Can Cars Come Clean?

STRATEGIES FOR LOW-EMISSION VEHICLES

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Strategies for Low-Emission Vehicles

OECD

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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– to achieve the highest sustainable economic growth and employment and a rising standard of living in member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;

– to contribute to sound economic expansion in member as well as non-member countries in the process of economic development; and

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Publié en français sous le titre :

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Stratégies pour des véhicules peu polluants

FOREWORD

The OECD brings together 30 member countries and helps governments meet the challenges of a globalised economy. The OECD's Programme of Research on Road Transport and Intermodal Linkages (RTR) takes a co-operative international approach to addressing transport issues among OECD member countries.

The mission of the RTR Programme is to promote economic development in OECD member countries by enhancing transport safety, efficiency and sustainability through a co-operative research programme on road and intermodal transport. The Programme recommends options for the development and implementation of effective transport policies for members and encourages outreach activities for non-member countries.

This study was carried out by the OECD Working Group on Low-Emission Vehicles. It assesses the impact of a wider use of low-emission vehicles in member countries, drawing on experience to date, research results and the responses to a survey to which 18 OECD countries responded. The main section of this report – Policy Options – presents in non-technical language the current and expected performance of conventional and innovative technologies together with the implementation issues associated with each technology. It analyses possible measures to facilitate the introduction of low-emission vehicles, and makes recommendations on policy and market-oriented actions to promote the purchase and widespread use of vehicles that can be considered clean in terms of local and global emissions. It is followed by technical annexes, which present the vehicle emission legislation in force in Europe, North America and Japan in more detail. The annexes also describe the emissions performance and potential of each technology, provide case studies and outline the measures being adopted to promote low-emission vehicles in OECD countries.

This report is published on the responsibility of the Secretary-General of the OECD.

ABSTRACT

ITRD* Number: E119515

Emissions of pollutants from motor vehicles have been the focus of longstanding concerns for both governments and the public at large because of their impact on air quality and human health. More recently, emissions of greenhouse gases have been of growing concern because of their impacts on global warming.

Despite the sustained increases in the number of vehicles on the roads and the overall distance travelled, substantial improvements in conventional vehicle and fuel technologies over the past ten years have led to considerable reductions in emissions of local pollutants. These reductions have contributed to improvements in air quality in urban areas in most OECD countries.

At the same time, CO_2 emissions from road vehicles - which contribute around 23% of total CO_2 emissions in OECD countries - are continuing to increase by nearly 2% per year.

This report, undertaken by an OECD Working Group, reviews the potential of conventional and innovative technologies (including hybrid and fuel cell vehicles) to reduce both local polluants and greenhouse gas emissions. It also analyses the implementation issues associated with the widespread development and usage of low-emission vehicles, and describes the strategies being implemented in OECD countries to promote them.

The report is completed by technical annexes which give detailed information on the current international regulations on vehicle emissions, the development of conventional (petrol and diesel) vehicles and advanced technologies - illustrated by case studies of practical experience with a variety of technologies - and on the incentives implemented in OECD countries to promote these vehicles.

Fields: 15 (environment); 90 (vehicles).

Keywords: vehicle; emission; emission control; urban area; air pollution; OECD; battery; car; electric vehicle; hybrid vehicle; legislation; international; policy; technology

* The OECD International Transport Documentation (ITRD) database contains more than 300 000 bibliographical references on transport research literature. About 10 000 references are added each year from the world's published literature on transport. ITRD is a powerful tool to identify global research on transport, each record containing an informative abstract.

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KEY MESSAGES

Local air pollution

Over the last ten years, tighter emissions controls on air pollutants from motor vehicles have ensured that emissions of local pollutants from motor vehicles have decreased, in most cases significantly, despite increasing sizes of vehicle fleets and increasing distance travelled.

Most OECD countries have legislated tighter new emissions standards for local air pollutants and these will generally take effect in 2004 or 2005.

Conventional vehicles with the best current technologies are "near clean" in terms of local air pollution. They already meet the new standards and can be regarded as low-emission vehicles in terms of local pollutants.

Overall emissions from current vehicle fleets will continue to decrease as older motor vehicles are replaced by new motor vehicles with the latest technology.

Some new technologies, including hybrid vehicles, also offer scope as low-emission vehicles in terms of local air pollutant emissions. However, the market penetration of new technology vehicles has been relatively low to date. Conventional diesel and petrol engine vehicles are expected to remain highly competitive in terms of market share, at least in the short term.

Greenhouse gas emissions - CO_2

One of the major current concerns is the increasing levels of CO_2 emissions from the road transport sector which represent around 23% of total CO_2 emissions in OECD countries and are growing at a rate of 2% per annum in absolute values.

Technology has been available to substantially reduce fuel consumption and, as a consequence, per-vehicle emissions of CO_2/greenhouse gases.

Despite technological advances, efforts to reduce per-vehicle fuel consumption have been partly offset by higher levels of power and weight per vehicle, in line with consumer preferences for larger vehicles with increased comfort and performance.

Further reductions are still possible in per-vehicle fuel consumption and CO_2 emissions from conventional motor vehicles, with high pressure diesel direct injection engines offering the best prospects.

In terms of overall emissions from vehicle fleets, improvements in per-vehicle emissions have been to date negated by an increase in the size of vehicle fleets and the growth in the annual distance travelled and this trend is expected to continue.

Hybrid (diesel/electric) vehicles and, in the longer term, fuel cell vehicles appear to offer the best prospects amongst new technologies for surpassing the CO_2 emissions performance of conventional diesel and petrol engine motor vehicles while meeting market requirements for vehicle performance.

The future emission performance of vehicle fleets depends on consumers' vehicle purchase decisions. The official test cycles do not fully inform consumers on the emissions performance and fuel consumption of new vehicles in real use because they do not reflect real-world driving conditions and the use of vehicle equipment and accessories.

SUMMARY AND CONCLUSIONS

Overview

Transport networks perform a key role in modern societies in meeting the needs of the people and facilitating trade and industry. Road transport plays a central part in these networks, and while providing a lot of positive benefits, the operation of road vehicles can also lead to adverse environmental impacts. These include local air pollutants and greenhouse gas (GHG) emissions.

Worldwide, petroleum-based fuels dominate the transport fuel market, supplying around 96% of the transportation demand. At the global level the use of the different alternative fuels such as liquefied petroleum gas (LPG), compressed natural gas (CNG) or biofuels in the transport sector is not significant, although in some countries there is very large usage.

In OECD countries, transportation (including road transport) accounted for around 62% of the final consumption of oil in 2000. Road transport was responsible for the major share of oil consumption by the transportation sector.

To control emissions of local pollutants from motor vehicles, member countries have legislated vehicle emissions regulations which have been tightened considerably over the last 20 years. The current and future European, US and Japanese vehicle emission standards impose strict limits on vehicle air pollutant emissions known to have most effect on local pollution (CO, NO_x, VOC, PM_{10}). Equivalent standards are also adopted in a range of other OECD countries. Some other motor vehicle emissions are not specifically identified in the air pollutants currently regulated by the various emission standards. There is a lack of knowledge of the impact on human health and the environment of these non-regulated emissions.

One of the major current concerns is the increasing greenhouse gas emissions from the use of petroleum fuels, with the transport sector being a major contributor. On a worldwide basis in 2000, transport (including road transport) produced 23% of total CO_2 emissions and road transport alone was responsible for 18% of total CO_2 emissions worldwide. In OECD countries in 2000, transport (including road transport) was responsible for 27% of CO_2 emissions and road transport alone was responsible for 23% of CO_2 emissions (*i.e*. 86% of transport emissions) (IEA, 2002a).

To address these concerns, policy makers have largely focused on vehicle and fuel-based measures, as these are often simpler and less politically sensitive to implement than measures which directly impact on vehicle use, such as road pricing – even if the evidence suggests that pricing vehicle use may be more effective. In addition, measures which would require significant changes to existing urban infrastructure, including the location of schools, offices, factories, houses, etc., are often difficult to implement.

Low-emission vehicles are not the "magic bullet" to the problem of pollutant and greenhouse emissions. However, the widespread adoption of low-emission vehicles – particularly very low-emission vehicles operating on fuels with a lower life-cycle carbon content – offer the capacity to deliver significant reductions in emissions from the transport sector, even in an environment of increased transport activity.

The main findings and conclusions on the key emissions-related issues – and the potential offered by low-emission vehicles to address these issues – are set out below.

Emissions from motor vehicles

Conventional vehicles

Emissions causing local air pollution

The strategy of progressively tighter standards and regulations for emissions from conventional motor vehicles has worked well in terms of reduced vehicle emissions of local and regional air pollutants.

Over the last 20 years, tighter standards have led to progressive improvements in vehicle technology. Improved engine technologies and fuels have contributed to significant reductions in emissions of local air pollutants from new vehicles. New petrol vehicles sold in Europe from 2000 onwards (and thus meeting "Euro 3" standards) emit around 90% less CO, NO_x and HC than vehicles sold in the 1980s, and emissions from new diesel vehicles have also been reduced significantly. This has contributed to reductions in local pollutants as newer vehicles with lower emissions have replaced older, more polluting vehicles.

In most OECD countries, fleet emissions of NO_x, CO and HC were at their highest levels in the early 1990s. Since then, they have dropped significantly (by 20-50%), despite a continuous increase in vehicle-kilometres travelled (+25% between 1990 and 2000). The overall result illustrates that technological improvements have made a significant contribution to improvements in local air quality in most OECD countries over this period.

The current vehicle emission standards are due to be tightened further (Tier 2 in the United States in 2004, "Euro 4" in Europe in 2005 and new long-term regulation in Japan in 2005). After the programmed introduction of these new standards (and equivalent standards adopted in other countries), all new conventional petrol and diesel vehicles that meet these tighter standards will be extremely low emitters (and therefore "near clean") in terms of local air pollutants. The expected availability of conventional motor vehicles with such low emissions of local pollutants is an important development that significantly improves the prospects for widespread use of low-emission vehicles in future.

