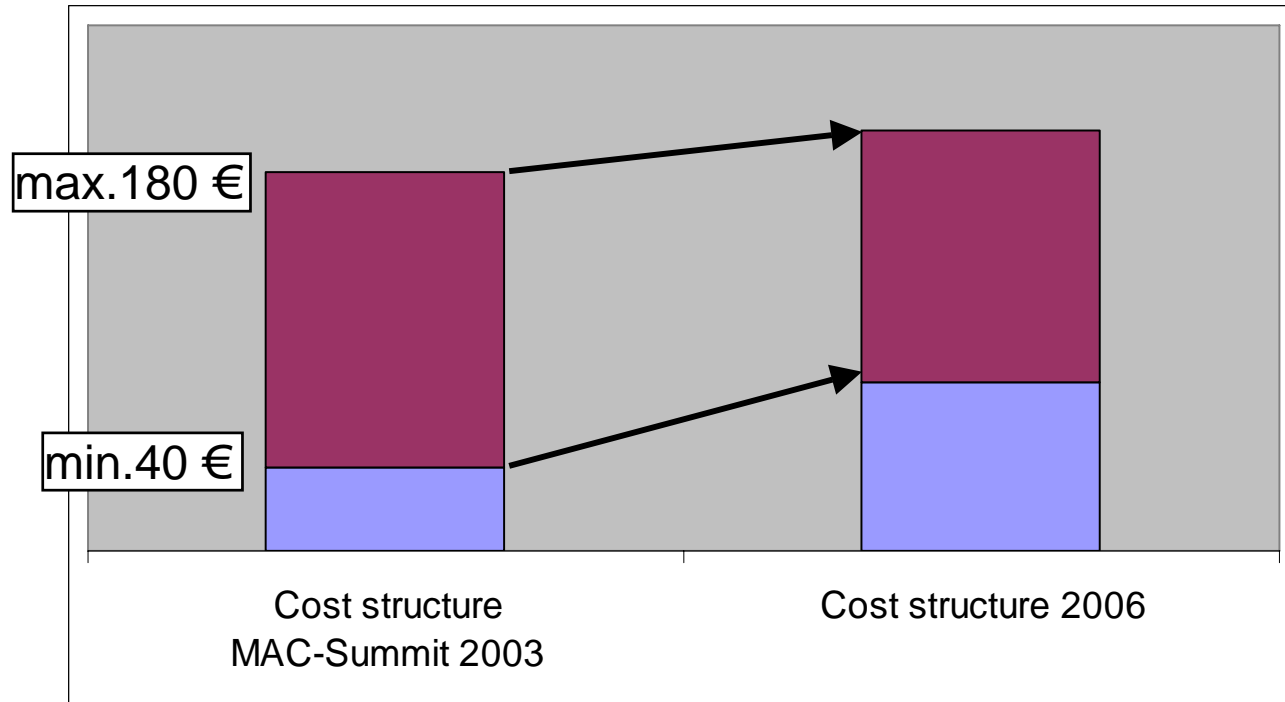
Open Points

- Cost structure
- Confirmation of the safety concept
 - Int'l establishment of method and process "Safety Concept"
 - Odorization of the refrigerant
 - Safety concept for "simple" MAC's
- Small vehicle with low torque engines
- Elastomer hoses for R744-MAC
- Hybrid-Systems
- Engine-Stop Operation
- Heat pump applications



Technical Status

Cost structure



- Past: MAC-Summit 2003 shows 40 .. 180 € for the first application in 2008
- Today's situation: no reduction of costs for the first application, because of regulatory isolation of EU

→ Cost Increase

Technical Status.

Our Partners.



Thank You !

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Functional Status.

R744 Joint Working Group.



H.Hammer,

J.Wertenbach,

Dr. R.Mager,

P.Hellmann

Functional Status.

R744 Joint Working Group.

Industry Agreement on Boundary Conditions for a R744 A/C System

- High efficiency.
- Minimal system costs.
- The R744 A/C unit must have the same or better cooling performance than a HFC-134a A/C unit at all relevant operating and ambient conditions.
- The R744 A/C concept is essentially the same for all OEMs, all components contained in that R744 A/C system should have a common basic specification.
- The A/C control concept should (is not) be standardized, the same type of sensors can be implemented by all OEMs.
- Integration of the sensor and the capacity control of the compressor in the existing HFC-134a AC controller.
- A parallel usage of HFC-134a and R744 in one vehicle platform shall be possible.
- Benchmark of negative characteristics of A/C systems such as noise, evaporator odor, variation in air temperature and cooling performance with fluctuating boundary conditions is a state-of-the-art HFC-134a A/C system).
- Safe operation of the R744 A/C system must be ensured at all times.

Functional Status.

