Over the last three decades, automobile manufacturers have made a lot of progress in specific fuel consumption and engine emissions of pollutants. Yet the impact of these improvements on vehicle consumption has been limited by increased dynamic performances (maximum speed, torque), increased safety (power steering and power brakes) and increased comfort (noise and vibration reduction, electric windows and thermal comfort). Because of this, the real CO2-emission levels in vehicles is still high in a context where road transport is a major factor in the balance sheet of greenhouse gas emissions, thus in complying with the international climate convention.

Although European, Japanese and Korean manufacturers signed an important agreement with the European Commission for voluntarily reducing CO2 emissions from their vehicles, with a weighted average emission goal by sales of 140 grams per km on the MVEG approval cycle by 2008, it has to be noted that the European procedures for measuring fuel consumption and CO2 emissions do not take accessories into account, especially air-conditioning (A/C).

The big dissemination of this equipment—recognized as a big energy consumer and as using a refrigerant with a high global warming potential—led ADEME to implement a set of assessments of A/C’s energy and environmental impact. In particular these assessments include studies of vehicle equipment rates, analyses of impact on fuel consumption as well as regulated pollutant emissions in the exhaust, a characterization of the refrigerant leakage levels and an estimate of greenhouse gas emissions for all air-conditioned vehicles.

This leaflet summarizes the results of these actions. All of these studies and additional data are presented in greater detail in the document, “Automobile Air-conditioning” (ADEME reference no. 4985 – 23 €).
Air-conditioning distribution

Sales

The rate of air-conditioning in new vehicles increased in France from under 15% in 1995 to over 60% by 2000. This trend, begun as standard equipment on high- and middle-range vehicles and as an optional promotional offer (as little as 1 euro!) in smaller sized vehicles, will continue in the coming years. This expansion in annual sales is continuing with about 70% penetration of this accessory in both France and Europe for 2003. Progressive saturation is expected according to an “S curve”, shown in the following graph, i.e. it is more than likely that the air-conditioning rate will settle down at over 90% by 2010, reaching the distribution levels seen for the past years in Japan and the United States.

This distribution in sales has a direct consequence, i.e. the air-conditioned fleet of vehicles is growing significantly.

The fleet

The evolutionary outlook carried out by ADEME, according to the present growth hypotheses of the French automobile fleet and according to the “distribution law” given above, leads to an evaluation of over 20.7 million units in the fleet by 2010 (2 of every 3 operating vehicles will be air-conditioned!), then 30.5 million A/C equipped vehicles by 2020, i.e. nearly 88% (nearly 9 vehicles of every 10 will be fitted out!), as shown in the following graph.

Fuel over-consumption

To study the effect on consumption of fuel used by automobile air-conditioning, over the past few years ADEME carried out two test campaigns on market-representative vehicles and is presently continuing its evaluation with the implementation of a new measurement campaign. The tests carried out in 1997 with UTAC used 20 vehicles and followed on the initial evaluations done in 1996, which revealed considerable over-consumption (cf. ADEME summary, ref. 2471 – July, 1996).

The general observations on the second measurement campaign are of a higher average over-consumption than in the first campaign (partly due to a hardening of the MVEG cycle), a tightening of over-consumption values for gasoline and diesel (about 3.2 l/100 km in the urban cycle) and a confirmation of poor performances by turbo-charged diesel vehicles. Moreover we note that over-consumption is clearly higher for the urban part of the MVEG cycle than for the extra-urban cycle.

A summary of the evaluations carried out
In the following table you have the main over-consumption values according to the test cycle:

<table>
<thead>
<tr>
<th>Over-consumption in L/100 km</th>
<th>Urban cycle (ECE)</th>
<th>Extra-urban cycle (EUDC)</th>
<th>Mixed cycle (MVMEG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline (average of 10 vehicles)</td>
<td>+3.1 (+31%)</td>
<td>+0.9 (+16%)</td>
<td>+1.7 (+23%)</td>
</tr>
<tr>
<td>Natural aspiration</td>
<td>+2.4 (+26%)</td>
<td>+0.7 (+12%)</td>
<td>+1.3 (+19%)</td>
</tr>
<tr>
<td>Turbo-charged diesel</td>
<td>+4.0 (+43%)</td>
<td>+1.5 (+28%)</td>
<td>+2.5 (+36%)</td>
</tr>
<tr>
<td>All diesel (average of 10 vehicles)</td>
<td>+3.2 (+35%)</td>
<td>+1.1 (+20%)</td>
<td>+1.9 (+27%)</td>
</tr>
</tbody>
</table>

Average over-consumption in L/100 km between the test with A/C on and off.

