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HOW TO CONSIDERABLY REDUCE GREENHOUSE GAS EMISSIONS DUE TO MOBILE AIR CONDITIONERS

CONTENTS

SUMMARY

This paper is one input to respond the Council request of 10 October 2000 to *"study and prepare measures in reduction of all greenhouse gas emissions from air conditioning in vehicles"*.

Greenhouse gas emissions due to mobile air conditioning are significant and growing fast in the European Union. The European Commission estimates that the emission will be between 31 and 53 Mt CO_2 eq in 2010 and between 54 and 90 Mt CO_2 eq in 2020 without technological improvement or additional policies. About one third of these emissions are due to higher fuel consumption and consequent CO_2 emissions and two thirds due to the emissions of the refrigerant, HFC-134a. Both CO_2 and HFC-134a are greenhouse gases controlled under the Kyoto Protocol, ratified by the EU in May 2002.

The consequence of this development that the improvements of the CO_2 /car commitments of to reach the 140 g/km by 2008 are significantly eroded. Action is needed to reduce both HFC and CO_2 emissions.

Containment of HFC 134a is possible but seems rather expensive. Substitutes for HFC 134a are available and seem to be the more cost-effective solutions. Overall the conclusion of this paper is that it is possible to phase out the refrigerant without excessive cost.

There are still a number of open questions with regard to the most appropriate substitute to HFC-134a. The policies should not prescribe the substitute in all details but lay down a flexible approach which allows manufactures and suppliers to select the most appropriate option within given time limits.

Since the additional fuel consumption is significant one should define test procedure as a pre-requisite for monitoring and future policy development. Therefore, the test procedure work should be continued, and a test procedure ready for use should be developed.

In this paper also relevant questions to stakeholders are posed in order to get their views by 11 March 2003 so that these can be taken into account when the Commission will make its proposal or proposals to significantly reduce greenhouse gas emissions due to mobile air conditioning. This paper is an input to a stakeholder conference that is organised in Brussels on 10 and 11 February 2003.

1. INTRODUCTION

Mobile air conditioners (MACs) result in the direct emissions of fluorinated gas (HFC-134a in most systems after 1994) and the indirect emissions of carbon dioxide from increased fuel use. Both fluorinated gases and carbon dioxide are greenhouse gases covered by the Kyoto Protocol. MACs are already considered standard equipment on Japanese and North American vehicles. They are now penetrating very rapidly to the vehicle fleet of Europe. With increasing income, MACs are expected to penetrate every market.

Both the European Commission and the European Union (EU) Member States are concerned about the impact of this development on the emissions of greenhouse gases. In its conclusions on 10 October 2000 Council of the European Union requested the Commission to *"study and prepare measures in reduction of all greenhouse gas emissions from air conditioning in vehicles"*. As part of the European Climate Change Programme (ECCP) the Commission is studying the different aspects of greenhouse gas emissions due to mobile air conditioning and will make legislative proposals to reduce the emissions in 2003.

As vehicle manufacturing is a global business, the Commission considers it important to consult stakeholders. To this end, it has organised a stakeholder conference on the options to reduce greenhouse gas emissions due to mobile air conditioning. The purpose of this paper is to give the preliminary assessment of the European Commission services of the order of magnitude of the environmental problem related to MACs as far as emissions of greenhouse gases are concerned. It will also outline the main options that are available to reduce such emissions and ask which of these measures would reduce emissions in a sustainable and credible manner. At the end of each section some specific questions are posed. In annex 2 some additional question related to policy development are also posed.

This paper – prepared by Environment Directorate-General (DG) in close consultation with Enterprise, Trade, Economic and Financial Affairs as well as Transport and Energy DGs – is an input to the Conference on Options to Reduce Greenhouse Gas Emissions due to Mobile Air Conditioners, which is due to take place in Brussels on 10 and 11 February 2003.

The Commission would welcome replies to the specific questions raised during the conference, and in any event, no later than March 11 2003. The responses can be sent to env-mac-responses@cec.eu.int.

1.1. European action: European Climate Change Programme

The European Climate Change Programme (ECCP) was established in June 2000 to help identify the most environmentally and cost-effective measures that would help the European Community to meet its Kyoto Protocol target to reduce overall greenhouse gas emissions to 8% below 1990 levels by 2008-2012. One of the ECCP working groups considered the policy options for reducing emissions of the fluorinated greenhouse gases, including emissions of hydrofluorocarbons (HFCs) from MAC.

The working group was made up of stakeholders from Member States, industry and environmental NGOs. In its report of June 2001, the working group noted that MAC sector was evolving into one of the major sources of HFCs with additional indirect emissions from consequential increase in fuel consumption. The working group considered that there was ample potential for cost-effective emission reductions, including HFC based systems and “next generation” systems.

The potentials identified by the working group to reduce the refrigerant emissions of existing HFC systems were i) improving leakproofness by design, ii) effective recovery during servicing, iii) effective recovery at end of life, and iv) the reduction of specific charge per system. The identified options to improve the MAC systems were i) the use using carbon dioxide as the refrigerant, ii) the use of hydrocarbon systems with secondary loop and iii) the construction of hermetic systems.

In 2001, the working group considered that more time and research was needed to determine the practicality of some of these options. However, it recommended that emissions monitoring and containment of current MAC systems be included of the regulatory framework for reducing the overall emissions of fluorinated gases. The working group recommended that a Community wide legislative framework should be introduced, as opposed to Member States promoting their own legislation, and that this legislative framework should include measures to improve the containment of fluorinated gases, to restrict uses in certain applications and require the reporting of data on fluorinated gases. This regulatory framework is currently being developed by the Commission and is expected to be ready by the end of September 2003.

Since the ECCP report, the Commission has been considering in more detail the problem of greenhouse gas emissions from MACs both in terms of additional CO_2 emissions due to additional fuel consumption and in terms of HFC emissions due to the leakage of refrigerant at different stages. At the same time, industry has researched and developed further the options to reduce considerably greenhouse gas emissions from MACs. These actions have been discussed under the auspices of the Mobile Air Conditioning Climate Protection Partnership, the Alternate Refrigerants Task Force of the Society of Automotive Engineers (SAE) Interior Climate Control Standards Committee, the SAE Alternative Refrigerant Cooperative Research Program (http://www.sae.org/calendar/aars/2002/), the VDA Alternate Refrigerant Winter Meeting 2003 (http://vda.cysell.com/index2.php) and other fora. The first commercial application of a MAC based on carbon dioxide as the refrigerant was introduced by Toyota and supported by Denso a few months ago in Japan and California and considerable research and development of both CO_2 and HFC-152a of companies in the EU, Japan, the US and elsewhere is on the verge of bearing fruit.

