GLOBAL ENVIRONMENTAL CONSEQUENCES OF INTRODUCING R-744 (CO_2) MOBILE AIR CONDITIONING

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ABSTRACT

Life Cycle Climate Performance (LCCP) of mobile air-conditioning (MAC) systems is estimated for different locations in Asia, where the car marked is growing very fast.

The test data from *SAE AR CRP*[1] have reconfirmed that system energy efficiency is no argument against R-744. Fuel use of R-744 systems is significantly lower than with HFC-134a, even in the warm climates considered in the present comparison. Another benefit of R-744 is the potential for compact system design and the good properties R-744 offers for using the system as a heat pump in reversed mode.

R-744 systems represent a sustainable alternative for mobile AC systems, ready for a European implementation in the near future.

LCCP results for hot locations in China and Indian indicate an energy saving potential related to the operation of the AC system by up to 12 % by applying an R-744 system. The total GHG emission could be reduced by 40 % (India) and 55% (China).

If the current HFC-134a systems implemented in new Chinese cars would be replaced by R-744 systems in 2008 instead of 2012, between 38 and 93 x 10^6 metric tons of GHG emissions could be avoided. The same scenario would give a saving between 13 and 31 x 10^6 metric tons of GHG emissions in India.

1. INTRODUCTION

HFC-134a emissions from mobile air conditioning systems are the largest source of HFC-emissions and the resulting direct greenhouse gas emissions are the second largest within the refrigeration sector. Due to the growing number of AC systems installed in the world fleet of cars, especially small cars, the emissions are likely to increase also in the future, even if efforts are made to reduce leakage. The high global warming potential (GWP) of HFC-134a (GWP = 1410 according to IPCC (2005)) has led to the development of alternative technology in order to decrease the global warming impact from such systems.

In China around 3 million cars have been produced in 2005. (2.958.400 according to the National Bureau of Statistics, China) This represents an increase of 15.2% compared to 2004. 63 % of the new cars are classified as small cars, *i.e.* an engine displacement lower than 1.6 litre.

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[1] Society of Automotive Engineers, Alternative Refrigerants Cooperative Research Project, SAE ARCRP

Most of the cars are equipped with an AC system with an aftermarket installation cost approximately 200 € (~2000RMB). The price for recharging the system in China with HFC-134a is in the region of 5 €, which is similar in India, *i.e.* 1 kg HFC 134a = 444Rs ~ 8€.

Figure 1 shows the car production numbers of the fast growing car manufacturing nations in Asia, India (A) and China (B).

A 20% growth based on the current production numbers is seen as a realistic scenario for the two nations. (SIAM and CAAM, 2005).

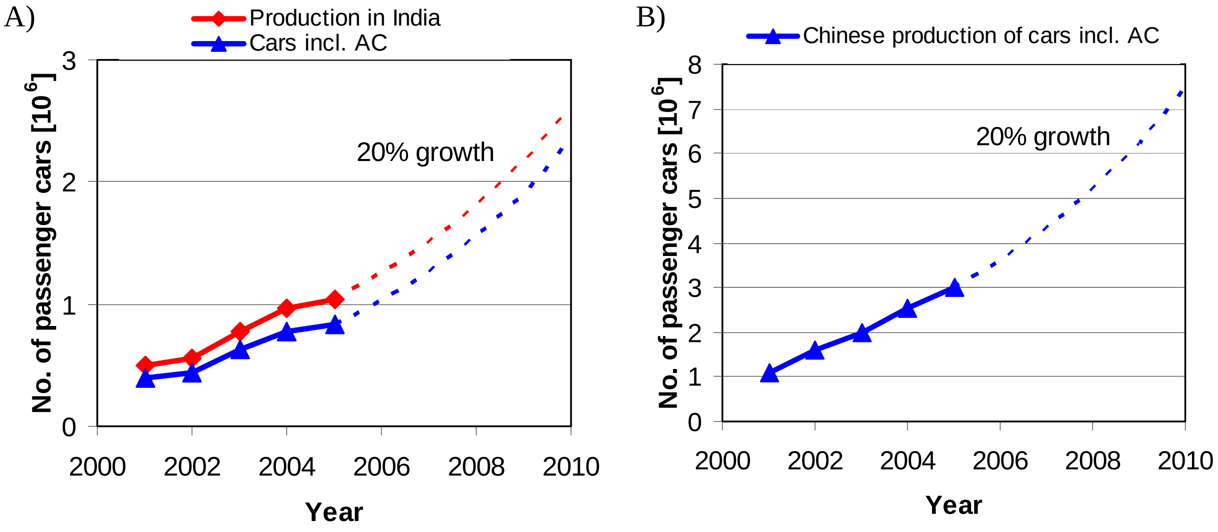

Figure 1. Car production numbers of India (A) and China (B), *(SIAM, 2005 & CAAM, 2005)*