Over-emissions of regulated pollutants (CO, HC, NOx and particulates)

The results shown hereafter were obtained by using a measurement dynamometer on the modified bases of directive 98/69 (the modified MVEG cycle, canceling the first 40 seconds of cold idle). Although the values obtained are on the whole higher than for the first campaign (because of making the test cycle harder), the observed trends (especially relatively) are confirmed with an increase of pollutants CO, NOx for gasoline and NOx and particulates for diesel.

The effects contained in the following table can be noted according to the pollutant, the type of engine and the part of the test cycle assessed:

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>Particulates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>+17%</td>
<td>–</td>
<td>+74%</td>
<td>–</td>
</tr>
<tr>
<td>Extra-urban</td>
<td>+75%</td>
<td>–</td>
<td>+51%</td>
<td>–</td>
</tr>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>–30%</td>
<td>–24%</td>
<td>+47%</td>
<td>+60%</td>
</tr>
<tr>
<td>Extra-urban</td>
<td>–28%</td>
<td>–23%</td>
<td>+27%</td>
<td>+32%</td>
</tr>
</tbody>
</table>

Average pollutant emissions measured in g/km % spread between A/C on and off

Refrigerant loss

Automobile air-conditioning systems because of their design have a big drawback in terms of greenhouse gas emissions:

- they use refrigerants (HFC: hydrofluorocarbons), the emissions of which have high impact on the increase of greenhouse effect, i.e. the global warming potential (GWP) of HFC-134a, presently used in automobile air-conditioning, is 1,300, which means that 1 kg of this HFC emitted into the atmosphere has the same impact as 1.3 tons of CO2!
- the constraints of placing devices under the hood imply using flexible linking elements, which pose not-insignificant problems of porosity and permeability, not to mention imperfect refrigerant-tightness at the connections;
- to keep the fluid in a closed circuit, driving the air-conditioning compressor by the internal combustion engine implies using a shaft seal, which is a major source of refrigerant loss.

This architectural design requires careful maintenance and means using and handling large quantities of refrigerants (production, recovery, recycling and disposal).

So as to make it possible to better understand the nature of escaping refrigerant emissions and to provide the possibility of listing the hierarchy of the responsibilities of various components, then suggesting ways of limiting them, a set of actions aimed at characterizing the emissions linked to leaks of the air-conditioning systems has been implemented by ADEME.

An assessment of the emission levels of the hoses and the connections on the one hand and of the mechanical air-conditioning compressor on
the other, has been successfully carried out by the Centre d’énergétique (Center for Energy Studies) of the Ecole des Mines de Paris.

**Rubber hoses and connections**

A dedicated test bench made it possible to characterize a series of components and to highlight the importance of component design for their refrigerant-tightness, i.e. a range of 1 to 9 was recorded on 4 rubber hoses studied and from 1 to 20 on several connections, for which leakage volumes are nonetheless lower. According to the various leakage volume levels observed during these test campaigns, what can be retained, according to the test pressure conditions, is that new components have leakage volumes between 1 g/yr and 20 g/yr.

**The shaft seal of the air-conditioning compressor**

A dedicated test bench also made it possible to measure the leakage rates of two categories of compressors of different brands and types for varied operating conditions (in rotation, shut down and at different pressures of R134a in the compressor):

- new or practically new compressors (compressors having been in operation for a few hundred hours for less than 6 months);
- and used compressors, taken from circulating vehicles, supplied by the VALEO CLIM Service company.

We give the main lessons from this research below.

**Static mode** tests, not illustrated in the present document, show that the emission levels occur between 0.2 and 5 g/yr., depending on the compressor, for moderated test pressures and become very high, even unacceptable (several hundreds of grams per year) for some compressors under strong test pressure.

Dynamic mode tests (in rotation), shown below, also give contrasting response “profiles”, most especially with used compressors.

The leakage rate measured for “new” compressors is located between 1 g/yr to 6 g/yr, depending on the rotary regime and the fluid pressure. For “used” compressors with typical operating pressures of 2.9 bars, tests showed two kinds of behavior:

- some compressors have similar emission levels to those of new compressors with 2.5 to 5 g/yr;
- for other compressors, the aging effect is clearly characteristic since the estimated leakage rates can vary from 15 g to 60 g/yr., or ten-fold in relation to the emissions of new compressors under these conditions.