As far as the impact of the usage of mobile air-conditioning on fuel consumption is concerned the Commission launched in 2002 a study on options to integrate the use of mobile air conditioning systems and auxiliary heaters into the EU type approval and the EU fuel consumption tests for passenger cars (Directives 70/220/EEC and 80/1268/EEC). A final report has been forwarded in December 2002 (TNO 2002), and follow-up activities will be discussed in the beginning of 2003.

1.2. National Action in Europe, Japan and the US

Some EU Member States have begun to put in place or propose measures to reduce greenhouse gas emissions from MAC. Austria has banned the use of HFCs in MACs from 1 January 2008. Switzerland also intends to introduce a similar prohibition. Denmark introduced in April 2001 a tax on all fluorinated gases. For HFC-134a it was €13,5 (DKK 100) per kilogram. In 2002, Denmark introduced a number of prohibitions on the use of fluorinated gases, although the use of HFCs in MACs is not prohibited. On 1 January 2004 will introduce a tax of €31 (NOK 234) per kilogram of HFC-134a.

Most other Member States are developing policies for limiting emissions of fluorinated gases. For instance, the German Federal Environment Ministry issued on 30 September 2002 a consultation paper in which it proposed possible actions to minimise emissions of fluorinated gases. Thus far about 70 institutions, companies etc. have reacted on the paper in writing. Further consultations take place in Bonn in and there will be a specific consultation with regard to MACs at the end of January. However, given the conclusions of the Council of 10 October 2000, many Member States are waiting for the Commission proposal before actually putting policies into place.

In Japan, the recovery of CFCs and HFCs mobile air conditioning has been mandatory since 1 October 2002 in accordance with the Fluorocarbon Recovery and Destruction Law. As part of the final disposal of a vehicle by a registered recovery operator, a fixed fee of €21 (or 2,580 yen) per vehicle has to be paid to the association of automobile manufacturers called "Japan Automobile Recycling Promotion Center" to recover and destroy the refrigerant. The fee was decided by manufacturers based on the actual cost in accordance with guidelines issued by the Government. An owner of a vehicle can pay the fee at anytime before disposal of the vehicle by purchasing so-called "Fluorocarbon Coupon". As mobile air conditionings are concerned, there is no regulation on air pollution or energy efficiency in Japan.

In the United States, recovery and recycle at service and vehicle disposal is mandatory and is strongly supported by vehicle manufacturers and automotive service technicians. The Mobile Air Conditioning Society, the US EPA, environmental organisations and others cooperate to promote proper service (“no recharge without repair”). The Society of Automotive Engineers is just beginning new voluntary efforts to promote the use of quality parts that help contain refrigerants and maintain fuel efficiency. Further, the Supplemental Federal Test Procedure (40CFR 86.132-00, 86.160-00 and 86.161-00) prescribes the tests designed to cover the influence of air conditioning systems on fuel consumption and emissions. The SFTP has been implemented in the US in the standard test procedure for emissions in the year 2001, starting with 25% of the model year 2001 vehicles. A 100% coverage will be achieved with the year 2004-model year.

1.3. Existing EU legislative framework

In addition to Regulation (EC/2000/2037), which prohibited the use of CFCs in refrigeration and air conditioning equipment from 1 January 2001, there are several directives that are relevant directly or indirectly to MACs. MACs are not covered by the EC type approval system yet and thus, there are no requirements relating to the safety or environmental performance of MACs. During the type approval tests the air conditioner is switched off. Thus, the impact of MACs and other auxiliary equipment on fuel consumption as well as the emissions of CO_2, NOx, CO, PM, benzene etc. is not tested. In consequence, the customer purchasing a car has inadequate knowledge of the car’s increased fuel consumption or environmental performance when the air conditioner is operated. Table A1 in Annex 1 summarises Directives, which have relevance to mobile air conditioning as far as the type approval is concerned.

Table A2 in Annex 1 shows the Directives having relevance to MACs but not being part of the vehicle type approval system. The End-of-life vehicle (ELV) Directive[1] – approved on 18 September 2000 – is the only one that has direct relevance to MACs. It states that Member States need to ensure that the treatment operations for de-pollution of end-of-life vehicles are such that the cooling liquids and air conditioning system fluids are removed, separated and stored. There is an overall requirement to recycle 85% of the weight of the car.

The other Directives indicated in Annex 1 are relevant if the environmental impact of MACs needs to be regulated.

2. Impact Of Mobile Air Conditioners On EU's Greenhouse Gas Emissions up to 2010

This section discusses the overall impact of MACs using HFC-134a on greenhouse gas emissions. First, the lifetime emissions of HFC are estimated. This is followed by an assessment of CO2 emissions due to additional fuel consumption as a result of operating MACs. In section 2.3 these estimates are summarised to obtain the overall order magnitude of the environmental impact of MACs.

2.1. Direct lifetime emissions of vehicle using a MAC based on HFC-134a

Losses of HFCs occur at six stages of a life of a car and there are no studies that include all such emissions. Therefore, the Commission requested Ecole des Mines de Paris (2003) to provide the best estimates of direct greenhouse the emissions that are due to the use of HFC-134a as a refrigerant. Since it was expected that the emissions during the regular use of the car would be the dominating source, the Commission selected Öko-Recherche and Ecofys (forthcoming) to carry out an empirical study on the leakage rates. Based on these two streams of work, the Commission estimates that the total direct lifetime emissions of a vehicle with a MAC running with HFC-134a would be 1555.3 kg of CO_2 equivalent in the optimistic case (Table 1).

However, the emissions during the "regular" use of the car[2] are estimated by Öko-Recherche and Ecofys (forthcoming) to be rather high being 57 grams per annum in the EU[3]. These emissions occur because of small leaks in the compressors (shaft seal, O-

[1] Thus far five Member States (Austria, Denmark, Germany, the Netherlands and Sweden) have officially communicated their transposition measures to the Commission. The Commission is now in the process of assessing the answers to the Reasoned Opinions and, should these answers not be sufficient to put an end to the breach of the communication obligation, the Commission will further pursue the infringement procedure by applying to the Court of Justice.