2. LIFE CYCLE CLIMATE PERFORMANCE

Simple theoretical analysis indicates low energy efficiency for R-744 systems compared to HFC-134a, especially at elevated ambient temperatures. However, experimental investigations (SAE ARCRP, 2002 and Hrnjak, 2003) have shown that R-744 systems can be made with equal or better energy efficiency than HFC systems if the design takes into account the special characteristics of the refrigerant. By applying a LCCP analysis to compare different systems, their real life behaviour is taken into account, in contrast to comparison at design point conditions.

LCCP is divided into three parts representing the equivalent GHG emissions:

- related to transportation of the system (mass),
- the direct impact, related to the refrigerant (leakage, production, etc.)
- the indirect impact, dependent on the system performance.

The main LCCP analysis input values are shown in the following figures. The calculation procedure is similar to the investigation shown by Hafner, 2005.

The local climate is an important factor for the usage of the mobile AC system. The hourly temperature bin[2] of the main cities in India and China are identified as reference locations for the LCCP calculations, as shown in Figure 2.

Focus will be given to the warmest cities, since they are representative for a 'worst' case scenario.

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[2] Accumulated number of hours with a certain temperature range (see also Figure 2)

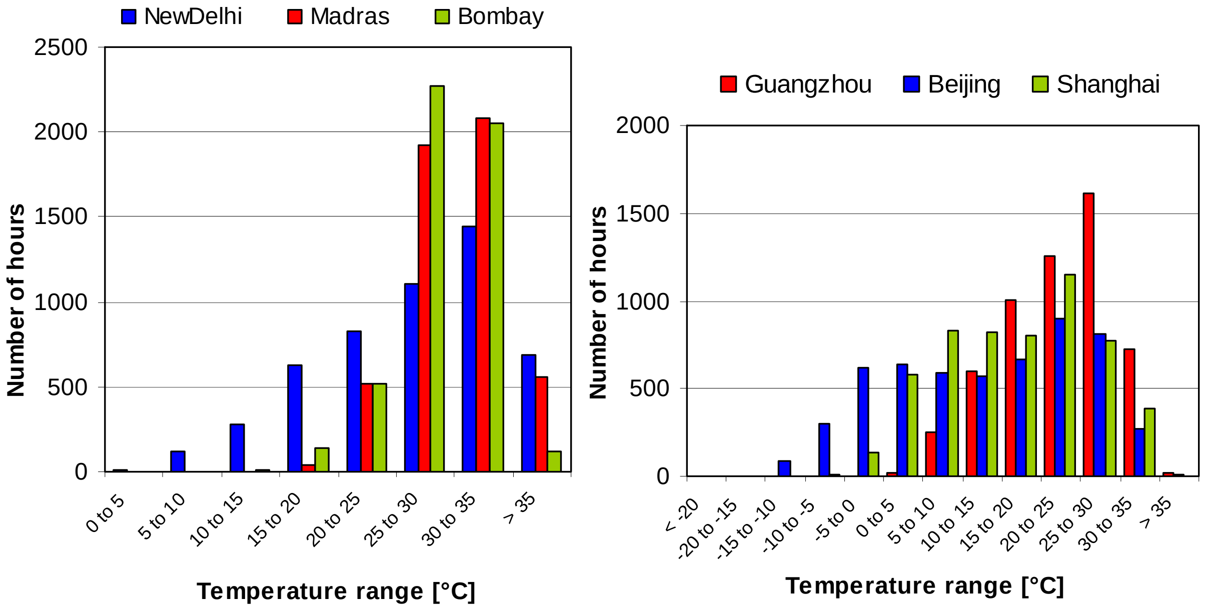
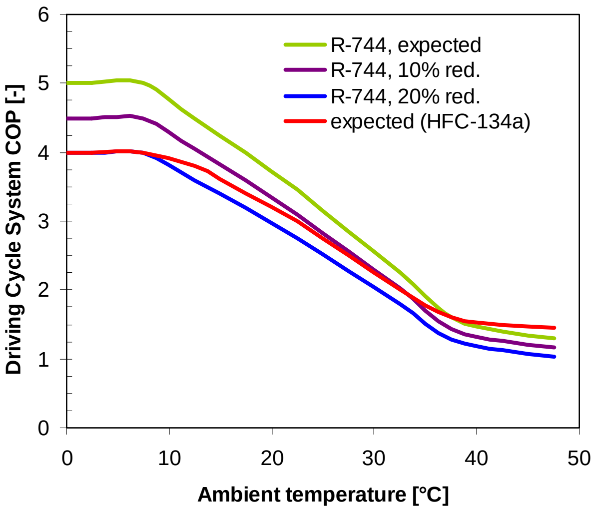