Conventional petrol vehicles meeting Euro 4 and/or Tier 2 standards can be readily regarded as low-emission vehicles in an air pollution sense. With respect to diesel vehicles, this may also be the case, depending on whether they are supplied to the market with advanced after-treatment systems (diesel engines may be able to meet Euro 4 standards without particulate filter traps or de-NO_x devices). With the application of exhaust after-treatment and filter traps, light-duty diesel vehicles could perform as well as petrol vehicles – even in terms of NO_x and PM emissions – and will therefore also be properly considered "low-emission vehicles".

As the programmed tightening in standards takes effect and older technology vehicles in current fleets are replaced with conventional vehicles with the best current technology, the improvements in per-vehicle emissions of local pollutants will continue and levels of local pollutant emissions from motor vehicle fleets will continue to fall.

Emissions causing global warming

The situation with greenhouse gas emissions is quite different.

There is continuing concern about the level of GHG emissions – particularly CO_2 – in the context of global warming and climate change. GHG emissions from transport in OECD countries are about 27% of total anthropogenic greenhouse gas emissions and in absolute terms, are currently estimated to be growing at the rate of around 2% per annum. Over the past ten years, CO_2 emissions from road transport have increased by 24 % in OECD countries.

There are no internationally agreed standards for the maximum emission of greenhouse gases from new cars, although a number of countries have set targets for the fuel consumption of individual cars and fleets or developed voluntary agreements with the industry to reduce the average CO_2 emissions of new cars. For example:

- In Europe, an agreement was reached in 1998 between the European Commission and the European automobile industry (ACEA) to reduce the emissions of CO_2 on average by 25% (compared with 1995) for new cars sold in 2008 and to reach an average emission level of 140g/km. Similar agreements have been made between the Commission and the Japanese and Korean automobile industry (JAMA, KAMA).
- In Japan, there are vehicle energy efficiency targets for 2010, which all Japanese car manufacturers have to meet. Because of the close relationship between fuel consumption and greenhouse gas emissions, these efficiency targets will influence GHG emissions.
- In California, there is a law requiring automakers to reduce GHG emissions from non-commercial vehicles starting in the 2009 model year. The new law does not set specific limits or targets, but instead requires the California Air Resources Board (CARB) to develop and adopt regulations by 1 January 2005. However, the law is being opposed in court by the industry, which is likely to cause delay in its implementation.

Technology is available to substantially reduce fuel consumption per vehicle and, as a consequence, per-vehicle emissions of greenhouse gases. However, despite the technological advances in engine efficiency, efforts to reduce per-vehicle fuel consumption have been partly offset by market trends towards increasing power and weight of vehicles, in line with consumer preferences for larger vehicles with higher levels of comfort and performance. In addition, improvements in vehicle efficiency have been negated by an increase in the vehicle fleet and in the average annual mileage.

High pressure direct injection diesel technology offers, today and in the near future, the best results from conventional vehicles in terms of fuel consumption and CO_2 emissions, given the technologies currently available and all the aspects of vehicle performance sought by consumers (including on-road performance). Further improvements in the CO_2 performance of diesel vehicles are possible through the use of hybrid technology and regenerative braking.

However, if current trends in the manufacturing, purchase and use of motor vehicles continue – *i.e.* unless there is a breakthrough in technology or the use of alternative fuels in sufficient quantities – total CO_2 emissions from motor vehicles can be expected to continue to increase.

Alternative fuel vehicles

A range of alternative fuels is available for road transport vehicles and many have been in use for a number of years. There has been sufficient experience with alternative fuel vehicles to allow them to be assessed comprehensively on a comparative basis with conventional petrol and diesel fuels.

Worldwide, *LPG* (liquefied petroleum gas) vehicles are the most widely produced alternative fuel vehicles. LPG gives comparable performance to *petrol* engine vehicles on levels of pollutant emissions, and reduced CO_2 emissions. In comparison to *diesel* engine vehicles, LPG technologies offer very good results in particulate emissions, but produce somewhat higher levels of CO_2 emissions. With the improvement of diesel technology and diesel's popularity in Europe, some major engine makers have decided to stop the production of LPG vehicles.

CNG (compressed natural gas) engines have excellent low-emission properties, especially particulates, when compared to current diesels. Noise and vibration levels of CNG vehicles are much lower than diesel vehicles. However, there are range limitations, the loss of storage space due to the CNG cylinders is an impediment and fuelling infrastructure is also often limited. In addition, a significant issue is the need to install in the vehicle pressurised cylinders to store the fuel. Compared to diesel fuel, CNG produces equivalent or higher CO_2 emissions.

Methanol is an alternative motor fuel which can be produced from various feedstocks including biomass. Largely because of problems resulting from its corrosiveness, ground water contamination and its toxicity for health, methanol is no longer commonly used as a motor fuel.

Biofuels can be produced from various biomass stocks including agricultural products. One important advantage is that they can be blended with petroleum fuels and used in conventional vehicles. Using biodiesel in conventional diesel engines can substantially reduce emissions of unburned hydrocarbons, carbon monoxide, sulphates, and particulate matter. However, ethanol and biodiesel costs are typically two to three times higher than petroleum fuels. Producing biofuel from grain feedstocks on a large scale would require a huge amount of land. For example, to meet all of France's transport fuel needs with biofuels, more than 25% of France's land area would be required, displacing regular agricultural activities. Other methods for ethanol or methanol production, *e.g.* from cellulose, are possible but appear to be even more expensive.

New technology vehicles

Electric vehicles

Electric vehicles produce no local emissions during their operation and therefore are often regarded as a potentially desirable technology in urban areas. They have a high level of comfort and their acceleration is generally excellent. High cost, a short range, long recharging times and the absence of infrastructure for charging batteries have been problems encountered in the real world. At this stage, only small electric vehicles and motorcycles can compete in the market. The key to electric vehicle technology is to improve the performance of the batteries. Although a variety of advanced batteries is under development, a breakthrough leading to mainstream applications of full electric vehicles does not appear likely. However, new concepts are being developed, of which the most promising is the hybridisation of the electric vehicle.

Hybrid vehicles

Hybrid vehicles can be either electric vehicles equipped with a range extender, or in most cases, petrol/diesel vehicles with an electric drivetrain and an electric battery system to improve their global efficiency. Recent trends are for the development of mild hybrid technologies that use an alternator-starter system to improve the efficiency of petrol/ diesel engines. A hybrid vehicle can operate with higher engine efficiency and the braking energy is partly regenerated. Hybrid technology is a promising route principally to reduce CO_2 emissions, while also reducing air pollutant emissions. Hybrid vehicles offer better air pollutant emissions performance than the best petrol and diesel vehicles, but production costs are currently significantly higher than conventional vehicles with similar on-road performance. While around 130 000 hybrid vehicles are already operating worldwide, the future success of hybrid vehicles will depend largely on manufacturers being able to reduce their incremental vehicle production costs.

Fuel cell vehicles

An enormous amount of research is currently being devoted to fuel cell vehicles. Fuel cell technology for road vehicles is a promising technology with potentially high efficiency and low emissions. Fuel cell electric vehicles operating on pure hydrogen produced from renewable or other zero-carbon-emitting sources could be considered “zero emission” vehicles, because if the fuel is hydrogen, only water is generated.

However, if the fuel cell vehicle is equipped with a reformer to produce the hydrogen from petrol, diesel or methanol, hydrocarbon (HC) and CO_2 emissions are likely to be around the same as for future advanced diesel vehicles. NO_x emissions are likely to be around the same as for future petrol vehicles.

Fuel cell vehicles require considerable research and development to refine the technology and have recently attracted considerable research funding. Apart from cost issues, there are some practical problems facing the commercialization of fuel cell vehicles. One is the choice of fuel: hydrogen, petrol or methanol? Hydrogen would require the very costly development of a complete new distribution network. Methanol or petrol would require the vehicle to be equipped with a reformer, which would imply no significant benefits over new generations of petrol and diesel vehicles, in terms of emissions of air pollutants. Given the current technical challenges to be overcome, fuel cells are unlikely to provide an optimal solution for motor vehicles for some considerable time to come.

In 2002, Japanese car makers released a small number of fuel cell vehicles for trial by key government agencies in Japan and the United States.

Well-to-wheel assessments

Energy efficiency

On a well-to-wheel basis, the energy efficiency of a petrol vehicle is about 14% and that of a diesel vehicle around 18% of the original energy content of the fuel, for petrol and diesel produced from crude oil. For a CNG vehicle, the figure could be up to 17%. Similarly, a vehicle with an internal combustion engine (ICE) operating on hydrogen has an efficiency of about 14%.

Thermodynamic, engine and transmission losses count for about 75% of the original energy content of the fuel. There are also considerable "well-to-tank" losses with many fuels, due to extraction, production and transport of the fuels. For petrol and diesel these amount to 15 to 20%. For methanol from natural gas, these losses are around 35% and for hydrogen from natural gas around 25%.

CO_2 emissions

Internal combustion engines in single and hybrid configurations. Compared to latest current technology vehicles, future advanced petrol engines could achieve a CO_2 emission reduction on a well-to-wheel basis of about 20% through application of new engine technologies. When hybrid drive-train concepts are applied, the reduction could be as much as 50% for the same vehicle model. "Mild hybrid" configurations will not achieve a 50% improvement, but could nevertheless offer significant improvements in fuel consumption and CO_2 emission at a relatively low cost. Diesel engines could achieve a more moderate 15% reduction, but the reduction could be as much as 40-50% with hybridization of the diesel engine. Additional savings may be achieved through weight reduction, better aerodynamics and new tyre designs.

Biofuels. On a life-cycle basis, CO_2 emissions very much depend on the source of the biomass and its production method. Taking into account the energy required to produce the crops (*e.g.* fertilizers and pesticides), and then to process and distribute the fuel, it may be possible to reduce CO_2 emissions by 30-60% compared to vehicles fuelled with petrol or diesel.