[2] Calculated here using 12 years as the average lifetime of a car and 13000 km as the average vehicle kilometres per car.

[3] Using a different empirical estimation method, Schwarz (2002) found the annual "regular" leakage rate of three German manufactured cars in Germany to be 6,3% (with a tolerance band of 25% around it) which would translate to 47 grams.

rings), hoses, fittings etc. during the normal use. In addition, there are "irregular" emissions due to accidents, stone hits, product defects etc. Based on the analysis of the refrigerant carried in vehicles regularly serviced by the nine authorised dealers within the period 1999 to May 2001, Schwarz (2002) estimated these losses to be 1,9% per annum[4]. Using the average charge of 750 grams as the basis, these irregular leaks would amount to 15 grams per annum. Thus, in total the fugitive emissions (including accidental rupture) are estimated to be 72 grams per annum.

Table 1:
Estimates of direct lifetime emissions from mobile air conditioners using HFC-134a as the refrigerant in EU-15

	Optimistic	Pessimistic	Optimistic	Pessimistic
	HFC-134a (grams)	HFC-134a (grams)	CO_2 eq (kg)	CO_2 eq (kg)
Heels*)	7,5	45,0	9,8	58,5
Emissions at filling of the system	5,0	10,0	6,5	13,0
Fugitive emissions (including accidental rupture)	900,0	1287,0	1170,0	1673,1
Emissions from recovery during servicing	198,0	621,0	257,4	807,3
Emissions at ELV	67,5	428,3	87,8	556,8
Total	**1178,0**	**2391,3**	**1531,4**	**3108,7**

*) Heels = Residues of HFCs left in non-refillable containers.
Source: Estimates of DG Environment based on Ecole des Mines de Paris (2003) and Öko-Recherche and Ecofys (forthcoming)

Emissions from garages during maintenance and repair are probably the most difficult to estimate because these emissions depend on the on recycling and recovery equipment used, and in particular the skills and practices of the mechanics. Depending on the skills, knowledge and care taken by the maintenance personnel, the leaks during service and repair of MACs are widely different. Some leaks occur when connecting of hoses, and some refrigerant will remain in the hoses and in the MAC system (in lubricating oils). The latter will be released when MACs are repaired. However this amount is probably included in the estimate of "irregular leaks" of Schwarz (2002) so this emission should not be re-estimated because this would be double-counting.

Overall it is estimated that – for each service – about 5-10 grams is lost when connecting and disconnecting the hoses to the recovery and recycling machine and during the recycling stage, and another 90 grams remains in the hoses. Finally, there are small emissions due to the handling of the gas in garages but these are difficult to estimate. If the recovery and recycling is not carried out all HFC would be vented (i.e. about 400 grams would be lost). Thus, for the purposes of getting an overall estimate of practice, the "optimistic" loss in service is estimated to be 99 grams per service. [5]

Siegl et al (2001) measured through Sealed Housing for Evaporative Determination apparatus the leakage rates for the regular losses. They found the leakage to be 0.07g of HFC-134a per day resulting into about 3.2% leakage rate. This is a lower figure but does not include the irregular losses (which were estimate at 1.9% by Schwarz). Note that service losses are not included in any these leakage rates.

4 The percentage varies from 1.5 to 2.2 % according to make of car.

5 In Mobile Air Conditioning Society-Worldwide (MACS-W) 2000 Field Survey it was assumed that 6% refrigerant is lost the recycling process. This would imply a loss of 45 grams of HFC-134a per service

It is also is difficult to estimate the emissions of HFCs is at the end-of-life of a car. In the EU, the recovery of the fluid is mandatory due to the End-of-Life Vehicle Directive. However, there is considerable uncertainty about how much of HFCs will be recovered. In a survey carried out by Auto Recycling Nederland (ARN) for NOVEM (Gröniger 2003) it was found that of the cars having HFC-134a based mobile air conditioners reaching their end-of-life without an accident, ARN was able to recover 38% of the initial charge, and of for cars involved in accident it was able to recover still 34%[6]. The sample of this survey was small (10 and 136 cars respectively), and thus the results should be interpreted as illustrative. But it is clear that the amount of refrigerant recovered depends on how much was left in the system and that again depends on what the "regular" leak rate was.

It is assumed in the "optimistic" case that the ELV Directive will ensure the recovery of most of the refrigerant. Thus, is assumed that some 10% of the original charge would not be recovered and thus only 68 grams of HFC-134a would be released to the atmosphere.

Finally, CO_2 and HFC-134a emissions during the manufacturing and distribution of HFC-134a because of additional energy use and fugitive emissions, as well as the emissions from destroying HFC-134a at ELV stage should be included in the estimates. Due to lack of time, and given the fact that these emissions are likely to be rather small (i.e. about 1-2 percent), they are not considered further in this paper.

It is quite possible that current emissions are higher than what was presented above. The emissions due to heels[7] could be as high as 6% of initial charge (i.e. 45 grams) and the emissions during the fill of the MACs could be 10 grams. Thus, the emissions before the car is taken to use could be already 55 grams. The "irregular losses" may have been underestimated, and thus in the "pessimistic" case, those losses are assumed to be twice as high as in the optimistic case. The "regular emissions" are not changed in the "pessimistic" case. Thus, fugitive emissions could be as high as 1287 grams over the lifetime of MACs.

If there is no recovery and recycling in garages, the emissions would be much higher at this stage. This is reflected in the "pessimistic" case assuming that refrigerant would be vented. This would result in a loss of 621 grams over the lifetime of a MAC. Finally, in the "pessimistic" case, it is assumed that refrigerant would not be recovered at the ELV stage at all resulting in an end-of-life loss of 428 grams of HFC-134a.

In table 2 the results of "optimistic" and "pessimistic" cases are summarised in terms of EU-15 wide emissions in 2010 and 2020. Given the likely share of MACs (70% in 2010 and 95% in 2020) of the total EU-15 vehicle stock the lifetime emissions from a MAC are estimated to be between 128 and 262 kg of CO_2 eq in 2010 due to refrigerant leaks. This would result into EU-15 emissions of 18-28 Mt of CO_2 in 2010 and of 28-58 Mt CO_2 eq in 2020.