Figure 2. Temperature bin of the major cities in India (A) and China (B), hourly values between 6 a.m. and 8 p.m., 5475 h/a; *(METEONORM 5.1)*

The influence of different system efficiencies will be investigated by applying the COP values shown in Figure 3 in the LCCP calculations. The COP figures assumed are based on earlier measurements in different projects, such as ARCR project, and ongoing discussions in the EU B-COOL project (Hafner and Nekså, 2005). The AC systems are operated/controlled as shown in Figure 4, *i.e.* the AC usage ratio and the required cooling capacity is a function of the ambient temperature.



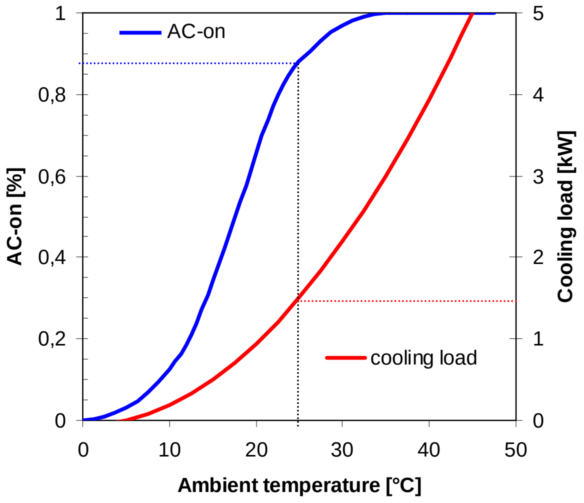


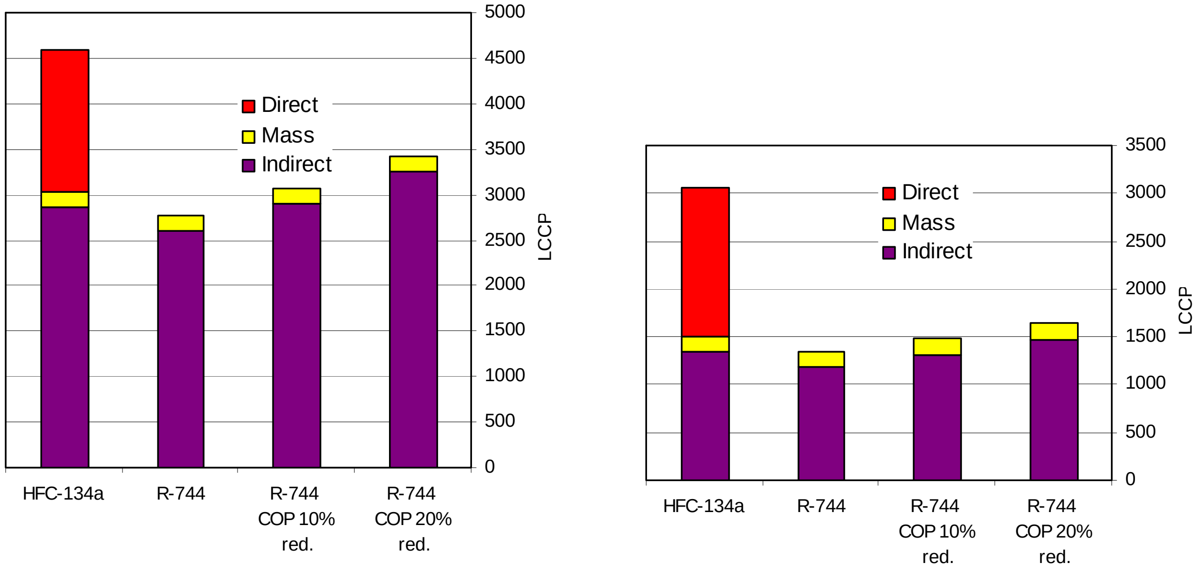
Figure 3. System COP, different scenarios

Figure 4. Major LCCP input characteristics

As an example, if the ambient temperature is 25°C, the required cooling capacity is appr. 1.5 kW, while the AC system is in operation 88% of the time when the car is driving at these conditions.