Electric vehicles. The level of CO_2 emissions, when considered on a well-to-wheel basis, depends on the way the electricity is produced. When electricity is produced from coal or gas (which in OECD countries is the most common source of electricity), the CO_2 balance is not better than for petrol or diesel vehicles. When electricity comes from nuclear or renewable sources (*e.g.* hydropower), electric vehicles can be considered as zero-emission vehicles.

Fuel cell vehicles. Fuel cells powered with petrol, diesel or methanol do not offer any advantages in terms of GHG emissions compared to current conventional vehicles. However, if hydrogen is the fuel source and is produced by renewable sources, fuel cell vehicles could theoretically offer the best performance in terms of CO_2 emissions.

Comparative on-road performance

Experience on the road has shown that alternative and new technology vehicles so far have not been able to compete with vehicles equipped with conventional powertrains. Their main drawbacks are performance, cost, availability of new fuels (hydrogen, biofuels), range (CNG and electric vehicles in particular), reliability, comfort, and safety (crashworthiness of cars equipped with new technologies, safe handling of new fuels and safety of fuelling stations). This means that a significant amount of effort would need to be put into the development of vehicles and large investments would be required for the production and the distribution of new fuels such as hydrogen to close the gap between new, alternative fuel and conventional technologies.

Vehicle emissions: official test cycles

The ultimate test of the effectiveness of all efforts to reduce pollutants and to increase fuel efficiency is the performance of the vehicles on the road. Standardised test procedures as adopted in official test cycles (FTP in the United States and MVEG in Europe) can give an indication of actual levels and trends in vehicle fuel consumption and emissions. However, in practice, there are a number of parameters that can significantly influence actual fuel consumption and emissions, including driving style, engine tuning, use of air conditioning and other auxiliary equipment, urban or highway use, and vehicle condition.

Regardless of the vehicles and technologies, there is generally a significant gap between results obtained during official test cycles and those obtained in real driving conditions. Research conducted over many years has shown that fuel consumption levels resulting from real-world driving conditions are usually much higher (around 25% more) than official test cycle results.

While these conclusions are not new, they are increasingly important in the context of fuel conservation and low-emission vehicles. They are also of growing importance to consumers, given the increasing use of air conditioning and accessories expected in the future that will produce greater differences between official cycle and real use results.

Information and consumer behaviour

Consumer information

At present, there are no indications that the current trend involving the purchase of more powerful and heavier vehicles has come to an end. On the contrary, apart from the increasing popularity of sport utility vehicles (SUVs) and more powerful passenger vehicles, there is a continuing trend towards installing more equipment for safety, comfort and utility, including air conditioning (especially in Europe, where there has been a large market share increase for cars equipped with air conditioning).

Many consumers are making decisions about new vehicle purchases with little knowledge about the actual fuel consumption and relative environmental performance of different vehicle models. This is unfortunate given that a well-informed consumer is a key element in the effectiveness of strategies to encourage an increasing proportion of low-emission vehicles in the market. There is considerable variability in emissions and fuel consumption performance from model to model – even in conventional vehicles and within the same vehicle types.

Consumers need to be aware of such differences to be able to factor environmental performance into their vehicle purchasing decisions. Internet-based guides, supported by vehicle labelling, are one way which is being used with success to deliver this information to consumers. To be effective, both guides and labels need to present the information accurately, but also in a form which is readily understood by consumers.

Incentives

Consumer behaviour can be influenced by an appropriate set of incentives carefully targeted at reducing fuel consumption and/or reducing emissions.

One rationale for incentives for low-emission vehicles is that, in most countries, the market functions imperfectly and there are no explicit charges directly linked to actual usage - and therefore to the real pollution of vehicles at the location and time of vehicle use. In such an environment, vehicle purchase decisions will continue to be made in ways that do not take full account of the longer-term social and environmental impacts.

The most common forms of incentives involve taxation, clean fuel incentives, infrastructure subsidies and incentives for use of low-emission vehicles.

Tax incentives (applied at the time of purchase and/or via annual tax reductions) are the most common incentives used by OECD governments to favour the adoption of low-emission vehicles. Depending on the size of the incentive offered, they can have a significant impact on consumer choice, especially when associated with reliable consumer information and when the technology targeted and its associated infrastructure are credible, and vehicle performance meets consumer expectations.

Clean fuel incentives, such as incentives offered in some countries for the production of low-sulphur fuels, have been effective in advancing the availability of fuels which enable vehicles to achieve their optimum emissions performance and which support vehicle manufacturers in supplying advanced technology vehicles to the market.

Infrastructure incentives could be important and may be a useful measure in promoting the development of new distribution networks for alternative fuels (*e.g.* natural gas, hydrogen).

Incentives for low-emission vehicle use, such as low-emission zones, access to high occupancy vehicle lanes, special or restricted access on high pollution days or parking concessions are low-cost measures in use in some countries.

Government leadership/incentives applied to government purchases. Governments can also play a leadership role and encourage its administrations to adopt purchasing policies for their own vehicles that favour low-emission vehicles.

Outlook

Local pollutants

The standards that have been approved for introduction in 2004-2005 (*e.g.* Euro 4, Tier 2) will further substantially reduce emissions of local pollutants (CO, NO_x, VOC, PM). For example, the Euro 4 standards (to be implemented in 2005) will achieve a 50% reduction in CO, HC and NO_x emissions from new petrol vehicles, relative to Euro 3. For diesel vehicles, they will achieve a 50% reduction in NO_x and PM emissions and a 20% reduction in CO emissions, relative to Euro 3.

Looking further ahead, for future vehicles with petrol engines, a reduction of the emissions of CO, VOC and NO_x by 80% compared to current European (Euro 3) standards appears technically feasible.

For future diesel engines, with advanced exhaust after-treatment and incremental improvements to the engine, a reduction of the emissions of CO, VOC and NO_x by 75% and of PM by 90% compared to Euro 3 (i.e. about as much as petrol engines) also appears technically feasible. However, although carbon monoxide and hydrocarbons for diesel engines will be considerably lower than from petrol engines, NO_x and particulate emissions will remain relatively higher. The ability of light-duty diesel vehicles to achieve further reductions in NO_x and PM emissions will depend on the capacity of diesel technology to meet the contradictory objectives of both lower NO_x emissions and lower CO_2 emissions. It will also depend on the extent to which manufacturers build new vehicles utilising the latest technology (*e.g.* particulate filter traps). A further consideration is the performance of diesel engines over the lifetime of the vehicles, which will depend on the reliability and long term efficiency of their after-treatment systems.

Further stringent standards (*e.g.* beyond Euro 4) would only bring marginal benefits in terms of CO and VOC but could bring more significant benefits for PM and NO_x, principally from diesel vehicles.

Fuel consumption and CO_2 emissions

The "well-to-wheel" energy efficiency of current technology passenger cars fuelled with petrol, diesel, LPG or CNG is in the order of 15-20%. Widespread adoption of improved technologies in conventional vehicles could increase the well-to-wheel efficiency up to approximately 30%. Other things being equal, with maximum use of such technologies (including hybrids), GHG emissions of future vehicle fleets could be reduced by 50% compared to current technology vehicles. Of course, the actual reductions will depend on the types of vehicles actually purchased. If the trend towards heavier vehicles with more power and more electrical equipment continues, this potential gain will be greatly reduced.

Theoretically, fuel cell technology could even further improve fuel efficiency, depending on the fuel actually used. However, in the medium term (until about 2020) the use of fuel cells for powertrains is expected to remain quite small in relation to total fleets.

Vehicles operating on fuels with a lower life cycle carbon content also offer the potential for significant reductions in emissions. Vehicles operating on biofuels or fuels (*e.g.* hydrogen) produced from renewable sources can have relatively low CO_2 emissions on a life-cycle basis. Currently, the cost of these fuels is significantly higher than the cost of fossil fuels, ranging usually from two to five times the cost of petrol. Faster market penetration of the above-mentioned vehicles and fuels may occur if the price of conventional fuels rises significantly, perhaps due to international movements in the price of crude oil or the introduction of policies to achieve a higher level of internalisation of the external costs.

Emissions and safety

Research has demonstrated that increasing the power of motor vehicles increases their emissions in normal everyday use. In addition, significant increases in power will have an impact on driver control of the vehicle, and thus on road safety. Reducing the power-to-weight ratio of motor vehicles would be one of the most effective ways available to reduce vehicle fuel consumption, whatever the technology of the engine. Limits on maximum power/weight ratios could also produce significant safety benefits.

Health

In OECD countries, with a continuous decrease in emissions of regulated air pollutants, the risk to human health from vehicle emissions is progressively declining. However, particulate matter emissions from diesel engines remain a major concern. The situation in some non-OECD countries is completely different, with local pollution from road vehicles increasing and causing increasingly severe health problems.

There is a lack of knowledge of the impact on human health and the environment of the non-regulated emissions (aldehydes, ketones, carcinogens, heavy metals, N_2O). If in the future there is clear evidence of negative impacts, specific vehicle-based regulations may be required.

Policy conclusions

In attempting to minimise the environmental impact of motor vehicles, policy makers have retained a focus on vehicle emissions and fuel-based measures. To date, the low-emission policies and strategies pursued by OECD member countries have been very successful in achieving cleaner vehicles. Technologies adopted and developed by manufacturers have been dramatically successful in reducing pollutant emissions per vehicle-kilometre driven.

Vehicle technology advances have been so important that not only have per-vehicle local pollutant emissions been reduced, but also pollutant emissions from the vehicle fleets, despite an average 50% increase in distance travelled (in vehicle-kilometres) by passenger cars in OECD countries over the past 20 years. The levels of local pollutant emissions are expected to continue reducing for many years as latest technology vehicles replace older technology, more polluting vehicles in national vehicle fleets.

However, there is widespread concern about GHG emissions – especially CO_2 emissions – from motor vehicles, which are expected to continue to increase.

From a policy viewpoint, it is important to recognise that, based on current trends, the market-based outlook is for a continued increase in vehicle size, power and weight – and consequently in average fuel consumption per vehicle – and a continued increase in vehicle ownership rates and distance travelled per vehicle.