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assuming that recovery and recycling is carried out properly. In this paper the "optimistic" case assumes that not all garages carry out the recovery and recycling properly, but that most do.

6 For CFC-12 based MACs in cars coming to a normal end of life (no accidents) the recovery rate was much lower, i.e. 13%.

7 Residues of HFCs left in non-refillable containers.

Table 2:
HFC-134a emissions in "optimistic" and "pessimistic" cases in EU-15, 2010 and 2020

	2010	2020
Number of cars in EU-15	206	233
of which with air conditioners	144	221
emission per car (optimistic) kg CO2 eq	127,6	127,6
emission per car (pessimistic) kg CO2 eq	262,4	262,4
Total emissions (optimistic) Mt CO2 eq	**18,4**	**28,2**
Total emissions (pessimistic) Mt CO2 eq	**37,8**	**58,1**

Source: Estimates of DG Environment based on des Mines de Paris (2003) and Öko-Recherche and Ecofys (forthcoming)

2.2. Emissions of CO_2 due to increased fuel consumption

The ECCP Working Group estimated that the usage of air conditioning systems under average EU conditions cause an increase of fuel consumption of about 5%. TNO (2002) estimated 3.1% increase for Northern Europe, 4.2% for Central Europe and 6.2% for Southern Europe[8].

The most recent estimate of additional fuel consumption due to MACs (Johnson 2002) showed that in the US the additional annual CO_2 emissions were 6% higher due to MACs. These results cannot be transferred to the EU directly because three reasons: i) the engines in the US cars are bigger than in the EU (implying that the percentage would be higher in the EU[9]), ii) the EU is more temperate than the US (implying that the use of MACs would be less intense in the EU and thus CO_2 emissions would be lower) and iii) in the EU the technology (compressors and controls) of MACs and driving cycles are not the same as in the US (implying either a higher or a lower fuel consumption).

CO_2 emissions from EU 15 in 2010 from all on-road passenger cars are estimated to be about 430 Mt CO_2 in 2010 and about 415 Mt CO_2 in 2020. The reduction of the emissions is reflecting the increased fuel efficiency of the vehicle fleet: average EU-fleet CO_2 emissions are projected to be 154 g/km in 2010 and 130 g/km in 2020. Finally, the share of MACs in the passenger car fleet of the total vehicle stock are estimated at 70% and 95% in 2010 and 2020 respectively. With these estimates, it is possible to make an "optimistic" and "pessimistic" estimate.

In the "optimistic" case it is estimated that the additional fuel consumption from MACs would be only 4% whereas in the "pessimistic" case the fuel consumption is actually 8%

8 It should be mentioned that the actual additional fuel consumption is in the range of 20 to 40% if just the average of the additional fuel as measured under the UDC+EUDC is taken. These values are then weighted by climatic conditions and "usage pattern" the EU regions. These "usage pattern", however, are quite uncertain and based on "best estimates".

9 It should be noted that the thriftier the cars get the higher the load of auxiliary equipment, like mobile air conditioners, and the higher the relative increase in fuel consumption (Johnston 2002). In other words, the percentage increase in fuel consumption due to a MAC is much larger for a fuel-efficient car (with a small engine) than for a car with a powerful, fuel inefficient engine.

reflecting the fact that when cars are getting thriftier the relative power demand from auxiliary equipment increases.[10] Table 3 summarises the estimates.

Table 3:
Additional CO_2 emissions due to additional fuel consumption due to mobile air conditioning in EU-15, 2010 and 2020 (Mt CO2)

	2010	2020
Optimistic case	12.0	15.8
Pessimistic case	24.1	31.5

Source: Estimates of DG Environment based on Johnson (2002)

2.3. Total greenhouse gas emissions due to MACs up to 2010

The current penetration rate of MACs is over 80% and projected to be 90% in a couple of years. The EU-wide (EU-15) vehicle fleet is projected to be about 206 million cars in 2010. Assuming that 70% of that total fleet would be equipped with mobile air conditioners by 2010, the direct HFC-134a related emissions are estimated to be 18.4 Mt of CO_2 eq. per annum in the "optimistic" case in 2010 without any additional policies. By 2020, these emissions would be as high as 28.2 Mt CO_2 eq in the "optimistic" case with practically full share in the market of about 233 million cars.

Table 4:
Estimated annual greenhouse gas emissions due to mobile air conditioning in EU-15, 2010 and 2020

Mt CO_2 eq	2010		2020	
	Opti-mistic	Pessi-mistic	Opti-mistic	Pessi-mistic
Direct emissions because of the refrigerant HFC-134a	18,4	37,8	28,2	58,1
Indirect emissions due to additional energy consumption	12,0	15,8	24,1	31,5
Total	**30,4**	**53,6**	**52,3**	**89,6**

Source: Estimates of DG Environment based on Johnson (2002), Ecole des Mines de Paris (2003) and Öko-Recherche and Ecofys (forthcoming)

In addition, the energy consumption due to mobile air conditioners would represent 4% or 8% of the total CO_2 emissions of cars in 2010 12.0 Mt CO_2 in EU-15 reaching 15.8 Mt CO_2 in 2020 ("optimistic" case). Table 4 summarises the direct and indirect effects of MACs in EU-15 for 2010 and 2020[11] for both "optimistic" and "pessimistic" cases. It needs to be noted that the "optimistic" case of HFC emissions could also be added up with the "pessimistic" case concerning fuel consumption. In Table 4 all combinations are not presented to keep the table legible. It should be noted that as traffic becomes congested the fuel use per hour increases (due to less airflow through the condenser) and

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[10] Robert Farrington (NREL) will present results of the latest calculations of NREL of likely increase of fuel consumption for the EU during the conference. The preliminary calculations indicate that the fuel consumption is fairly close to the numbers presented in the "optimistic" case in this paper.

[11] Note that as emissions in 1990 were practically zero as the number of MACs was very small in the EU-15 almost all emissions presented here are additional to 1990/95 which is the base year for the Kyoto Protocol.

the speed decreases – with a net effect of a substantial increase in the fuel consumption due to mobile air conditioning.

