REDUCING THE IMPACT OF TRANSPORT ON THE GLOBAL ENVIRONMENT

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INTRODUCTION

Many politicians and environmental analysts agree that global warming is one of the most important environmental challenges facing the world today. Transport has been identified as a major source of global warming, and moreover a source which is predicted to grow considerably in volume over the next 20 to 30 years.

The aim of this paper is to describe and assess the technologies available for reducing the impact of transport on the global environment. The paper is based on work which ETSU has recently completed for DGXII of the European Commission. This work was focussed on producing a research and technology strategy to help overcome the wide range of environmental problems caused by transport, and ETSU carried out the key analyses in the area of global pollution.

1. GLOBAL WARMING

It is useful to begin with a brief outline of the mechanisms and effects of global warming. About two-thirds of the energy received by the earth from the sun is absorbed within the earth's mass, but some infra-red energy is reflected back into space from the earth's surface. Some of this energy is trapped by certain gases in the upper atmosphere and returned to the earth as heat. This is the so-called greenhouse effect.

Greenhouse gases such as carbon dioxide occur naturally and keep the earth about 30 degrees Celsius warmer than it would be otherwise. Without this effect life as we know it could not survive. The problem arises because various human activities lead to the release of additional greenhouse gases. The gases include water vapour, carbon dioxide caused by the burning of fossil fuels, methane from agriculture, fossil fuels and waste disposal, nitrous oxide from burning materials and farming, and low-level ozone. An entirely man-made and extremely powerful group of gases are the chlorofluorocarbons, widely used in aerosols, refrigeration and as solvents. They also attack the ozone layer, and international efforts are now being made to control their use.

2. ENERGY USE IN TRANSPORT

A major factor in the emission of greenhouse gases is the combustion of fossil fuels. Fossil fuels provide the energy source for transport activities through fuel production and processing, manufacture, operation and disposal of road vehicles, aircraft, ships and trains. For this reason, the central focus of the analysis of global warming is that of energy utilisation. Efforts to reduce the impact of global warming from transport are likely to be centred on reducing or at least stabilising transport demand and on reducing the energy consumption and improving the energy efficiency of transport activities.

Broad statistics indicate that all forms of transport are responsible for nearly 30% of final energy use in the European Community, and the combustion of fossil fuels by transport accounts for about 23% of the Community's emissions of carbon dioxide. Energy use in transport also produces over 50% of the emissions of nitrogen oxides, over

85% of the carbon monoxide and nearly 40% of the volatile organic compounds released into the environment from man's activities in the European Community.

3. ENERGY EFFICIENCY AND EMISSIONS CONTROL

There is a wide range of technological measures which are available to reduce energy consumption or to improve energy efficiency in the transport sector. However, some of these measures are thought to be in conflict with the aim of reducing the regulated emissions from vehicle exhausts which contribute to local air pollution.

National Governments in the European Community have introduced regulations over recent years to encourage and force vehicle manufacturers to develop and commercialise emission control technologies in motor cars and commercial vehicles. These actions have had the result of achieving worthwhile reductions in the regulated gases - carbon monoxide, the nitrogen oxides and hydrocarbons. The most appropriate technology which is commercially available to satisfy these regulations for gasoline fuelled cars is the use of three-way catalytic converters and closed loop fuel/air ratio controls.

Catalytic converters work by using the carbon monoxide in exhaust gases to reduce the nitrogen oxides to inert nitrogen, and then use the oxygen released by this process and oxygen from the air to oxidise the remaining carbon monoxide and hydrocarbons to produce carbon dioxide and water vapour.

Three-way catalytic converters (TWC) can only work at a stoichiometric air-fuel ratio and with unleaded gasoline, both of which lead to reduced fuel efficiency for the vehicle. Hence there is a trade-off between reducing the amount of local air pollution and improving fuel efficiency. It is necessary to analyse this trade-off in more detail and to assess its relevance to global pollution. The analysis must be extended to the range of technological options which are currently under examination. To do this analysis, ETSU has used recent atmospheric modelling results and research carried out at Harwell to quantify both the direct and the indirect effects of greenhouse gases from all transport technologies. (see, for example, Johnson et al, 1992, which examines global warming impacts from nitrogen oxides).