The widespread use of conventional vehicles equipped with the latest technology can help curb increases in CO_2 emissions. These benefits could be extended with the development and increasing use of very low-emission vehicles operating on fuels with a lower life-cycle carbon content.

However, based on the most recent forecasts, the total distance travelled (*i.e.* vehicle-kilometres) of passenger cars in OECD countries is expected to increase by 16% from 2000 to 2010 and by a total of 32% from 2000 to 2020. This means that, other things being equal, to compensate for this increase and to stabilise CO_2 emissions at today's level, it would be necessary to improve the fuel efficiency of the whole fleet by the same magnitude - which would present a real challenge. This suggests that, unlike air pollutant emissions, vehicle technology alone cannot be relied on to halt the increase in GHG emissions in the short to medium term.

If these trends continue in the medium term, current consumer preferences and upward trends in vehicle-kilometres travelled are likely to overwhelm the impact of foreseeable reductions in per-vehicle fuel use and CO_2 emissions that can be expected from efficiency improvements in conventional petrol and diesel vehicles.

Governments therefore need to consider further measures that can modify current trends if countries are to achieve their environmental and energy policy goals, including those related to GHG emissions. Although outside the scope of this report, all such feasible measures should be explored and, if appropriate, integrated with vehicle-based measures as part of a package of policy measures to achieve overall objectives, including containing anticipated increases in GHG emissions.

Alternative policies which are more politically sensitive – but may be more effective in the future – include measures which directly impact on vehicle use (such as road pricing) or measures aimed at reducing the necessity for travel and transport. The latter could require significant changes to overall land use policies, town planning, logistics and existing infrastructure and would be more difficult to pursue.

Research undertaken by the International Energy Agency (IEA, 2002b) has concluded that a package of such alternative measures – including improved vehicle fuel efficiency, increased use of alternative fuels, increasing proportion of new technology vehicles and reducing travel demand growth and switching to less energy-intensive modes – would only slow the anticipated rate of increase of oil consumption. This conclusion suggests a need for further action.

Strategies to promote low-emission vehicles

Consideration needs to be given to a range of strategies that will address the concerns outlined.

Reducing local air pollutants

In all countries – within and outside the OECD area – the majority of vehicles in national fleets meet standards that applied to new vehicles a number of years ago. As a result, the emissions performance of the majority of vehicles is below the levels demanded of new vehicles by the latest standards. Vehicle technology has developed in advance of the mandated standards to be introduced in 2004-05. Some models already include the latest technology that in some cases exceeds these future standards.

The emissions performance of the vehicles currently being purchased could be improved if consumers were to buy vehicles with the latest pollution control technology. In many cases, they would only buy low-emission vehicles in advance of the mandatory standards being adopted if they were given incentives to do so.

Reducing energy consumption and greenhouse gas emissions

To date, the objectives of slowing the rate of growth and subsequent reduction of GHG emissions from vehicles have been pursued differently in regions of the world. In the European Union and Australia, for example, such reductions have been pursued principally through voluntary agreements between government and industry. This is leading to positive results in terms of lower average CO_2 emissions of new vehicles being sold in the EU.

Alternative legislative approaches have been pursued in some other regions enabling the setting of fuel consumption standards to be pursued from the outset. Japan (Top Runner Programme), the United States (CAFE Programme) and some other countries have set mandatory fuel economy standards.

In the future, if the results of voluntary agreements prove to be insufficient, governments may need to consider developing and setting appropriate mandatory standards. The expectation is that a strategy of progressively tighter goals for greenhouse gas emissions could work as well in reducing GHG emissions as it has for emissions of local pollutants, although it is likely to be more complex to administer.

Another option which is at least technically feasible and could be effective if it were publicly supported would be to take initiatives that would encourage and lead to the purchase of less powerful vehicles. Reducing the power-to-weight ratios would be an effective way to reduce fuel consumption, whatever the technology of the engine. It would have immediate benefits on both local pollutants and global emissions as well (and could also be expected to have positive impacts on road safety). At present, although vehicle manufacturers are proposing vehicle models with low power-to-weight ratios, consumers are continuing to buy increasingly heavier and more powerful vehicles with higher power-to-weight ratios.

Provision of incentives

An effective set of incentives, supported by a well-informed consumer, offers considerable potential to accelerate the uptake of low-emission vehicles in vehicle fleets. Governments in a number of OECD countries have already introduced a range of measures based on the provision of incentives.

The available data and experience suggests that a combination of differentiated vehicle and fuel taxes, based on environmental performance, can be cost effective in increasing the proportion of low-emission vehicles on the market. In some countries, such incentives are offered on a budget-neutral basis, with the funds required to provide incentives for low-emission vehicles being raised by additional taxes on vehicles with poor emissions or poor fuel consumption performance. In other locations, the taxes imposed on poor emissions performance outweigh the incentives offered for good performance. The absence of explicit taxes on CO_2 emissions (*e.g.* carbon tax on fuels) in most countries could provide the basis for adopting such incentives.

Such taxation incentives could be extended to promote early compliance with the more advanced standards set to be adopted (*e.g.* Euro 4 standards which will apply in many countries from 2005), if governments wish to accelerate the benefits offered by the latest vehicle technologies.

Such incentive packages need to be carefully targeted and supported by adequate consumer information. Governments should only give consumers incentives to purchase vehicles on the basis of their emissions performance, when assessed using an agreed objective test (such as that required for vehicle certification). Incentives are likely to be more effective if they are supported by objective public information on the environmental performance of individual vehicle models.

To ensure the most appropriate outcomes, incentives for provision of vehicles with low pollutant and/or low GHG emission levels should in general be based on their actual performance rather than on the technology or fuel type.

Recommended actions

Low-emission vehicles are likely to become widely available and can play a useful role in addressing both air pollutant and greenhouse emissions from the road transport sector. Maximising this potential is likely to require a combination of measures, involving government, industry and consumers. This report does not propose to identify the specific roles for each of these groups in increasing the penetration of low-emission vehicles in the fleet, as this will vary from country to country. Nevertheless, the report recommends that the following actions are critical to maximising both the potential benefits of low-emission vehicles and the improvements actually achieved.

Development of consistent and integrated transport policy

While tremendous advances have been made and further improvements are still expected regarding vehicle technologies, it appears that technology by itself will not be able to resolve vehicle emissions issues, especially emissions of greenhouse gases, in the short to medium term.

Low-emission vehicle and fuel technology measures should be only one - albeit key - element of a broader transport policy that aims to reduce vehicle emissions. To be effective, such policy should aim to address road travel demand and, where appropriate, to shift part of the road transport demand to more environmentally friendly modes.

Inform consumers on performance in real use

There is a need to better inform the consumers on the environmental performance of the cars they are purchasing. In many countries the only “official” information of an environmental nature that consumers are provided with in relation to individual vehicle models is fuel consumption and, more recently, CO_2 emissions. There is usually little or no information from “official” sources on air pollutant emissions for individual makes and models, and no information on performance in real use.

Clearer and more systematic information diffusion is highly desirable, allowing consumers to evaluate emissions performance of vehicles in real use and compare alternative fuels and technologies. In the interests of greater transport sustainability, such consumer information should also include advice on well-to-wheel emissions, as this would help consumers to make responsible purchasing decisions with the required knowledge to understand the full environmental impacts of their choice.

Development of new test cycles for fuel consumption

The current official cycle tests do not reflect real driving conditions and do not account for the increasing use of air conditioning and other accessories. The official cycle tests tend to encourage manufacturers to optimise their vehicles for the test conditions, which may not be optimal for reducing emissions in real-world driving conditions. A further concern is that many consumers do not understand the limitations of the official tests and the different results to be expected in real driving conditions. This is particularly the case where these official tests are used to publish fuel consumption results. It would be highly desirable for the limitations in the current official test cycles to be addressed.

The new test that is required would be internationally agreed and establish a common methodology for measuring and comparing fuel consumption and GHG emissions – independent of the vehicle technology or fuel type. It would reflect real-world driving behaviour and use of vehicle equipment (including, for example, the now frequent use of air conditioning). Generally, performance-based standards or targets would be preferable to technology or fuel-based approaches, as they encourage manufacturers to innovate to achieve the desired outcomes. Further consideration would need to be given to the manner in which the new test cycle would be adopted, *e.g.* whether the new test cycle would simply be added to the existing official test cycles or whether more substantial changes would be preferable.

Appropriate and targeted incentives

Taxes on vehicle emissions

Explicit taxes on emissions of local pollutants and greenhouse gases give consumers price-based signals on the social and environmental consequences of their vehicle purchase decisions. In these circumstances, governments should develop incentive packages based on the actual road performance of the motor vehicles and not on the technology itself.

Demonstration fleets

Government subsidies and support are often essential to the development and uptake of new technologies. New vehicle technologies offering environmental benefits may need demonstration fleets with operating experience before there is widespread adoption by the public. In some cases, initial government support for the development and operation of these fleets may be warranted.

One of the options is for government to purchase low-emission vehicles for their own fleets. This would not only demonstrate to the public the reliability (or otherwise) of the new technology, but also contribute to a more rapid development of the required infrastructure.

Fuel infrastructure incentives

It is of little use to promote alternative fuel or new technology vehicles which have the capacity to deliver low levels of emissions, if a suitable fuelling or maintenance network is not available at the same time. This has been the cause of the failure of the introduction of some new fuels and technologies in the past. In future, governments should take action to facilitate the development by industry of suitable fuel storage and distribution infrastructure for new technologies and fuels which can demonstrate real environmental benefits. Consideration could be given to government assistance through pilot projects or possibly through appropriate incentives that encourage the industry to invest in the geographically dispersed infrastructure users require.

Evaluation of achieved outcomes

New technologies penetrating the vehicle market should be monitored over time and their pollutant emissions (both local and global) measured with the ageing of the vehicle. It would be counterproductive to continue providing incentives for low-emission vehicles utilising a technology with deteriorating or poor performance after a number of years in real use.