Given the estimated vehicle kilometres, the total annual emissions would indicate that the greenhouse gas emissions in grams of CO_2 equivalent per vehicle kilometre for vehicles having a MAC would be about 16 g/km in 2010 and 19 g/km in 2020 in the "optimistic" case. In the "pessimistic" case the emissions would be as high as 28 g/km and 32 g/km in 2010 and 2020. Such numbers are high given the commitment of vehicle manufacturers of the EU, Japan and Korea to reduce the CO_2 emissions of the average new car by about 25% to 140 grams/kilometre (which corresponds to about 5.5 l/100 or 40 miles per gallon) by 2008. As this commitment does not cover the effect of mobile air conditioners the environmental problem is that in reality the 25% reduction in CO_2 emissions is substantially eroded by the introduction of MACs to the car fleet of the EU by the increase of both CO_2 and HFC-134a emissions. These emissions are over 10% of total greenhouse gas emissions of vehicles in 2010 and even more in 2020.

Question 1.a: Do the stakeholder share the estimates of the order of magnitude of the problem? If not, what would be considered incorrect?

Question 1.b: To what extent are the direct and indirect emissions due to air conditioning of buses and trucks similar to the passenger cars?

3. Options To Reduce Greenhouse Gas Emissions From Mobile Air Conditioners

In this section the main options for reducing greenhouse gases due to mobile air conditioning are described. For each option the main advantages and disadvantages – from technical, environmental, economic and safety points of view – are presented to the extent they are known to the Commission before the conference.

3.1. Containment of HFC emissions – "Enhanced HFC-134a technology"

In order to contain the emissions action is necessary to reduce emissions where this technically possible without excessive cost. It is difficult to know to what extent emissions could be reduced through improving the design of MACs, through better components etc. It is even more difficult to estimate to what extent emissions could be reduced from garages and ELVs as such information is almost non-existent in EU Member States.

The advantage from the containment option is that industry can continue refining the existing technology that they know well. Thus, the costs of improving the technology are not considered as "additional" costs but simply normal research and development costs due to intense competition in the air conditioning market place. The "enhanced" HFC-134a MAC is estimated to cost €20 and reduce emissions below the "optimistic" case in tables 2 and 3 but it is difficult to tell how much lower. Assuming that there would be a 50% reduction in "regular" leakage due in an enhanced HFC-134a table 5 gives the cost of reduction per tonne or CO_2 equivalent. The most likely positive impact of an "enhanced" HFC-134a to fuel consumption is not estimated in table 5 because i) this improvement is not known[12] and ii) a similar improvement is possible with other technologies (see sections 3.2.1-3.2.3)[13].

Table 5:
Cost of reducing a tonne of CO_2 equivalent by enhancing a HFC-134a mobile air conditioner in EU-15

Emissions reduced in kg CO_2 eq	444.6
Cost euros	20
Cost per tonne of CO_2 eq	**45**

Note: Assuming that 50% of regular losses could be reduced in an "enhanced" HFC-134a MAC without any additional energy saving.

The main disadvantage it would be very difficult to verify if the emissions reduction of an "enhanced" HFC-134a would be as described (or lower or higher than) in table 5. Moreover, since emissions occur in different stages of the lifetime of the MAC, it is practically impossible to monitor and verify to what extent any progress has been made. Finally, there is no single organisation responsible for the lifetime emissions from MACs and thus different players try to shift the responsibility. However, what table 5 seems to indicate is that enhancing the MAC would in the optimistic case be rather cost-effective (as the cost of abatement per tonne of CO_2 equivalent is below €50).

The Commission proposal for a new EC Regulation on fluorinated greenhouse gases will introduce some measures that should improve the containment of HFCs in MAC systems. It is envisioned that all precautionary measures practicable are taken to minimise leakage. This is likely to include i) MAC systems to be inspected annually for leakage, ii) persons involved in servicing MAC systems to have training requirements, iii) recovery of HFCs during servicing to be mandatory and iv) the recycling or destruction of HFCs recovered during servicing

It will not cover the recovery of HFCs from MAC systems at final disposal of the vehicle as this is provided for by the End Life of Vehicles Directive. Nor will it prescribe measures for the design and installation of MAC systems, although this is an area the Commission could consider at some future time to determine whether more prescriptive measures are appropriate.

12 It has been suggested that an "enhanced" HFC-134a would reduce fuel consumption by 25%.

13 It should be noted that even if it was possible to know how much emissions could be reduced by containment it would be difficult or impossible for industry to know how much this option would cost. As these costs are "hidden" they could be much higher than the costs of other options to reduce greenhouse gas emissions from MACs. In other words, research and development costs are true costs for industry even if they are not considered "additional".

Question 2.a: To what extent will the HFC emission be reduced through improving the design of MACs, through better components etc. What policies would help or hinder this process?

Question 2.b: How could the HFC emissions be reduced in a verifiable manner from garages and ELVs, given that such information is almost non-existent?

Question 2.c: To what extent is the research and development for enhancing HFC-134a systems competing for human and financial resources with the alternative refrigerant technologies? Is the balance between these two streams of work optimal given the challenge facing mobile air conditioning?

Question 2.d: Is containment of HFC-134a emissions from MACs the most cost-effective long-term solution from society's point-of-view?

3.2. Phase out of HFC 134a to alternative refrigerants

There are three alternative refrigerants among which the industry could choose to replace HFC-134a: hydrocarbons, HFC152a and CO_2.

3.2.1. Hydrocarbons

Hydrocarbons are used already widely used in the EU in applications such as domestic refrigerators and freezers because the flammability in these hermetically sealed appliances with very small charges of are not considered to be an excessive risk. In vehicle applications the environmental NGOs have been active in promoting hydrocarbons and some retrofit demonstration projects have been undertaken in Australia and the United States.

The advantage of using hydrocarbons instead of HFC-134a is that the greenhouse effect of refrigerant leaks could be eliminated completely. A switch to hydrocarbons would unlikely bring about an energy penalty vs. HFC-134a.

The likely cost of using hydrocarbons as a refrigerant is likely to be higher than enhanced HF-134a. In table 6 an illustrative calculation has been made assuming that a MAC using hydrocarbons would be used in a safe manner at an estimated cost of €30 to €50. Assuming that there is no energy penalty from using HFC-134a as the refrigerant, the cost of abatement per tonne of CO_2 equivalent is moderate.