2.1 Results of LCCP analysis

The resulting LCCP of relative warm and large cities in India (Madras) and China (Guangzhou) is shown in Figure 5.


A) Madras, India

B) Guangzhou, China

Figure 5. LCCP for AC-passenger cars in India, Madras (A) and China, Guangzhou (B), HFC leakage scenario '*Case A*' as shown in Table 1.

Even if the R-744 system has a lower system COP at certain or all ambient temperatures compared to the HFC-134a, the total LCCP of an R-744 system is significantly lower than that of the HFC system. If the systems do have the expected system COP (see Figure 3), at equal cooling capacities an R-744 system would require 10 - 12% less energy, *i.e.* less fuel demand compared to the HFC system during the lifetime of an car.

The direct GHG emissions of the HFC-134a system (upper part of the HFC bar in Figure 5), due to refrigerant leakage, are equal to emissions of driving a car corresponding to use of additional 580 litres of petrol.

3. AMOUNT OF GHG EMISSIONS DUE TO MAC HFC-134a

To estimate the amount of GHG emissions related to HFC in cars, two scenarios are assumed:

Case A represents an optimistic scenario for the handling of HFC in mobile AC systems. The end of life recovery rate is high (80 %), mainly due to the value of the refrigerant. Also during service the feasible amount of refrigerant is recovered, however, about 20% of the refrigerant is not recovered due to the complex and time consuming process which is required to recover larger amounts. In this case, each vehicle releases around 1 kg of HFC during its entire lifetime.

Case B represents a worst case scenario, i.e. no recovery during the services and at end of life. An average vehicle will lose approximately 3.2 kg of HFC within 12 years of operation.

Table 1. Assumptions for the two HFC emission scenarios.

	Case A	Case B
Vehicle lifetime [years]	12	
System charge [g]	650	
Annual HFC leakage [g/a]	40	
No. of lifetime services [-]	5	
Emissions of HFC producing and re-processing [kg CO_2 eq.]	133	
End of life recovery rate [%]	80	0
Loss of remaining charge at service [%]	20	100
Total HFC leakage [g]	1034	3250

Figure 6 shows the equivalent CO_2 emissions due to HFC-134a to be released of vehicles in **India.** The numbers are based on production numbers of the year 2005. As a reference, the total annual GHG emissions of Norway are between 50 and 60 million metric tons.

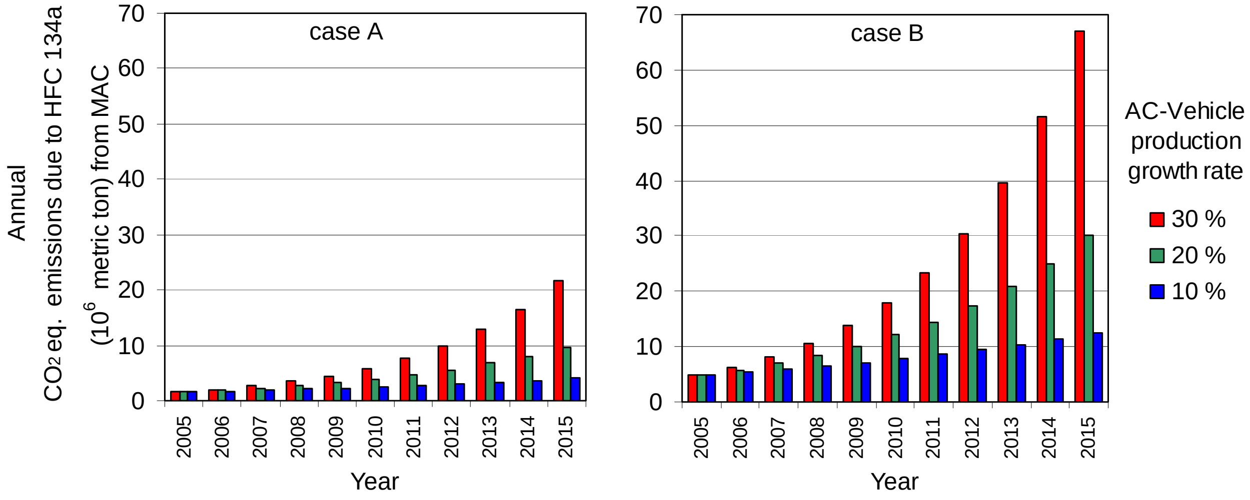


Figure 6. CO_2 equivalent emissions due to HFC-134a to be released from cars in India, case A & B.