Reduction of weight and power-to-weight ratios

There is a strong relationship between engine power, vehicle weight and fuel consumption. Changing the power-to-weight ratio is a direct way of changing the fuel consumption of motor vehicles. Reducing the power-to-weight ratios would be one of the most effective ways available to reduce vehicle fuel consumption, whatever the technology of the engine. Lower power-to-weight ratios would have immediate benefits for both local pollutant emissions and global CO_2 emissions and also contribute to improved road safety.

Measures which encourage a reduction in vehicle weight and lower power-to-weight ratios would not require any technical development but would require very strong political support – and the co-operation of vehicle manufacturers - given that any such limitations would be contrary to prevailing consumer preferences and would not be universally supported. A lowering of power-to-weight ratios could be pursued via public information and the support of manufacturers, but taxation and incentive measures could be required in order for there to be a significant impact.

References

International Energy Agency (IEA) (2002a), *CO_2 Emissions from Fuel Combustion 1971-2000*, 2002 Edition. IEA-OECD, Paris.

International Energy Agency (IEA) (2002b), *World Energy Outlook*, 2002 Edition. IEA-OECD, Paris.

Chapter 1

INTRODUCTION

Abstract. This chapter outlines the scope and objectives of the report and provides an overview of the environmental impacts caused by road vehicles, including local pollution and global emissions.

Mandate of the OECD Working Group on Low-Emission Vehicles: Implementation Issues

In the framework of its 2001-2003 Programme of Work, the OECD Road Transport and Intermodal Linkages Research (RTR) Programme launched a Working Group in 2001 on “Low-Emission Vehicles: Implementation Issues”. The objective of the group was to assess the performance of conventional and innovative technologies in terms of local pollution and global emissions and to identify and analyse strategies for the implementation of low-emission vehicles. The expected outcome was an analysis of the impact of the widespread use of low-emission vehicles in the medium-term (by 2020), in the context of policy objectives for more efficient use of energy resources and a reduction of emissions from road transport (CO, NOx, HC, PM and CO_2).

There is no internationally agreed definition of a “low-emission vehicles”, even though some countries (*e.g.* the United States) have developed such definitions and though some concepts of environmental friendly vehicles — EFV — (*e.g.* in Japan or in the EU) are used. For the purpose of this report, the OECD Working Group took the following approach: a low-emission vehicle (LEV) can be defined as a vehicle which has:

a) Low fuel consumption levels (thus producing low levels of CO_2 emissions).

b) Low levels of those emissions which adversely effect air quality and human health.

c) Both (a) and (b).

This report can be divided in two parts. The first – Policy Options - provides basic information about LEVs, the problems and future possibilities, leading to conclusions and recommendations. It is complemented by technical annexes which give detailed information on the current international regulations on vehicle emissions, the development of conventional (petrol and diesel) vehicles and advanced technologies - illustrated by case studies of practical experiences with a variety of technologies — and on the incentives implemented in OECD countries to promote these vehicles.

Objectives and scope of the report

While it is clear that the operation of motor vehicles produces emissions can have adverse impacts on human health and the global environment, the question that needed to be addressed was to what extent vehicle and fuel technologies can contribute to bringing air pollution and greenhouse gas (GHG) emissions under control.

The first objective of this report is to determine the potential for vehicle technology and fuels to reduce the level of pollutant and GHG emissions which have adverse impacts on human health and/or the environment. The second objective is to identify and evaluate possible strategies which could be implemented to promote the adoption of LEVs.

The scope of this report is limited to reviewing the potential of *new* vehicles and focuses on implementation aspects related to LEVs. It does not intend to identify or analyse measures to improve the performance of *existing* vehicles.

While reducing air pollution, fuel consumption, and GHG emissions from transport requires a combination of strategies going beyond vehicle technology - such as in-service maintenance and management of road travel demand - the report will only address issues related to the potential benefits and contributions of LEVs and what measures might be effective to facilitate the wider adoption of LEVs in the marketplace.

The report mainly focuses on light-duty passenger vehicles. Two-wheel and heavy-duty vehicles are not covered in this report. However, case studies of urban buses using new technologies are included in the annex.

While it could be argued that reducing vehicle noise could form part of the LEV "package", it is considered that the scope for noise reduction in new vehicles based on vehicle technology factors is limited, and as such, noise emissions will not be dealt with in detail in this report.

General introduction on vehicle-related environmental issues

As well as the emissions produced in use, the building, maintaining and scrapping of vehicles generate air pollutants, greenhouse gases, heavy metals and toxic wastes. Producing and distributing fuels also generate emissions and consume energy. Road transport vehicles are significant sources of air pollutants and greenhouse gases.

Vehicle-based air pollutants include:

- Particulate matter (*e.g.* PM_{10}) and nitrogen dioxide (NO_2), which can lead to health problems.
- Nitrogen oxide (NO_x) and volatile organic compounds (VOCs), which contribute to photochemical smog.
- Sulphur dioxide (SO_2), which can lead to acidification of waterways.

The principal greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), with CO_2 being by far the most important of the greenhouse gases produced by the transport sector.

All the various factors related to emissions of local pollutants and greenhouse gases must be taken into account in identifying the combinations of vehicle technology and fuels that will produce the lowest level of vehicle emissions.

Chapter 2

REGULATED AIR POLLUTANTS[1]

Abstract. After reviewing the history of the standards set to regulate air pollutants from road vehicles, this chapter reviews the evolution of the technologies and their contribution to the reduction of local pollutant emissions to date. It also explores the potential of advanced technologies in achieving further reductions in future per-vehicle emissions of local pollutants.

Introduction

There is clear evidence of human health and environmental impacts from exposure to the pollutants emitted from motor vehicles. This report does not aim to investigate the linkages between the vehicle emissions of those pollutants which affect air quality and their health and environmental impacts, as there is already considerable literature on the subject.[2] By way of illustration, the following chart from research undertaken in the Netherlands (de Hollander *et al.*, 1999) indicates that particle, noise and ozone pollution have significant human health impacts. Motor vehicles contribute significantly to the exposure of the population to all of these pollutants.

History of vehicle emission standards in major vehicle manufacturing countries[3]

United States

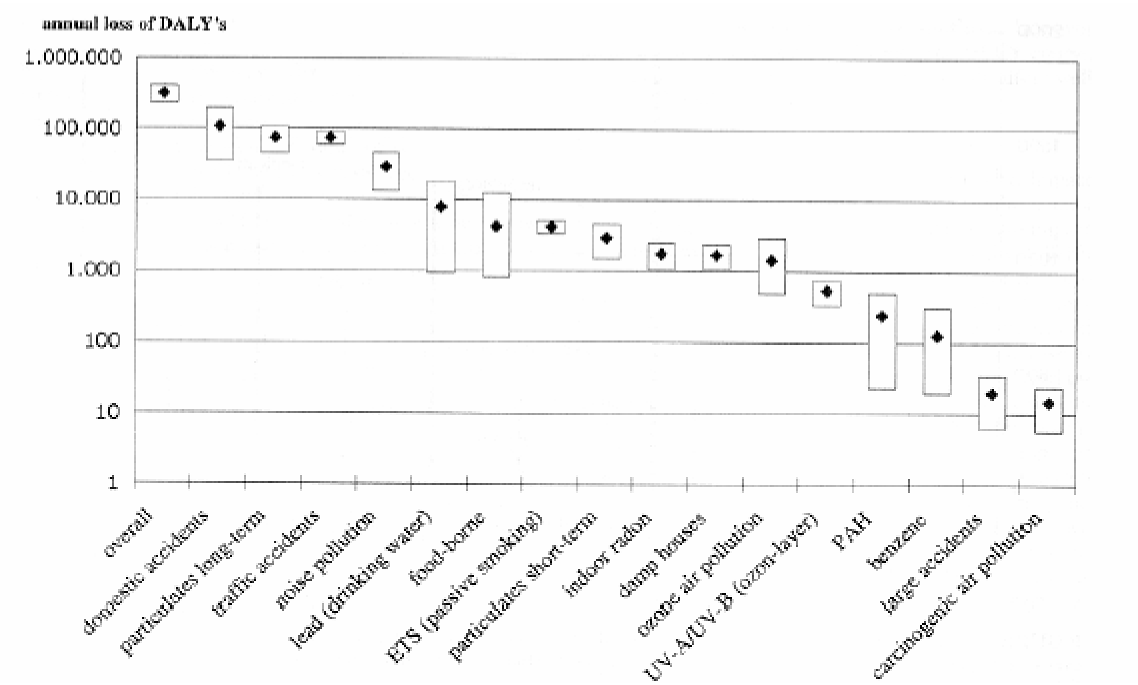
In the late 1960s and early 1970s it became clear that the growing numbers of petrol-fuelled vehicles on the road contributed to acid rain and air pollution. At the time, the United States had made significant technological advances through its *Space* Programme and was in a position to reallocate research resources no longer required for it. These circumstances created the opportunity to apply the new knowledge gained and the resources available to motor vehicle-related pollution. The United States launched the implementation of the Clean Air Act in 1970.

[1] In this chapter, "emissions" refer to tailpipe emissions unless well-to-wheel emissions are specifically mentioned.

[2] Information on standards regarding health risk can be found at *http://www.euro.who.int/document/e71922.pdf*, *http://www.epa.gov/airs/criteria.html* and *http://www.iceline.be*.

[3] More detailed information on emission standards can be found in Annex 1.

Figure 2.1. Annual health loss in disability-adjusted life years (DALYs) for selected environmental exposures in the Netherlands



Note: The graph shows point estimates and 5th and 95th percentiles of probability intervals.

ETS = environmental tobacco smoke; UV-A = ultraviolet light; PAH = polycyclic aromatic hydrocarbons.

Since then, major efforts have been put into the reduction of the emissions of motor vehicle pollutants under the force of tightening legislation. Legislation controlling the emissions of pollutants from passenger cars first emerged in California where air quality problems were quite severe. The first measures to be taken on petrol-fuelled cars were improved carburettor settings and the use of exhaust gas recirculation systems. However, despite the improvements made throughout the 1970s, these measures were not sufficient to meet the tightening emissions standards set out in the legislation. This led to the introduction by manufacturers of catalytic converters in the mid-1970s. To prevent damage to catalytic converters, lead-free fuel was introduced as well, which also eliminated the vehicle fuel-related lead pollution that had become one of the sources of concern.