Table 6:
Illustrative example of the cost of reducing a tonne of CO_2 equivalent by shifting to hydrocarbons as the refrigerant, and assuming that the safety related issues are solved in mobile air conditioner in EU-15

Emissions	**Optimistic case**	**Optimistic case**	**Pessimistic case**	**Pessimistic case**
Emissions reduced kg CO_2 eq	1531	1531	3109	3109
Costs	**Low**	**High**	**Low**	**High**
Euros	30	50	30	50
Cost per tonne of CO_2 eq abated	**20**	**33**	**10**	**16**

However, hydrocarbons are highly flammable and thus pose a risk to car passengers and overall road safety. It is the understanding of the Commission services that due to the flammability of hydrocarbons car manufacturers both in the EU and elsewhere have ruled out the use of hydrocarbons as the refrigerant in MACs unless they are fully contained with the engine compartment by the use of a secondary loop that has an inherent energy efficiency penalty.

It needs to be noted that the Directive of type approval of vehicles (1970/156/EEC) does not cover MACs. In other words, if someone decides to sell a car in the EU with a MAC that uses hydrocarbons as the refrigerant, the type approval authority would not even know about this. However, when such a car should be registered in a Member State, someone may complain about the safety problem caused by the use of hydrocarbons to the registration authority. The authority then may use Article 7(3) not to register the vehicle. This should be notified to the Commission, the other Member States and the type approval authority that has granted the type approval. The Commission then will solve the problem together with the Member State that has rejected the registration and the type approval authority that has granted the type approval.

Question 3: Given the flammability of hydrocarbons, what is the view of car manufacturers of introducing such refrigerants to the MAC systems?

3.2.2. HFC-152a

Some systems suppliers and car manufacturers have started to reconsider the use of HFC-152a as an alternative to HFC-134a. These two chemicals are rather similar. The clear advantage of HFC-152a over HFC-134a is its lower global warming potential (120 instead of 1300), and so there would be a benefit from climate change point of view. Also the proponents of HFC-152a point out to the higher cooling performance and potentially higher fuel efficiency of HFC-152a. Given the similarity of HFC-152a with HFC-134a the expectation is that the introduction of HFC-152a would be economically feasible (up to €15 if no secondary loop was required, and up to €40 if a secondary loop were necessary).

In table 7 a calculation has been made assuming that a HFC-152a is used as an alternative refrigerant with € 15 and €40 as the cost estimates due to safety features. Given the global warming potential of HFC-152a being about 90% below HFC-134a, the greenhouse gas emissions due to HFCs would be considerably reduced but not eliminated. Assuming that there is no energy penalty from using HFC-152a as the refrigerant, the cost of abatement per tonne of CO_2 equivalent is moderate.

Table 7:
Cost of reducing a tonne of CO2 equivalent by using HFC-152a in a mobile air conditioner in EU-15

Emissions	**Optimistic case**	**Optimistic case**	**Pessimistic case**	**Pessimistic case**
Emissions reduced kg CO_2 eq	1390	1390	2858	2858
Costs	**Low**	**High**	**Low**	**High**
Euros	15	40	15	40
Cost per tonne of CO_2 eq abated	**11**	**29**	**5**	**14**

However, as hydrocarbons, also HFC-152a is flammable, albeit mildly flammable. If HFC-152a burns the end result is hydrofluoric acid which is toxic and thus dangerous to human health. To avoid this, it would be possible to run a MAC safely with a secondary loop. However, in this case this alternative would lose most of its advantages: a system running with a secondary loop would be more expensive and less efficient in terms of energy consumption.

According to the understanding of the Commission, when considering the replacement for CFC-12 (the refrigerant used in MACs but being phased-out under the Montreal Protocol), HFC-152a was not selected by the industry as the refrigerant because technology available in 1990 could not adequately contain the refrigerant and safety systems that not been designed with regard to the unwanted characteristics of HFC-152a. However, it is less clear to the Commission, if any car manufacturer is considering HFC-152a as a credible alternative to HFC-134a. Also the Commission does not know what the view of registration authorities in the Member States might be considering the safety aspects of HFC-152a (ref. Art 7.3 of Directive 1970/156/EEC).

Question 4: What is the meaning of "mild flammability" in terms of vehicle safety? Given the flammability and toxicity of HFC-152a, what is the view of car manufacturers of introducing such refrigerants to MAC systems? If introduced, what safety mechanisms would be required? Are the estimates of cost implications of this realistic?

3.2.3. CO_2

The environmental impact of the direct emissions of a CO_2 based system over HFC-134a is clear: all HFC emissions would be eliminated. Also as the refrigerant for the MAC would be a by-product (i.e. "waste") of existing plants, the amount of energy required to produce CO_2 would be small.

The Commission understands that the CO_2 technology has matured but that there are still some technical and safety related issues that need to be solved before a full scale commercialisation of the CO_2 based MACs is realised. The technical issues seem to evolve around the reliability and fuel efficiency of the system in real life conditions. According to the understanding of the Commission the safety related aspects include high pressures and the consequences of CO_2 system leaks to the cabin. It seems, though, that as the industry is capable of handling much higher pressures the potential explosion of the system is not of primary concern – also taking into account that the energy content of the system is low. One safety issue that needs to be resolved relates to a rupture of CO_2 system and the consequent increase of CO_2 concentration in the cabin. In this case, one option is to use a pressure valve. Also a device to monitor CO_2 concentration in the cabin would ensure that no accidental increase of CO_2 concentration could take place.

The Commission recognises that there has been and still is a lively debate about the energy consumption of a CO_2 based system in relation to an HFC-134a based system. Some claim that CO_2 based systems have in practice a higher energy consumption while others claim the opposite. What seems to be clear is that when a car is driving slowly or is idling (i.e. in urban situations), the CO_2 based system would not be as effective as an HFC-134a based system while the reverse is true in milder and more humid weather.

Overall one problem in this CO_2 vs. HFC-134a (and vs. HFC-152a) debate seems to be that apples and oranges are being compared. In other words, the comparisons have not standardised the same kinds of technologies (e.g. compressors, controls, system design) because of the experimental status of all other systems than current HFC-134a based systems. What would be ideal is to compare an "enhanced" HFC-134a system with an "enhanced" CO2 based system. All in all it seems that these other technological issues (compressors, control of the system etc.) are at least as important as the choice of the refrigerant. In other words, there is no clear evidence of a CO_2 based MAC having an energy penalty vs. HFC-134a systems.

The Commission recognises that many European, Japanese and American car manufacturers and MAC systems suppliers have carried out research and development to replace HFC-134a with CO_2 as evidenced, for instance, by the increase in patent applications for that technology in the recent years. It also notes that the first commercial application has been launched recently in the market, albeit on a very small scale.