4. GREENHOUSE GAS ANALYSIS

One immediate observation about this situation is that most of the regulated emissions also influence the greenhouse effect, either directly as greenhouse gases in their own right or indirectly through various chemical processes in the atmosphere which lead to the formation or destruction of other greenhouse gases.

Calculation of the impacts of greenhouse gas emissions needs to take into account the vertical distribution of ozone concentrations in the atmosphere, since this appears to have a substantial effect on the global warming impact. The work on which this is based makes important approximations which could substantially affect the results, but the analysis carried out in this paper reflects the most up to date results from the modelling work.

Table 1 lists the estimated global warming potentials relative to carbon dioxide of the main chemical species associated with fossil fuel use in transport. It is important to note that each of the chemical species has a global warming potential, and that the greenhouse problem is not caused solely by the emissions of carbon dioxide. Indeed, attention to reduction of all air pollution emissions will be essential for the transport sector to tackle these global pollution problems.

TABLE 1 GLOBAL WARMING POTENTIALS

Gas	Emission	Time Horizon (years) 20	50	100
Carbon dioxide	1	1	1	1
Carbon monoxide	1	4	3	2.5
Methane	1	47	27	17
Other hydrocarbons	1	14	9	7
Nitrogen oxides	1	8	3	1
Nitrous oxide	1	244	270	274
CFC-11	1	4268	4147	3526
CFC-12	1	6738	7350	4559

In the case of the nitrogen oxides and the hydrocarbons, most of the warming impact is due to tropospheric ozone which is produced in complex photochemical reactions. The modelling work indicates that ozone levels depend almost linearly on both nitrogen oxides and hydrocarbon emissions, for changes in emission levels up to 20%.

5. AVAILABLE TECHNOLOGIES

The available technologies for reducing energy consumption or improving energy efficiency can be conveniently classified into three clusters, namely:-

* *engine technology;*
* *alternative fuels;*
* *vehicle design.*

5.1. Engine technology

Engine technology determines the efficiency with which fuel energy is converted into engine power. It also determines the quantities and chemical compositions of the gaseous emissions from the vehicle. Present-day engine technology utilises petroleum derived fuels and these are responsible for greenhouse gas emissions. There are many aspects of engine technology, including different engine types, which either by improving energy efficiency or by lowering the levels of regulated emissions can reduce the overall emissions of greenhouse gases.

Three way catalysts on gasoline engines operating under stoichiometric air/fuel ratio conditions are already available and offer benefits in terms of reducing the emissions of regulated air pollutants. Lean-burn engine technology can also offer reductions, particularly when combined with an oxidation catalyst. However, emissions of nitrogen oxides would still be greater than those form the three-way catalyst equipped stoichiometric engine, and further developments of this technology will be needed for it to satisfy the increasingly stringent standards being introduced in Europe.

The most important improvements are likely to come from engine management, including electronically controlled fuel injection and electronic valve timing. Variations in valve timing can be used to control air intake, avoiding the need for a throttle and associated inefficiency at part load. By closing the exhaust valve early and opening the intake valve late, exhaust gases can be retained, diluting the charge and thus reducing nitrogen oxides emissions. Variable valve timing also allows for the engine to operate in a variable compression or expansion ratio mode, which allows for further optimisation of engine efficiency and reduced emissions.

The maximum potential from introduction of these technologies is thought to be about 20% improvement in fuel consumption which would offer a corresponding 20% reduction in carbon dioxide emissions. Reductions of up to 90% in other regulated air pollutants, namely carbon monoxide, nitrogen oxides and unburnt hydrocarbons, can also be obtained, although not at the same time as the 20% improvement in fuel consumption.

5.2. Alternative fuels

Alternative fuels offer the opportunity to reduce dependence on petroleum derived fossil fuels. Substitution by alternative fuels is attractive when the combustion process can produce lower emissions of greenhouse gases per unit of useful energy. For example, if carbon dioxide emission reduction is the main priority, the direct injection (DI) diesel engine has more to offer in the long term than the gasoline engine - although DI gasoline engines are also a possibility currently under development.