Europe

In Europe the evolutionary path initially lagged about ten years behind the United States. During the 1980s, some European countries adopted catalytic converters: Sweden, Switzerland, Austria, and a small proportion of new cars in Germany. In several other countries, the first catalytic converters emerged in the late 1980s under tax incentive programmes. It was not until the 1992 "Euro 1" legislation that the application of a closed loop-controlled three-way catalyst became the industry standard. From 1993 catalytic converters were required for all new petrol cars sold in Europe (15 countries). Legislation in Europe subsequently became more stringent. In 1997, Euro 2 became the standard, followed by Euro 3 in 2000. In 2005 the next stage will be reached as Euro 4 will replace the existing Euro 3 standards. In contrast to the United States, Europe has a significant light-duty diesel fleet. In 2001, 34% of the new cars in Europe had diesel engines (up to

60% in France and Austria). Since the early 1990s diesel regulations have become progressively more stringent in Europe.

Japan

The first vehicle exhaust emission control in Japan started with CO regulation for petrol-fuelled vehicles in 1966. When air quality problems became quite severe, especially in large cities, the exhaust emission regulation was strengthened progressively on CO, HC and NO_x. In 1978 the base of the very stringent current exhaust emission regulations was completed for petrol-fuelled vehicles. The exhaust emission regulation for diesel vehicles – which was introduced after the regulation for petrol vehicles – started with the black smoke regulation in 1972. The regulation of emissions of particulate matter (PM) from diesel vehicles began in 1994.

Evolution of standards

The trends in European rulemaking on emissions from new cars are outlined in Figures 2.2 and 2.3, for petrol and diesel engines. Similar trends were evident in the United States and Japan.

Figure 2.2. Emission reduction due to ECE regulations (petrol cars)

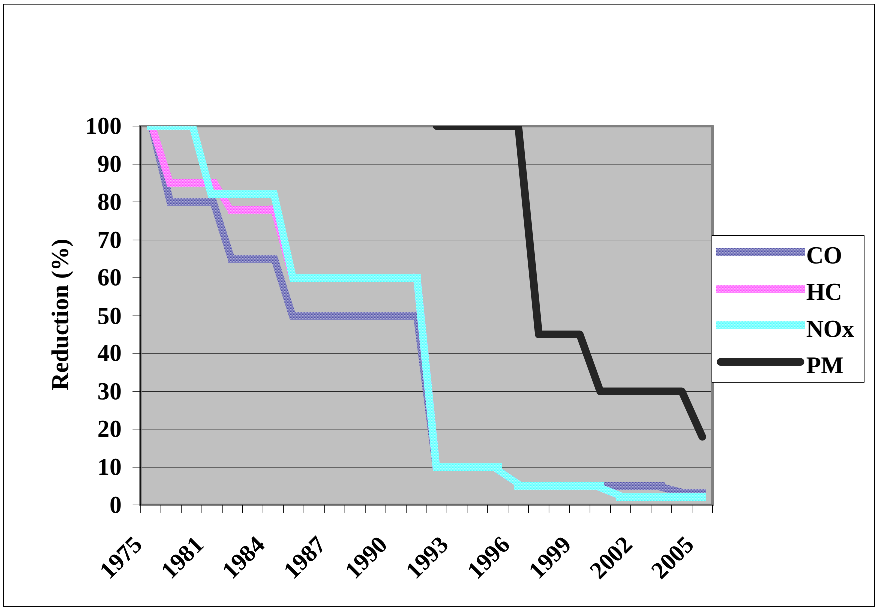
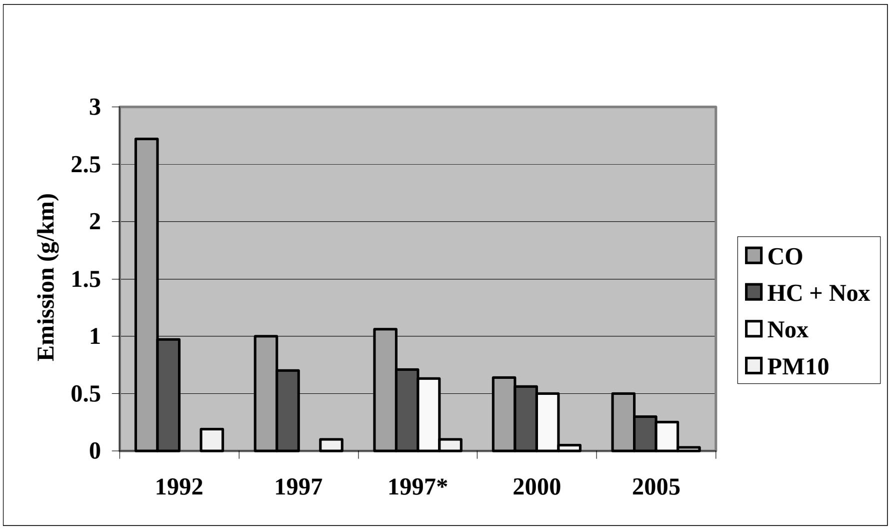


Figure 2.3. Effect of ECE regulations (diesel cars)



*Changing of test cycle.

Further details on the standards in European, US and Japanese regulations are provided in Annex A.

Evolution of the technology

Petrol engines

As mentioned above, the first measures to be taken for petrol-fuelled cars were improved carburettor settings and the application of exhaust gas recirculation. These were followed by the introduction of catalytic converters. The first catalysts were not regulated, and the engine mixture (air-to-fuel-ratio λ) was not optimised to deliver maximum catalyst performance. Because a catalytic converter has the highest reactivity for CO, VOC and NO_x at $\lambda = 1$[4], a closed loop system with an oxygen sensor became the mainstream technology on petrol passenger cars in the 1980s. These developments occurred in conjunction with the development of electronic engine management systems and electronic fuel injection, and now carburettors have virtually disappeared from modern passenger cars. Further tightening of the emissions limits led manufacturers to increase catalyst reactivity and develop more refined engine control systems, as well as other measures to reduce cold start and evaporative emissions control.

Table 2.1 illustrates emissions levels measured for cars with and without catalytic converters.

[4] λ =1, when the mass of air is 14.7 times the volume of petrol.

Table 2.1. Pollutant emissions of older model cars with and without catalytic converters

	CO g/km	HC g/km	NOx g/km
ECE 15 cycle			
(urban, cold start)			
Without catalyst	41.2	6.4	1.8
With catalyst	6.7	0.74	0.54
MVEG cycle			
(road, hot engine)			
Without catalyst	9.8	1.3	2.7
With catalyst	1.0	0.09	0.54
INRETS cycle			
(road, hot engine)			
Without catalyst	19.6	2.5	2.3
With catalyst	0.90	0.09	0.44

Source: Delsey (2002).

Note: Measurements were made by INRETS (France) in 1995 on vehicles from the existing fleet with an average mileage between 20 000 and 60 000 km. Vehicles with catalytic converters were 1993 and 1994 models. Vehicles without catalytic converters were 1991 and 1992 models.

Diesel engines

For diesel-engined passenger cars, the main challenges today with regard to air pollution are reductions of NO_x and PM. Under current standards, light-duty vehicle manufacturers have managed to meet the US, European and Japanese emission limits for diesel vehicles through the application of exhaust gas recirculation, increased diesel pump and injector refinement, high pressure and common rail technology. It is anticipated that tighter standards for particle emissions will require the use of particle filters or similar after-treatment technology. Although CO and VOC emissions from diesel engines are naturally rather low, the tightening European legislation led to the widespread use of oxidation catalysts on diesels in the late 1990s.

Evolution of fuels

Fuel standards have been adopted to optimise the functioning of vehicle emission control systems. These standards have embodied three principal elements:

- Controls on the composition of petrol and diesel fuel to achieve the best possible combustion and ensure the widespread availability of fuel having the same composition (*e.g.* across the countries of Western Europe).
- Development of lead-free petrol to prevent damage to catalytic converters and to reduce lead exposure in the population (because lead is a poison).
- Drastic reduction of the sulphur content in fuels to improve the efficiency and durability of emission control systems.

Lead-free (unleaded) petrol was introduced in the 1970s in the United States and at the beginning of the 1980s in Japan, Sweden and Switzerland. In Europe, lead-free petrol appeared in 1985. Because of the time needed to renew the fleet with new vehicles equipped with engines adapted to lead-free fuels, it was not until 2001 that the overall European fleet could be considered as “lead free”. Currently, and depending on the country, only 2-5% of the vehicle fleet in Europe still uses leaded petrol, with most OECD countries and many non-OECD countries no longer producing any leaded petrol.

The reduction of sulphur content in fuels is a more recent development. In the EU, for example, the sulphur content in diesel was more than 1000 parts per million (ppm) during the 1980s, and since the mid-1990s the standards have steadily reduced the sulphur limit to 500 ppm, and now 350 ppm. By the end of the decade, maximum sulphur levels in diesel (and in some cases petrol as well) in Europe, the United States, Japan, Australia and a number of other countries will be set at around just 10-15 ppm.