The main disadvantage of a CO_2 based system relates to its higher cost vs. HFC-134a, the challenge of reliability using high pressures, the safety of service and operation. A CO_2 based system requires in addition to an HFC-134a system a heat exchanger as well as some safety equipment. There are many estimates of these additional costs and the main uncertainty evolves at least around how long a production series is considered in the analysis. The research and development costs need to be recovered during the production of a CO_2 based MAC, but the price increase is much higher if one tries to recover all R&D costs during the first orders. Based on the preliminary estimates by Ecole des Mines de Paris (2003) the manufacturing cost increase in relation with HFC-134a of using CO_2 would be between €68 and €215 including the additional safety features.

Finally, the additional costs do not take into account the savings that CO_2 MACs would introduce to garages and ELV depots. In garages there would be no need to collect the CO_2 (it could be vented). However, garages using HFC-134a need to be equipped with a recycling and recovery equipment which costs about €3000. Furthermore, at the end of life the HFC from MACs needs to be collected. It should be noted, that during a possible transition period, garages would need to carry on recycling and recovering HFC-134a so the benefit from CO_2 would occur in the long run.

Table 8:
Cost of reducing a tonne of CO_2 equivalent by changing from HFC-134a to a CO_2 based technology in EU-15

Emissions	Optimistic case		Pessimistic case	
kg CO_2 eq	1531	1531	3148	3148
Costs	Low	High	Low	High
Difference in production costs (€)	65	215	65	215
Cost (€) per tonne of CO2 eq abated	**42**	**140**	**21**	**68**

Table 8 indicates the price per tonne of CO_2 if the refrigerant of MACs was changed to CO_2. Given the lifetime emission of a vehicle with a MAC the cost of abatement is between €21/tCO_2 eq (if lifetime emissions are high and cost of CO_2 based systems "low") and €140/tCO_2 eq (in the opposite case). The plausible cost per tonne of CO_2 seems to be around €50 in the option to use CO_2 as the refrigerant instead of HFC-134a.

Question 5.a: Do the stakeholders share the view that it is rather the design of the system, including the most important components, that plays the most important role to determine the energy efficiency of a MAC, and that the role of the refrigerant is unlikely to tilt that balance?

Question 5.b: Are the cost estimates presented in this paper reasonable considering CO2 as the alternative refrigerant?

3.3. Reduction of fuel consumption related CO_2 emissions due MACs

A prerequisite for any kind of measure, even for the assessment of measures or whether measures needed at all, is the knowledge of the additional tailpipe CO_2 emissions caused by the usage of mobile air conditioning systems. As long as no standardised tests are available all discussions are based on guesswork. Therefore, in a first step, the Commission aims at agreeing within expert circles on an EU wide standardised test. In this respect the study of TNO (2003) provides the basis for further discussions. TNO proposed to develop a relatively simple and cost effective test procedure. However, the proposal is not finalised yet, and needs in any case further refinement on the basis of laboratory results. It is planned to discuss options for the follow-up work within the coming months. Once a test has been agreed upon it could be used in many ways, e.g. to inform consumers as a part of the labelling Directive 1999/94/EEC, to use it within the monitoring of voluntary agreements, or as basis for mandatory legislation. It could also be expected that the simple fact that the additional fuel consumption becomes measurable would guide car manufacturers to improve the overall fuel efficiency of the systems further. The cost efficiency of these measures are difficult to assess. TNO estimates that the additional tests would cost between €0.09 to €14 per vehicle sold, mainly depending on the actual application of the proposed "family concept" and the number of vehicles produced from a tested vehicles model. However, in the light of the relatively high extra CO_2 emissions due to fuel additional consumption caused by the usage of air conditioning systems even slight improvements of the overall efficiency of air conditioning systems would result – in average – in quite attractive cost efficiency figures.

3.4. Trade aspects

Within the preparation, adoption and application of the future regulation to reduce HFC emissions from MACs, the Commission needs to respect international obligations under the WTO Agreement and, in particular, the Agreement on Technical Barriers to Trade (TBT). The TBT Agreement sets out the rights and obligations of WTO Members with regard to the use technical regulations, standards and conformity assessment procedures that can have an impact on international trade. Under the Agreement governments have on one hand the right to take measures to pursue legitimate public policy objectives, such as the protection of health, safety, and the environment at the level they deem appropriate. On the other hand, governments have the obligation to ensure that technical regulations, standards and conformity assessment procedures do not result in unjustifiable discrimination or an arbitrary or disguised restriction on international trade.

Key principles underlying the TBT Agreement are i) non discrimination; ii) measures should not be more trade restrictive than necessary to achieve the objectives pursued; iii) an obligation to use relevant international standards as a basis for technical regulations, unless those standards are ineffective or inappropriate to achieve the legitimate goals pursued; iv) a requirement to give positive consideration to accepting as equivalent other countries' technical regulations; and v) transparency, notably through an obligation to notify in some circumstances draft technical regulations and conformity assessment procedures to the TBT Committee and take account of subsequent 3rd country comments.

When preparing the proposal for regulating HFC emissions from MACs, the Commission is committed to follow its international obligations under the WTO Agreement and, in particular, the Agreement on Technical Barriers to Trade.

Question 7: Are there any international trade related issues that the Commission should be aware of when it prepares its proposal to reduce greenhouse gas emissions due to mobile air conditioning?

3.5. Conclusion

Advocates of each of the enhanced and alternative systems are confidant that fuel efficiency, safety and other issues can be solved. Therefore, it seems reasonable to conclude that the energy consumption of the MACs using these alternative technologies is similar to the MACs based on HFC and that the design of the whole system (including controls) – not the choice of refrigerant – would dominate the level fuel consumption. The choice of refrigerant might have some impact on the energy performance of the system, but the increase or decrease of energy consumption and related CO_2 emissions are not even closely comparable to the global warming impact that occurs due to refrigerant HFC-134a loss.