In addition to reducing dependence on petroleum products, some alternative fuels derived from biofuels could provide the opportunity to offset carbon dioxide emissions in use by carbon fixing in plant growth. Both these aspects could be major contributors to the reduction of global warming from transport. However, energy use in the production and processing of some of these alternative fuels can be significant, and may result in net emissions of greenhouse gases. Furthermore, the use of artificial fertilisers as an aid to increasing crop yields may pose additional environmental burdens

Renewable energy sources for transport fuels include electricity generated from either solar radiation or wind and biomass derived fuels such as bio-methanol and bio-ethanol, and hydrogen which may be produced either from electrolysis of water or from biomass. In addition, the use of compressed natural gas (CNG) and liquefied petroleum gas (LPG) is being examined.

Table 2 lists the estimated emissions due to engines operated on a variety of engine technologies and alternative fuels. The Table includes data on current production gasoline engine, using a small car with a fuel consumption of 7 litres/100km. The data on alternative fuels are mostly from experimental engines operated under a variety of non-standard conditions.

5.3. Vehicle design

Vehicle design determines the way in which engine power is converted into a useful transport product. The vehicle carrying capacity, weight, aerodynamic drag and rolling resistance are all influenced by the design requirements. Designs which improve the efficiency of this conversion require less energy and provided they are integrated with an appropriate drive-train they can reduce emissions of greenhouse gases.

TABLE 2 OPERATIONAL CAR ENGINE EMISSIONS

Emissions	CO_2	CO	NHMCs	CH_4	NO_x	N_2O
Gasoline	151	6.1	1.27	0.06	2.7	0.01
TWC gasoline	165	0.9	0.13	0.06	0.13	0.04
Lean-burn	132	8.2	1.1	0.05	1.5	0.01
Lean-burn+cat	144	4.5	0.5	0.03	0.7	0.04
IDI Diesel	131	0.43	0.23	0.01	0.46	0.01
DI Diesel	126	0.53	0.73	0.03	1.1	0.01
CNG without catalyst	130	0.25	0.1	0.2	0.6	0.01
LPG without catalyst	140	1.1	0.4	0.02	0.5	0.01
Bio-methanol with catalyst	0	0.5	0.05	0.06	0.1	0.04
Bio-ethanol with catalyst	0	0.5	0.05	0.06	0.1	0.04
Bio-hydrogen	0	0.5	0.5	0	1.0	0.01

Key to table:-

CO_2 - carbon dioxide
CO - carbon monoxide
NMHCs - non-methane hydrocarbons
CH_4 - methane
NO_x - nitrogen oxides
N_2O - nitrous oxide

6. COST-EFFECTIVENESS OF TRANSPORT TECHNOLOGIES

Clearly, it is possible to envisage a variety of combinations of engine technology, alternative fuels and vehicle design which may add together to give greater benefits than the sum of the individual technologies. However, for the purposes of simplifying the analysis, ETSU has examined each technology on its own without reference to the combinations which might be adopted. This simplification enables a broad brush analysis of the technological potential of new and innovative technologies to reduce global environmental problems from transport.

The cost-effectiveness of over 60 transport technologies in reducing greenhouse gas emissions has been estimated by ETSU in the work for the European Commission. These technologies embrace all transport modes, including road, rail, air and water.

The technical performance, the greenhouse gas emissions and the economic characteristics of these technologies have been identified and the benefits and costs assessed, either as a result of research already undertaken or based on prototype vehicles and trials of vehicles which make use of these technologies. This data can be combined with the global warming potentials described earlier into an analysis of the cost-effectiveness of each technology in achieving the desired environmental benefits of reducing global warming.

Table 3 summarises the results of this cost-effectiveness analysis for a selection of technologies. The parameters used in the analysis are the factors of:-

Economics, which describe whether or not the technology is cost-effective in all, some or none of the socio-economic scenarios used to examine the benefits;

Greenhouse gas reduction, which describes to what extent the technology is able to offer high, medium or low reductions in the emissions of greenhouse gases;

Local pollution reduction, which describes to what extent the technology is able to offer high, medium or low reductions in the emissions of local air pollution;

Supply security, which describes whether the technology can provide a high, medium or low level of improvement in the overall security of energy supply for the European Community;

Performance, which describes to what extent the technology is able to offer high, medium or low improvements in the performance of the transport system.