The amount of GHG emission which could be saved by introducing R-744 MAC systems in all new Indian cars from the year 2008 until 2012 is shown in Figure 7. If India gets sufficient support and decides to introduce R-744 MAC systems and phases out HFC-134a at the same time in 2008 instead of waiting until 2012, up to 31 million metric tonnes of GHG could be saved. If the phase out imitative is delayed until 2009, the saving potential is up to 28 million metric tonnes of GHG.

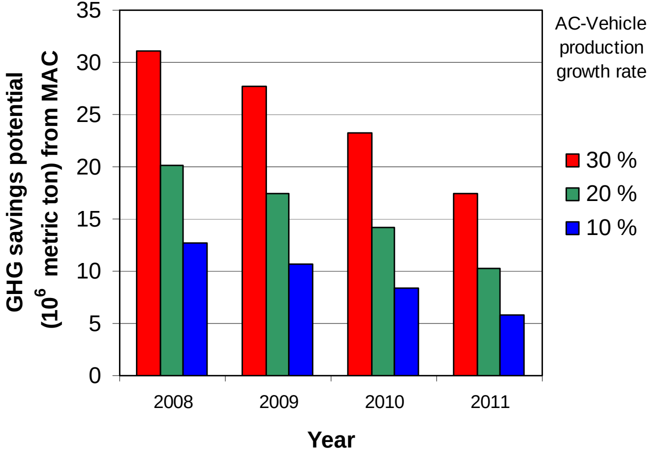


Figure 7. Total amount of GHG saved by introducing R-744 MAC systems in all new Indian cars, instead of delaying the introduction until 2012. Case A.

Figure 8 shows the equivalent CO_2 emissions due to HFC-134a to be released of vehicles produced an operated in **China**. The numbers are based on production numbers as of the year 2005.

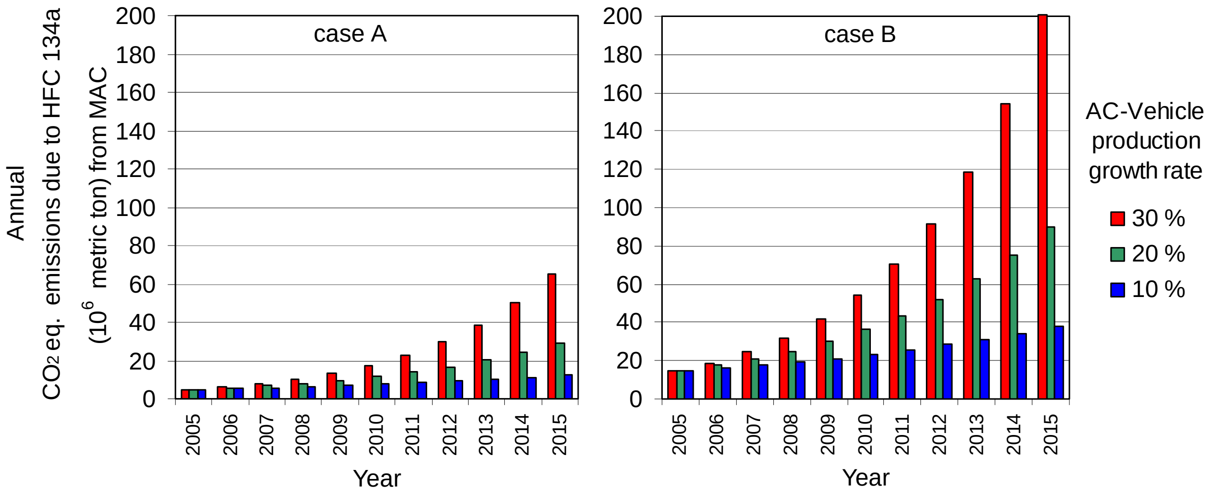


Figure 8. CO_2 equivalent emissions due to HFC-134a to be released from cars in China, case A&B.

If China gets sufficient support and decides to introduce R-744 MAC systems and phases out HFC-134a at the same time in 2008 instead of waiting until 2012, up to 93 million metric tonnes of GHG could be saved, as shown in Figure 9. If the phase out imitative is delayed until 2009, the saving potential is up to 83 million metric tonnes of GHG.