**Total air-conditioning loop**

The following elements may be kept in mind from these assessment campaigns:

- with the technology available on the market today, it is possible to design automobile air-conditioning systems that emit about 10 g/yr;
- numerous current automobile air-conditioning systems can have typical leakage rates of from 10 to 70 g/yr.

These conclusions plead in favor of making an effort in the design and/or selection of high-performance components. They also shed light on the fact that in addition to the necessary action of recovering HFCs during servicing and at end-of-life, a possibility exists of eventually marketing “filled for life” air-conditioning systems, which would make the problem of the present uneven quality of servicing become less acute.
The current annual loss of refrigerants - What order of magnitude?

Based on the present average capacity of automobile air-conditioning systems, i.e. 775 g of HFC-134a (the capacity varying from 650 g to 900 g depending on the size and power of the air-conditioned vehicle) and for a 12-year life expectancy of the vehicle with the two final years without maintenance, the following assessment elements have been noted:

- 15% annual leakage emissions, or 116 g/yr.;
- mass loss at servicing: 2 half charges, or 775 g/10 yrs.;
- charge emitted at end-of-life: a half charge, or 387 g/10 yrs.

On the vehicle’s balance sheet it must be verified that an emission of 232 g/yr. of HFC-134a, or 30% of the initial charge, is obtained.

For an optimistic improvement scenario for the three previous elements: annual leakage (limited to 10%), servicing and end-of-life (20% of a half-charge for each), the total annual emission could be limited to 93 g/yr. of HFC-134a. Nonetheless, such a release into the atmosphere represents an equivalent emission of 120 kg of CO₂ per year, or 10 g/km for a vehicle traveling 12,000 km/yr. This value is not insignificant in relation to the average conventional emissions of new vehicles in 2002, i.e. 155 g/km of CO₂.

Global impact in terms of the greenhouse effect

Given the knowledge acquired about over-consumption and the levels of refrigerant emissions through poor refrigerant-tightness, incidents, servicing and end-of-life non-recovery, it becomes interesting to assess the impact of the spread of automobile air-conditioning in the automobile fleets in terms of the greenhouse effect, i.e. to evaluate the quantity of CO₂ (or CO₂ equivalents) ejected into the atmosphere, attributable to the presence of air-conditioning in automobiles on both the French and European levels.

France

A simulation based on the forecast scenarios of air-conditioning in the automobile fleet and on the evolution of this same fleet, with the intention of estimating the quantities of CO₂ emissions (direct or indirect), was carried out by ADEME for France between 2000 and 2020.

For that, values of estimated annual refrigerant loss were required in parallel with the scenarios of fleet evolution. The following hypotheses were retained: 30% loss per year (including operations, servicing and end-of-life) for systems put in service since 1995, then improvement of refrigerant-tightness after 2000, reducing this loss to about 20% of the charge, then 10% after 2010. These estimates led to a high estimation of the impact of the spread of automobile air-conditioning in terms of CO₂ equivalents. For 1995, the impact obtained was about 2 Mt of CO₂, including 100 Kt for end-of-life, then, for the estimate up to 2010, about 4.4 Mt of CO₂ and 0.9 Mt of CO₂ for end-of-life; by the end of the study period in 2020, impact reached 3.6 Mt of CO₂ and 1.6 Mt of CO₂ for end-of-life.

Moreover an evaluation of the impact of using HFC by activity sector in terms of CO₂ emissions was carried out by the Centre d’énergétique de l’Ecole des Mines de Paris within the framework of the brainstorming by the “Fluorinated gases” working group within the French Interministerial Mission on the Greenhouse Effect (MIES). For automobile air-conditioning, this study supplies evaluations of CO₂ emissions of an order of magnitude in tune with the above-mentioned ADEME simulation. It also gives access to an estimate of the foreseeable gain potential of CO₂ according to the efforts carried out on the aspects of the A/C system’s technological quality, servicing phases and end-of-life.

This study’s estimates of the impact of using air-conditioning lead to the following responsibility levels for France: 4 to 4.5 million tons of CO₂ equivalents up to 2010. This highlights the existence of a considerable repository of savings (up to ~3 Mt CO₂ eq.) if determined actions for limiting emissions are imposed, as the following graph...
shows, where 3 scenarios for action are simulated:  
- Scenario 1: business as usual.  
- Scenario 2: improved refrigerant tightness + recovery at servicing.  
- Scenario 3: improved refrigerant tightness + recovery at servicing + recovery at end-of-life.

The European Union – potential of CO2 emissions limitation

Within the framework of the work by the European Climate Change Program (ECCP), ADEME has carried out an evaluation of what’s at stake in limiting automobile air-conditioning-related CO2 emissions on a European scale.