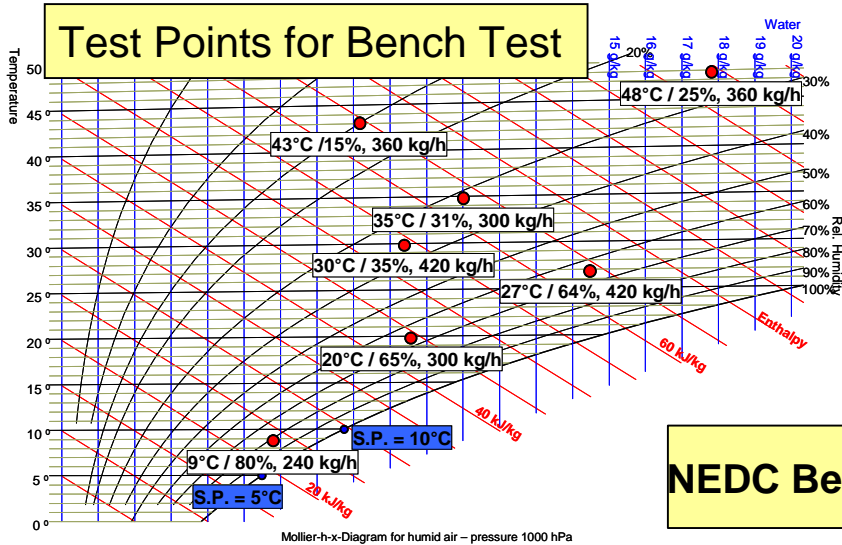
Status of the Concept.

- After two evolutionary optimization cycles in total 7 different systems have been installed in vehicles and been tested on road and climatic wind tunnel (4 different compressor models, 4 gas cooler models, 4 evaporators, 3 types of joints and expansion-valves, 3 types of internal heat exchanger / accumulator units, 1 separate internal HX and accumulator).
- The technical requirements within the specification for the components have been confirmed to a large extent by investigations with the vehicles.
- Only some R744 A/C components have fully met the specifications yet.
- The R744 system fits in existing vehicle and engine compartments packages with some difficulties, the system weight will be the same as today's weight (today 0.8 to 2.4 kg more).
- All R744 refrigerant circuits could be operated within the specified operation limits (temperature, pressure, capacity, etc.) in the vehicle at any time.
- The R744 vehicle systems worked well at road and climate tunnel tests , the R744 systems had been tight. The refrigerant charge for operation is 250g to 400g (further reduction potential).
- Elevated air temperature through the front end of the vehicle reduces the R744 system capacity and efficiency, recirculation and blow by of hot air at the engine compartment have to be eliminated.
- NVH caused by the compressor and the rigid design of the flexible hoses (corrugated tube instead of elastomer hoses).

Functional Status.

Efficiency Status.

Bench tests of 4 "Executive" and "Small Family" vehicle today's HFC-134a production AC system and as substitutes R744 concept systems (basic R744 technology)



Ambient Conditions

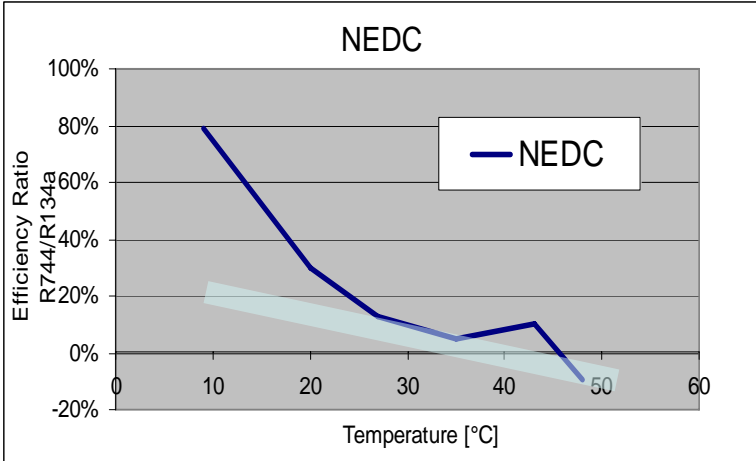
Cabin air flow

Ambient Conditions Compressor Speeds: 800 ; 2500 ; 5000 rpm

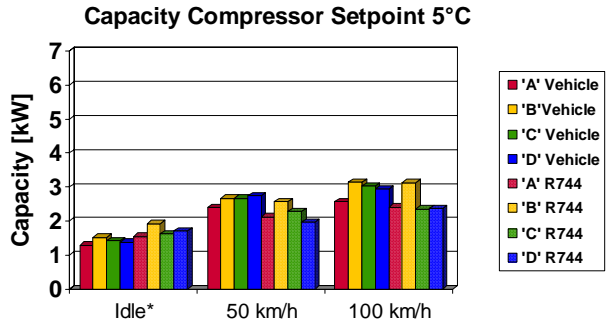
Vehicle Front end Air Velocity 1.5 ; 2.5 ; 4 m/s

Idle Conditions with elevated front end air temperature: + 8K

NEDC Bench Test



Steady State Tests



All systems are able to provide thermal comfort, the control of the required capacity was possible on demand. The R744 Systems are favorable in capacity and dehumidification. R744 is more sensitive regarding elevated temperatures at vehicle front end air inlet. Not all investigated R744 systems show sufficient efficiency potentials yet and need therefore further optimizations.