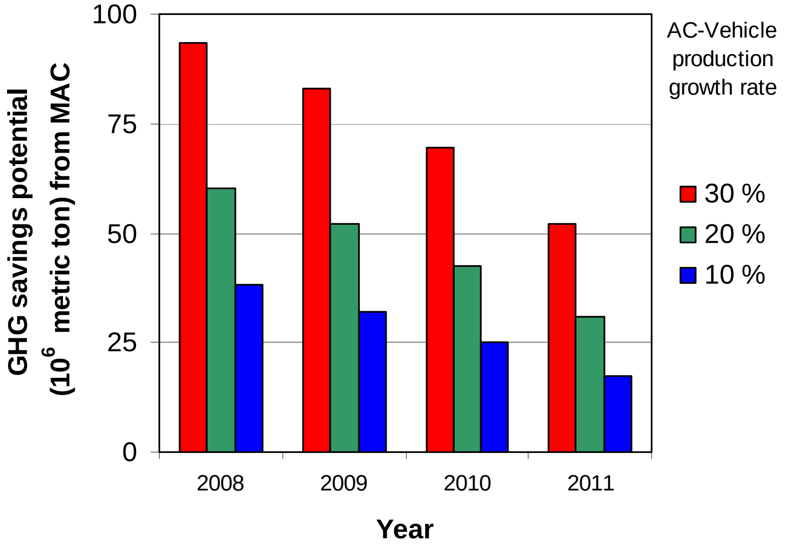


Figure 9. Total amount of GHG saved by introducing R-744 MAC systems in all new Chinese cars, instead of delaying the introduction until 2012. Case A.

If case B is applied the values in Figure 7 & 9 are 3 times higher.

This example shows the potential of GHG savings only related to the AC systems of passenger cars produced in China and India in the near future.

If the official phase out of HFC-134a is delayed beyond 2012, the potential savings shown in Figure 7 and 9 become substantially higher.

4. ALTERNATIVE MAC SYSTEMS

4.1 R-744 (Carbon dioxide)

The revival of applying carbon dioxide as working fluid started with successful experimental investigations in the laboratories of NTH / SINTEF in 1988, Lorentzen and Pettersen (1992). After many years of further research, the scientific community got interested in this alternative working fluid. The development of efficient system components was done within different national and international projects, .i.e. RACE, SAE ARCRP , VDA, etc.

Compared to state of the art HFC-134a systems, R-744 mobile AC systems offer (Wolf, 2004):

- faster cool down, improved comfort control,
- reduced weight,
- compactness, *i.e.* the size of the heat exchangers, accumulators, etc. is smaller,
- equal safety,
- less energy demand during operation (up to 26 € / year, means 312 € savings for the customer during the lifetime of the car),
- reduced cost of service and recharge,
- slightly higher system cost (between 5 € and 80 €),

In addition, the natural refrigerant carbon dioxide (R-744) offers new possibilities for design of flexible, efficient and environmentally benign mobile heat pumping[3] systems. As high-efficient car engines with less waste heat are developed, extra heating of the passenger compartment is needed in the cold season. A reversible transcritical R-744 system with gliding temperature heat rejection can give high air delivery temperature which results in quicker heating of the passenger compartment and improved defogging and defrosting of windshields.

4.2 Maturity of other alternatives

Recently, the chemical industry has identified another synthetic substance or a mixture of different synthetic fluids, which is claimed to offer a solution for the MAC systems of the future. However, related to these new synthetic fluids there are many open issues like, safety, toxicity (including by products and decomposition products), stability, etc. The required tests and verification procedures of these synthetic alternatives are time consuming.

Gustav Lorentzen 1995:
"… In the current situation, when the CFCs and in a little longer perspective the HCFCs are being banned by international agreement, it does not seem very logical to try to replace them by another family of related halocarbons, the HFCs, equally foreign to nature….In any case it must obviously be much more preferable to use natural compounds, which are already circulating in quantity in the biosphere and are known to be harmless, as I have advocated for years with only lukewarm response…"

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[3] Heat pumping system: Air Conditioning (refrigeration) or/and heat pump systems.

5. CONCLUSIONS

- Release to the atmosphere of chemicals that are foreign to nature involves a great risk
- R-744 AC systems are the sustainable solution for mobile AC and heat pumping systems of the future
- Large GHG savings can be achieved by an early introduction of R-744 and a rapid phase out of HFC-134a not only in Europe. The fast developing Asian nations India and China may avoid several hundred million metric tonnes of tradable GHG emissions.

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