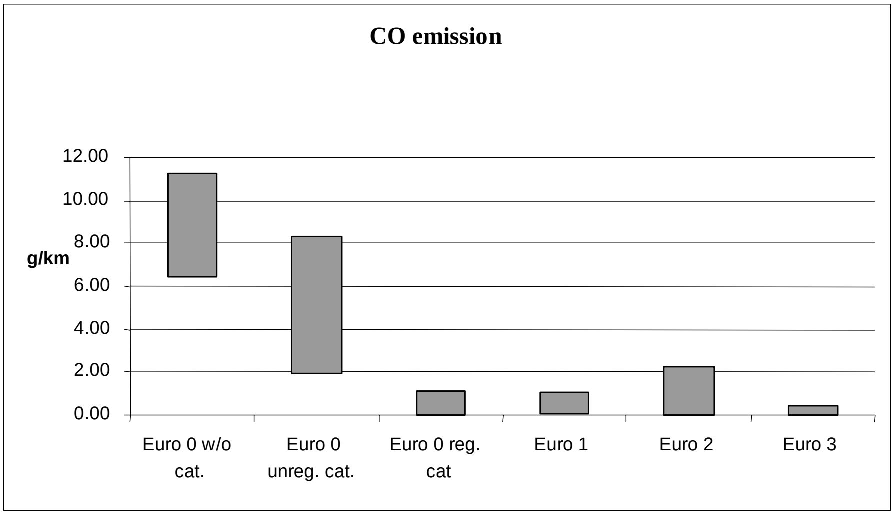
Impacts of standards on emissions per vehicle

Real-world emissions

Studies of emissions per vehicle from in-service vehicles in a range of countries have demonstrated that the introduction of tighter emissions standards for new vehicles has led to real improvements in the on-road emissions performance of their light-duty vehicle fleets. This has occurred despite the limitations of the official test cycles in representing real-world driving patterns.

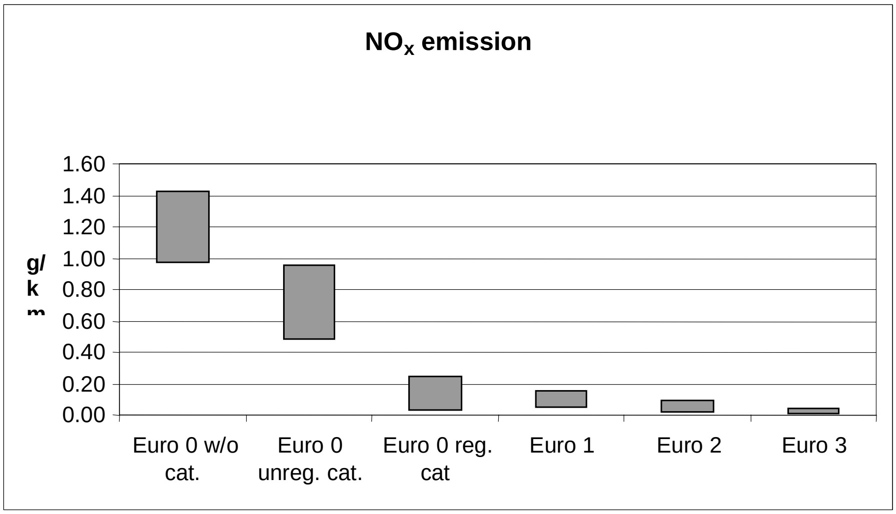
For example, in the case of the Netherlands' In-Use Compliance (IUC) Programme - a monitoring programme which tests representative samples of vehicles taken from the in-service fleet - the benefits that the standards have delivered in the "real world" are shown in Figures 2.4, 2.5, 2.6 and 2.7. The height of the bars indicates the spread of the emissions measured. The reduction in pollutant emissions from 1985 ("Euro 0") to 2000 (Euro 3) is impressive for the three pollutants (CO, NOx and PM).

Figure 2.4. CO emission reduction of passenger cars in real use (petrol)



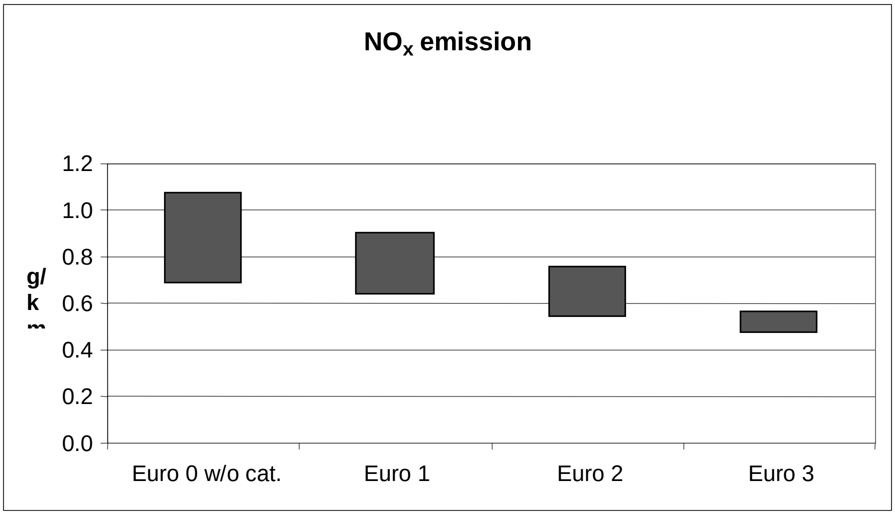
Source: Netherlands In-Use Compliance (IUC) Programme.

Figure 2.5. NO_x Emission reduction of passenger cars in real use (petrol)



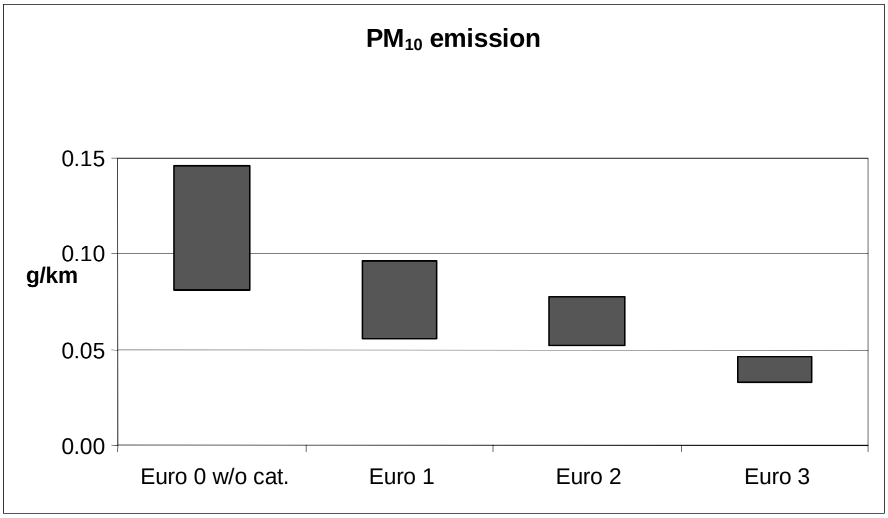
Source: Netherlands In-Use Compliance (IUC) Programme.

Figure 2.6. NO_x Emission reduction of passenger cars in real use (diesel)



Source: Netherlands In-Use Compliance (IUC) Programme.

Figure 2.7. PM_{10} Emission reduction of passenger cars in real use (diesel)



Source: Netherlands In-Use Compliance (IUC) Programme.

On all the regulated pollutant emissions, the figures clearly show that emissions from petrol vehicles have dropped dramatically since the introduction of standards requiring the use of three-way catalysts. In petrol vehicles utilising advanced emission-control technologies, the emissions are now so low they are very hard to measure using existing emissions analysers.

For diesel passenger cars, the reduction of NO_x and PM shows a significant, but more gradual decrease over the technology classes. This has left room for further improvements in the coming years, which will be achieved in Europe, for instance, with the introduction of Euro 4 standards in 2005.

After the planned introduction of the new standards (in Europe, the United States, Japan and other countries), all new conventional petrol and diesel vehicles that meet these tighter standards will be very low emitters of air pollutants (and therefore "near clean" in terms of local pollutants). However, in many countries, the standards for diesel vehicles still allow them to emit significantly higher emissions than equivalent petrol vehicles.

Test cycles and "real-world" driving

While the emission standards have clearly delivered improved emissions performance from in-service vehicles, it must be realised that the standard test cycle used to demonstrate compliance with the standards is not necessarily representative of driving behaviour in the "real world". This is evident from a comparison of speed and time relationships under the standard European emissions test cycle (Eurotest) and a more realistic "real world" cycle, as set out in Figure 2.8. The real-world cycle is much more dynamic, reflecting the more rapid acceleration and deceleration patterns experienced in on-road conditions. This more dynamic driving in real-world conditions leads to higher emission levels compared to those under the standard emissions test cycle (see Figures 2.9 and 2.10). Compared to the emissions test procedure, real-world driving is generally much more demanding on a car (and its fuel and emissions control system), especially with more aggressive driving styles.

The difference between the results on the Eurotest and real-world driving may also relate to the impact of the emissions tests on vehicle design decisions. Vehicles are often designed and engines calibrated to ensure the vehicles meet the emission limits on the standard test cycle, with its overall lower loads on the engine, leaving scope to calibrate the engine for optimal driveability at higher speeds and engine loads (*i.e.* primarily targeting performance rather than addressing emissions).