All components for the alternative refrigerant technologies are now commercially available but in some cases with a higher cost. It should be noted that the capacity of the industry to innovate and thus bring down the cost of the alternative technologies is usually underestimated in cost-benefit analysis (Harrington et al 2002). Therefore, the cost-effectiveness calculation carried out in this paper is most likely an overestimate of the costs of phasing out HFC-134a as the refrigerant to reduce greenhouse gas emissions due to MACs. The most expensive option considered by the industry, switch form HFC-134a to CO_2 does not seem overly costly. As there are other, perhaps cheaper alternatives available as long as the safety problems have been solved, it seems reasonable to conclude that phasing out the use of HFC-134a as the refrigerant would be feasible without an excessive cost.

Question 8: Do the stakeholder share the main conclusion of this paper, i.e. that it is possible to phase out HFC-134a without an excessive cost if the lead time for this is long enough? If not, what in this conclusion would be considered incorrect?

REFERENCES

Ecole des Mines de Paris (2003) Analysis of the economic and environmental consequences of a phase out or considerable reduction leakage of mobile air conditioners. A report prepared for Directorate-General Environment of the European Commission. February 2003.

Gröniger, Luciënne (Auto Recycling Nederland BV) and Arend Koppenol (Novem) (2003) Contents MAC system at end of life. Conclusions Auto Recycling Nederland (ARN) investigation 2002-2003

Harrington, Winston, Richard Morgenstern, Peter Nelson (2000) On the Accuracy of Regulatory Cost Estimates. *Journal of Policy Analysis and Management* 19:2 p. 297-322.

Johnson, Valerie H. 2002. Fuel Used for Vehicle Air Conditioning: A State-by-State Thermal Comfort-Based Approach. SAE 2002-01-1957

Schwarz, Winfried (2002) Emission of Refrigerant R-134a from Mobile Air-Conditioning Systems. Annual Rate of Emission from Passenger-Car Air-Conditioning Systems up to seven years Old. Study conducted for the German Federal Environment Office Sponsorship Reference 360 09 006

TNO (2002) Options to integrate the use of mobile air conditioning systems and auxiliary heaters into the emission type approval test and the fuel consumption test for passenger cars (M1 vehicles). Final TNO report prepared by Rijekeboer, Gense, Vermeulen 02.OR.VM.074.1/NG of 23.12.2002

Öko-Recherche and Ecofys (forthcoming) Establishment Of Leakage Rates Of Mobile Air Conditioners in the EU. A study prepared for Directorate-General Environment of the European Commission.

Table A1: Directives which could be concerned by air conditioners as far as the vehicle type approval system of M1 vehicles (passenger car ≤ 9 seats) is concerned

Number and Title of the Directive	Description
1970/156/EEC Type approval of the whole car	Approval contains all approvals for systems and parts.
1970/156/EEC (Amendment 1992/53/EEC)	Article 7(3): If a Member State finds that cars are a serious risk to road safety – even if the car is type approved – it may refuse to register these cars for up to 6 months. This action needs to be notified to the other Member States and the Commission and to the type approval authority that has granted the approval. The Commission shall, if necessary, hold appropriate consultations for reaching a settlement.
1970/157/EEC Permissible sound level and the exhaust system of cars	Sound level is tested at full acceleration from 50 km/h for ~ 20 m
1970/220/EEC Air pollution by emissions from cars	Tests are carried out during certain cycles, representing driving inside and outside of urban areas. On-board diagnostics (OBD) have to be installed.
1980/1268/EEC Fuel consumption of cars	Test procedure like the emission test; limits do not exist
1980/1269/EEC Engine power of cars	Test procedure for the max. torque and the max. net power of the engine
2001/56/EC Heating systems for cars	Heating systems and later probably air conditioner on safety aspects

Table A2: Directives which could be concerned by air conditioners (unrelated to vehicle type approval)

Number and Title of the Directive	Description
1999/36/EC Mobile pressurised equipment	Concerns inland transport of dangerous goods by road and does thus not cover MACs.
1996/96/EC Roadworthiness tests	Registered cars have to be checked in certain intervals (safety, noise emissions, lights …)
1999/94/EC Availability of consumer information on fuel economy and CO2	The information is based on the 80/1268/EEC approval and thus does not include the CO2 emissions due to increased fuel consumption due to MACs.
2000/53/EC End-of-Vehicle Directive	States that “air conditioning fluids need to be recovered” and states that 85% of the total weight of the car needs to be recovered. Thus, no specific percentage of HFC-134a has been set to be recovered while the expectation is that all refrigerants left in the MAC would be recovered.

Annex 2

Additional policy related questions

Considering policy options to considerably reduce greenhouse gas emissions due to mobile air conditioning can be reduced in a sustainable and credible manner the following general questions are posed:

Question A.1: Which policies would provide the incentives for improved environmental performance or discourage poor performance of MACs? Specifically, which of the following would be preferred options to reduce greenhouse gas emissions from MACs in a cost-effective manner:

a) Discourage the purchase of MACs by e.g. requiring that the cost of the MAC is not bundled to the price of the car.

b) Giving incentives the consumer to purchase or the manufacturer to sell "climate friendly" MAC

   (i) By labelling the climatic impact of the MAC

   (ii) By giving subsidies (e.g. tax breaks) to climate friendly MACs

   (iii) By setting a charge to HFC based MACs (like in the case of Japan, where the charge for HFC-134a is €21 per car)

   (iv) By setting an environmental levy on the refrigerant based on the global warming potential and a reference price, e.g. €20/tCO_2 eq.

c) By phasing out HFCs as the refrigerant

   In case of a phase-out, what would be considered a reasonable phase out time to allow the alternative technologies to mature and thus reduce the cost of compliance to producers and consumers.

d) By requiring that car manufacturers supply maintenance free MACs, e.g. with a 10 year/200.000 km environmental guarantee.

Question A.2: What policies would encourage good practices in garages to avoid the emissions of HFCs during repair and service of MACs? Specifically, which of the following would be preferred options to reduce greenhouse gas emissions from MACs in a cost-effective manner:

a) By raising the price of HFC e.g. through charging (see above) in particular only newly manufactured gas?

b) By setting minimum design requirements to facilitate servicing? What would such minimum requirements be?

c) By requiring the minimum training level of garage mechanics including the necessary skills profile?

Question A.3: Are there issues relating to the competitiveness of car manufacturers that the regulators need to be aware of?

Question A.4: In your view, is there a need for regulatory authorities in the EU, the US, Japan and elsewhere to co-ordinate their policies? If the technical requirements of MACs were regulated, what would be the advantages and disadvantages of carrying this out at EU or international (UNECE) level?