It should be noted that the voluntary accord of European Automobile Manufacturers Association (ACEA) and the goal of the European Union on CO2 emissions from vehicles (140 g/km by 2008; 120 g/km by 2012) do not at present include the use of auxiliary equipment.

ADEME’s evaluation factored in the two kinds of direct and indirect greenhouse gas effect (the loss of refrigerants and fuel over-consumption respectively).

For fuel considerations, to the average evolution of fuel consumption expressed in CO2 g/km of the conventional scenario (the European Union-European Automobile Manufacturers accord, “EU-ACEA”, on reducing vehicle consumption: goals without factoring in auxiliary equipment, 140 g/km of CO2 by 2008, 120 g/km by 2012) we applied factors of over-consumption due to functioning air-conditioning for two hypotheses:

- the first corresponds to the usual technological evolution of air-conditioning (the “Business As Usual” scenario).
- the second corresponds to an effort to improve the energy performances of air-conditioning systems (the “efficient air-conditioning” scenario).

The calculations of CO2 emissions of just the air-conditioned vehicles with the A/C on leads by comparison to possible CO2 savings between the “BAU” scenario and the “efficient air-conditioning” scenario. A cumulative CO2 emission reduction of 10 Mt is obtained for 2008 and 31 Mt for 2012 for this measurement dealing only with the energy efficiency aspect of air-conditioning systems. The following graph illustrates these data:
To evaluate what’s at stake in limiting refrigerant emissions, we carried out a comparison of HFC emissions (then CO₂ via the Global Warming Potential, GWP, of the refrigerant) between two scenarios:

- one, as with over-consumption, corresponding to a normal technological evolution of the systems (“BAU”);
- the other corresponding to an effort on the refrigerant-tightness aspect of the A/C loop and the recovery operations during servicing and at end-of-life (“improved HFC emission levels”).

In both cases we are interested in new vehicles introduced into the automobile fleet starting in 2000, then taking their survival in the fleet into account (and thus vehicles removed) and their initial emissions levels. By limiting HFC loss a cumulative CO₂ eq. emission reduction of 11.3 Mt CO₂ for 2008 and 37.4 Mt for 2012 is obtained for this measurement dealing with the fluid sector.

ADEME’s work presented above was included in the European Program for Preventing Climate Change Long Report (ECCP–Long Report*), which defines for the Commission the greenhouse gas limiting strategies. A reduction potential of from 2 to 4 Mt CO₂/yr. has been identified for automobile air-conditioning, and ultimately including the operation of this equipment in the certification tests of vehicles is foreseen.

Given the results on over-consumption and over-emissions of the pollutants induced by air-conditioning, the energy efficiency of the refrigeration loop must be improved. As an example, we can note than an optimized external control compressor ought to make it possible to reduce over-consumption up to twofold. Moreover, given R134a refrigerant leaks throughout the whole life-cycle of an air-conditioning system, actions must be carried out to limit them and to examine new refrigerants with a low global warming potential for the atmosphere.

It is thus important to implement two sorts of action as soon as possible:

- Research activities aimed at:
  - improving the energy efficiency of air-conditioning systems;
  - reducing the demanded refrigerating power by optimizing the vehicle’s thermics and by active or passive pre-conditioning at a stop;
  - reinforcing the refrigerant-tightness of the A/C loop operating with HFC-R134a;
  - perfecting and developing systems operating with new refrigerants (hydrocarbons, CO₂, HFC/CO₂ blends, etc.).

- Regulatory actions:
  - regulating and creating an efficient recovery sector for present air-conditioning systems using R134a;
  - developing a measurement methodology for the regulatory factoring in of air-conditioning energy consumption in the certification procedures of new vehicles.

In this sense and in continuity with the evaluations presented in this leaflet and given in greater detail in “Automobile Air-conditioning” (ADEME reference 4985 - 23 €), the Agency is presently participating in new studies that correspond to those avenues already cited, such as:

- “the in-put of the compressor’s external control”;
- “air-conditioning in hybrid vehicles”;
- “the pre-conditioning of the vehicle”;
- “reversible air-conditioning operating with CO₂”;
- “studying refrigerant blends of HFC and CO₂”;
- “the methodology of measuring air-conditioning consumption”;
- “brainstorming on a European-wide level about maintaining the R134a process”;
- “real-use measurements on instrumented vehicles”.

The findings of this work will be part of a new synthesis that will include the data from an upcoming campaign of vehicle tests.