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Global Applicability. Ecologic Impact.

The ecologic impact of MACs is driven by leakage (direct emissions) and use & efficiency (indirect emissions).

– Leakage:

Even if leakage is reduced from today's 85 g/yr (R.J.Hwang, 2004) by 50%, it still contributes a CO₂-equivalent of 2,9 - 5,6 g/km, global average 3,6 g/km ~ **2 %** of GHG-emissions depending on average mileages.

– Efficiency:

The efficiency of today's R744-systems following our test results varies from 30 % to 0% compared to today's HFC-134a systems. This could allow a CO₂-reduction from **1 – 1,6% depending on location (global average ~ 1,3%)**

– Total:

Compared to optimized HFC-134a-systems still R744 can help to reduce CO₂-equivalent emissions by further **~ 3 – 4%.**

Global Applicability. Ecologic Impact.

- It is understood as essential to reduce HFC-134a leakages.
 - In average R744 could bring an additional greenhouse-emission reduction.
 - Due to the physical properties of R744 - albeit the average customer will experience advantages in efficiency and performance, based on the results of our test vehicles – some customers and locations will perceive disadvantages, which communication has to be prepared for to create comprehensive understanding and acceptance.
 - During our tests we have met good and bad applications of HFC-134a and R744. The variation in sensitivity of system behaviour to application is higher than the average advantage of R744 indirect emissions. Specifically, the sensitivity against additional blockages from pedestrian protection is higher.
- => **From an ecological aspect we support HFC-134a leakage-reduction and further improvements, but see R744 as globally superior and applicable.**

Global Applicability. Economic Impact.

- Some suppliers and other sources have lobbied politics pretending deployment as too simple. The ban appeared too easy.
- R744-deployment is a complex endeavour. A ban affects all products. It makes no difference, if the individual application is simple or complex and if it is only a niche or a mainstream product.
- Since the regulation becomes reality, we encounter a cost increase instead of a degradation with progress in time. The assumed cost figures of the European commission now appear unrealistic. We have to deal with costs beyond 200 €.
- **The regulatory isolation of EU can produce a vicious circle:**

The higher the additional costs the more unlikely to introduce alternate refrigerants outside Europe.

The less likely to introduce alternate refrigerants outside Europe, the more likely costs will not approach system costs of enhanced HFC-134a systems.

=> **We are in deep risk to run into a split world.**

Global Applicability. Economic Impact.

– This vicious circle can and must be broken:

Further greenhouse-gas reduction by application of alternate refrigerant outside Europe will only occur in case of incentives:

direct (to customers or OEMs)

or

indirect (i.e. like CARB's ARB 1493 rewarding alternate refrigerants as reduction of CO₂-emissions).

=>It is not sufficient to overcome explicit or implicit barriers for deployment of alternate refrigerants.

If the ban in the EU should make sense, we must appeal to work on incentives that enhance deployment of alternate refrigerants outside Europe.

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Summary & Outlook.

Summary.

- The feasibility of R744 under requested properties could be demonstrated.
- There is increasing robustness of the technical solutions.
- There is growing consensus how to meet the safety-mitigating requirements raised by EPA.
- As part of a R744-system layout, air inlet and –duct must be optimized.
- Most of specifications could be successfully harmonized among German OEMs. Still under investigation is compressor-control.
- Although BMW Group is upfront with developing alternate refrigerants, still the timeline for the ban in 2011 remains an extreme challenge. Supplier base is reduced: not all suppliers are “alternate-refrigerant-ready” and will be very close to 2011 when industrializing their solutions.
- Still remain open issues: small cars, combination with consequences of other emission-laws (engine stop, hybrid ...)
- In several tests, i.e. dynamic tests (ARCRP II, German OEM working group) R744 could bring a significant improvement in efficiency with unchanged system-environment (control system, geometry). R744 could improve greenhouse emissions significantly.
- Future work will focus on:
 - Efficiency has to be verified under wider transient operating conditions
 - Better understanding for wide spread of MACs: HFC-134a & R744
 - Safety mitigation
 - System control
 - Small cars
 - Dual evaporator systems
 - Statistical experience
 - Combination with hybrid

Summary & Outlook.

Outlook.

- Removal of explicit or implicit market barriers for alternate refrigerants is a prerequisite with sufficient lead time ahead of 2011. Support of EU, that made the first step, is required.
- BMW Group with VDA-working group is committed to working with EPA & EU-commission to resolve the safety mitigation process and to develop solutions. BMW Group would welcome a global initiative.
- The ban of HFC-134a is a fact, but increases complexity, because it affects all products: complex or simple, niches or high-volume, efficient or inefficient. For further countries incentives are favorable rather than a ban.
- OEMs enter a split world with increased costs for both: alternate refrigerants in Europe, HFC-134a outside.
- **To overcome this, a political initiative in favor of incentives for deployment of alternative refrigerants outside Europe would be highly appreciated and is urgently needed.**

Thank You for Your Attention.