It should be noted that some of the costs and performance data on which this Table is based are speculative, and may not coincide with the costs and performance of fully-commercialised technologies. Nevertheless, the data do show the main features of which technologies need further development and which show the most promise.

TABLE 3 TECHNOLOGY ASSESSMENT SUMMARY

Technology	Economics	GHG Reduction	Local Reduction	Supply Security	Per
CNG	o	o	oo	o	x
biofuels	x	oo	o	ooo	-
hydrogen	x	ooo	ooo	ooo	xx
electric cars	xxx	oo	ooo	oo	xx
electronic valve timing	x	o	oo	o	o
IDI diesel engine	-	o	x	o	x
2-stroke engine	oo	o	x	o	o
reduced drag	o	o	o	o	oo
weight reduction	o	o	o	oo	oo
reduced rolling resistance	o	o	o	o	x

Key: ooo/oo/o : high/medium/low benefits
xxx/xx/x : high/medium/low disadvantages

Some useful conclusions can be drawn from this analysis. Firstly, it is important to note that very few entirely new transport technologies appear to be available as options for the reduction of global environmental pollution. Nearly all the technologies which ETSU examined have already been the subject of some level of research and development by the vehicle manufacturing industries. Moreover, the technologies under examination are available to the transport equipment supply industries in one form or another - what is needed to exploit them on the market is either improved economics or environmental legislation which would force the transport industries to introduce the most suitable technologies.

Although there are unlikely to be many "step changes" in technology which can offer a dramatic solution to these environmental problems, there are some real changes which could be made. However, these would require major changes in the car culture of our society. For example, various forms of one or two person compact vehicles are being examined, and these could make a significant difference to energy use in personal transport. Greenhouse gas emissions from personal transport could be reduced by a factor of three or four by the use of these vehicles. Similarly, moving freight from road to rail for long hauls would give at least a factor of two improvement in greenhouse gases.

For road vehicles, and in particular for cars, the analysis shows that the highest priorities for technical development are for the improvements in vehicle and engine design. A continuing move to market exploitation of diesel fuelled compression ignition engines or gasoline fuelled high compression ratio spark ignition engines is also required.

Alternative fuels for road vehicles and electric vehicles can also offer some worthwhile advantages. Especially in the case of biofuels such as methanol and ethanol, there are attractive benefits in reducing the overall emissions of greenhouse gases and other local air pollution emissions. The disadvantage is that there is much research and development required to fully exploit these benefits, and the cost-effectiveness of these fuels has yet to be proven. At present most alternative fuels are not economic, but the introduction of carbon taxes or other fiscal incentives could change the economics of their use. This might be particularly important for biofuels.

As for other transport modes, the global warming impact of aircraft appears to be higher than previously thought. Abatement of nitrogen oxide emissions from aircraft is an important priority. Suitable technologies for achieving this need to be developed. Other benefits in reducing global environmental pollution could also come from the more widespread use of high speed inter-city rail systems, light rail and buses in urban areas to encourage modal transfer from private cars to public transport.

7. OVERALL STRATEGY

It will be important for the development and implementation of the Commission's research and technological development strategy to take into consideration the non-technological policy requirements. It will also be necessary to take into account the broader policy orientations adopted within the Commission. For example, the introduction of the Single European Market, the possible extension of the Community to other countries in Central and Eastern Europe and the social and industrial development aspects of the existing Community structures all need to be included. An essential part of the overall strategy will be a co-ordinated approach which enabled a broad consensus of technical, social and economic needs to be realised.

Tackling global environmental pollution from transport represents a major challenge for transport users, for the transport industry, for national Governments and for the European Commission. Whilst technology has an important role to play in helping achieve desirable environmental goals, it is not an end in itself. The results and recommendations which we have identified in this brief paper should not be seen as advocating purely a "technical fix" approach to the problems of global environmental pollution from transport. Whilst technology has a role to play in helping achieve desirable environmental goals, it is not an end in itself. Technology has to be fully integrated with the social, fiscal and industrial development of our society.

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