Figure 2.8. Standard cycle (Eurotest) vs. operational cycle

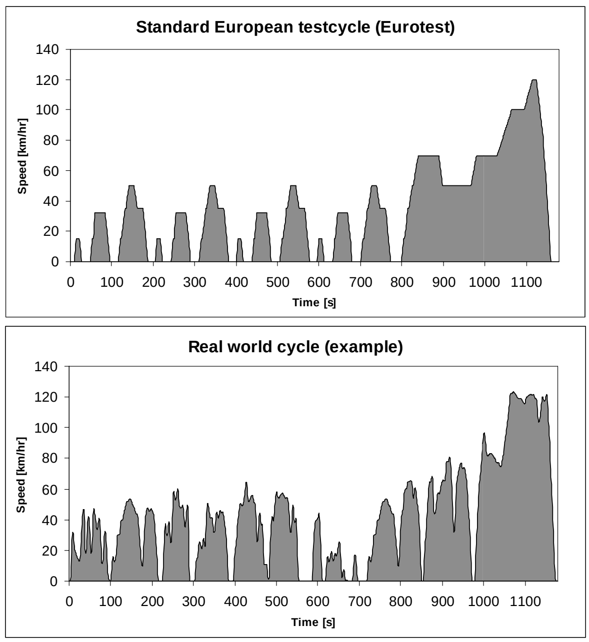
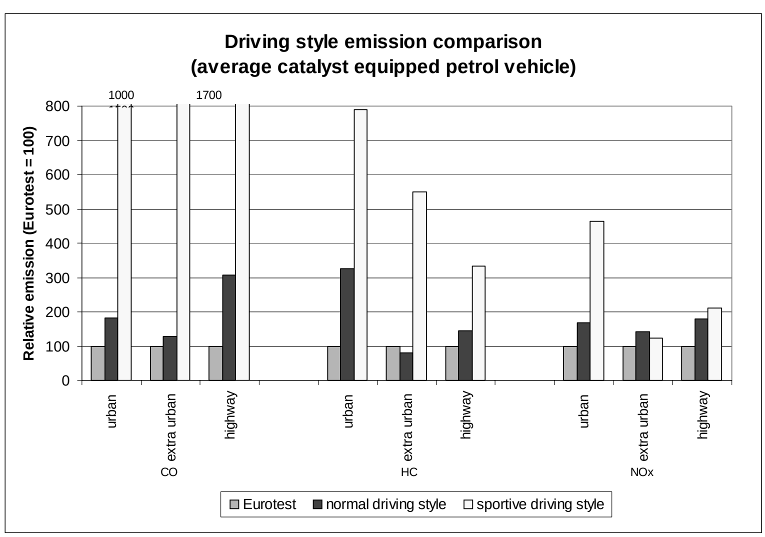
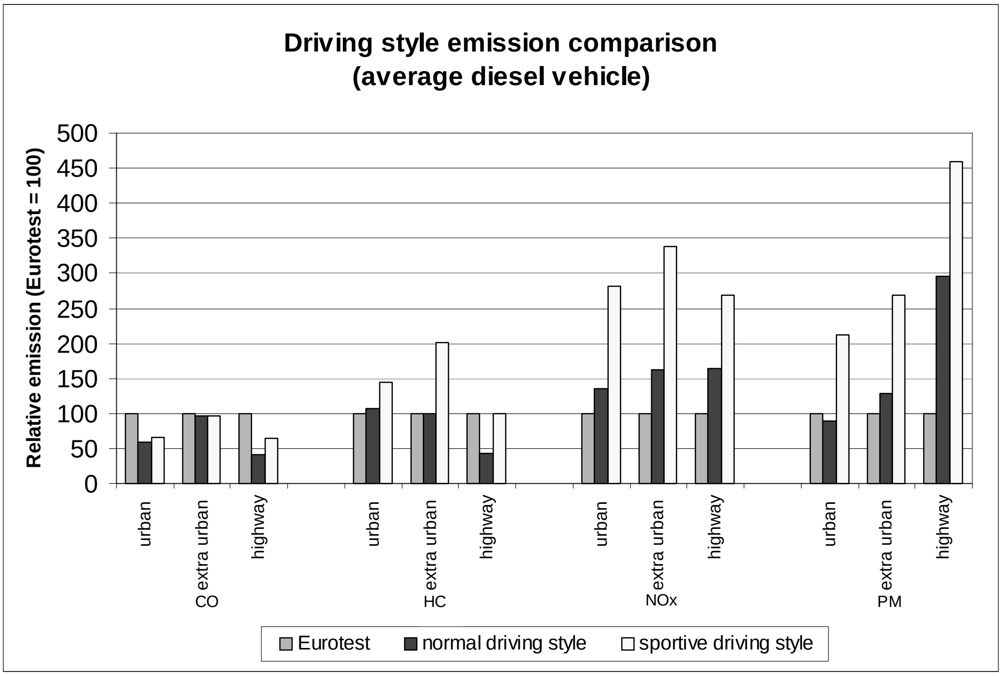


Figure 2.9. Driving style emission comparison (average catalyst-equipped petrol vehicle)



Source: Gense (2000).

Figure 2.10. Driving style emission comparison



Impact of standards on vehicle fleet emissions

In countries with advanced vehicle emission standards, these standards have made a significant contribution to improvements in air quality. Importantly, the improved technologies and fuels required to meet the standards are delivering air quality improvements, despite growth in vehicle-kilometres travelled and shortcomings in the standard test cycles. The charts and tables below illustrate these improvements in a number of countries where advanced vehicle emission standards have been in place for many years.

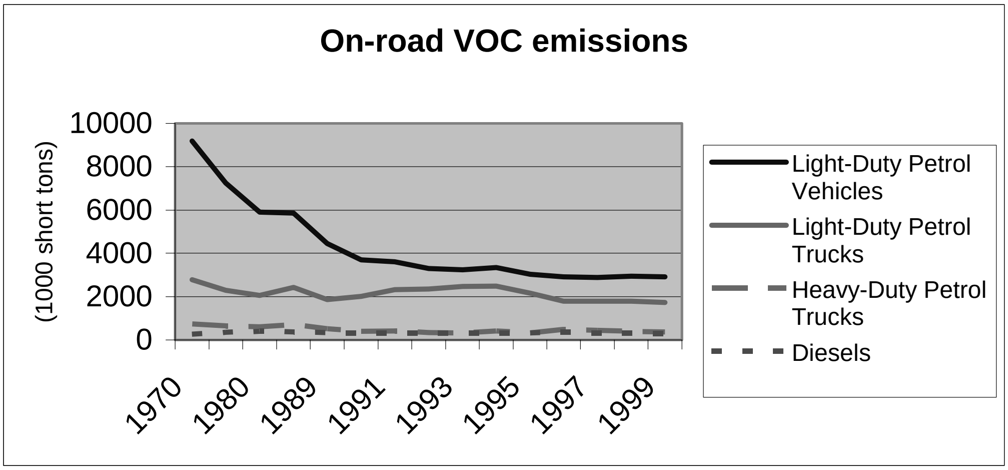
In the United States, 30-year trends illustrate that the total emissions of major vehicle pollutants (with the exception of NO_x from trucks) have declined, even through there has been a 150% increase in overall vehicle distance travelled by the fleet. Figure 2.11 shows the trend of the VOC emissions during the years 1970-1999.

In Switzerland, all pollutant emissions have decreased dramatically over the past 20 years (see Table 2.2).

Similar outcomes have been obtained in many other countries, including the Netherlands, France, Sweden, the United Kingdom, Australia and Japan. In most OECD countries, fleet emissions of NOx, CO and HC were at their highest levels in the early 1990s. Since then, they have dropped significantly (by 20-50%), despite a continuous increase in vehicle kilometres travelled (+25% between 1990 and 2000).

In Central and Eastern Europe, the decrease in the pollutants emitted was delayed by the later application of stringent standards. In Poland, for instance, the maximum levels of total emissions per year occurred in 1996 for CO, VOC and NO_x, in 1997 for PM_{10} and in 1998 for SO_2. Now, emissions of all the pollutants are declining.

Figure 2.11. Trends in emissions of volatile organic compounds emissions in the United States (1970-1999)



Source: US EPA (1999).

Table 2.2. Emission reduction obtained in Switzerland in 2000

Pollutant	Emission levels in 2000	
	Reduction since 1980	Reduction since 1990
CO	80%	50%
HC	70%	60%
NO_x	50%	50%
Particles	50%	40%
Lead	99%	99%
SO_2	75%	45%

Evolution of conventional technologies: outlook for 2010-2020

Petrol internal combustion engines

Recent analyses show that the most important contributions to the current exhaust emissions of light duty petrol vehicles (*e.g.* Euro 3 or equivalent) can be attributed to the following sources: cold start, air-to-fuel ratio (lambda) excursions, effect of ambient temperatures, off-cycle operation and warm conversion of the catalyst. For each of these causes, reductions can be achieved using current technology.

If engine efficiencies can be further optimised to deal with these sources of emissions, a reduction of the real-world emissions per vehicle of 85% to 90% for CO, VOC and NO_x could be achieved.

Diesel internal combustion engines

The exhaust emissions of modern diesel passenger cars (*e.g.* Euro 3, without de-NO_x catalysts and particulate filters) can be attributed principally to the following sources: cold start, effect of ambient temperatures, off-cycle operation and warm emissions.

Because of the desire to reduce fuel consumption, manufacturers have largely adopted direct injection technology for the latest diesel engine vehicles. While improving fuel economy, this switch can have negative consequences on other emissions, especially NO_x and PM. To comply with the emissions limits under current European emission legislation, most diesel engines are already equipped with oxidation catalysts (to reduce VOC and PM emissions) and exhaust gas recirculation (to reduce NO_x emissions). More recently, further emission reductions have been achieved by optimising the shape of the combustion chambers, increased injection pressures, flexible injection timing and rate shaping.

Manufacturers will have to adopt other measures to meet future emission legislation. Optimised oxidation catalyst reactivity and cooled and electronically controlled exhaust gas recirculation is unlikely to be sufficient. In order to lower diesel emissions – especially NO_x and PM emissions – to the level of petrol cars, technology such as de-NO_x systems and particulate filters, which have already shown their efficiency, are expected to be widely adopted. With advanced exhaust after-treatment and incremental improvements to the engine, the future CO, VOC and NO_x emissions of vehicles with diesel engines could be reduced by about 75% compared to Euro 3.

Regarding particulate emission from diesel engines, new particulate filters or traps now make it possible to drastically reduce the level of emissions across the spectrum of particulate matter. Tests conducted on vehicles equipped with filter technology have demonstrated their high levels of performance and effectiveness even after more than 100 000 km driven (see case studies in Annex C). Widespread use of particulate filter technology on diesel vehicles, which has already been successfully introduced in Europe where more than 500 000 new vehicles are equipped with such filters produced by European manufacturers, is an effective means of reducing emissions of particulates, provided that suitable quality low-sulphur diesel fuel is widely available.

Future output of regulated road transport pollutant emissions

New vehicles

As a result of mandatory standards, the emission of traditional pollutants is largely under control, at least for new petrol cars. The reductions in per-vehicle emissions of local pollutants that are being achieved will be sufficient to ensure that, as new vehicles meeting the standards replace older vehicles, total levels of pollutants will continue to fall. In most countries, this will occur despite the expected increases in levels of car ownership and in the overall distance travelled.

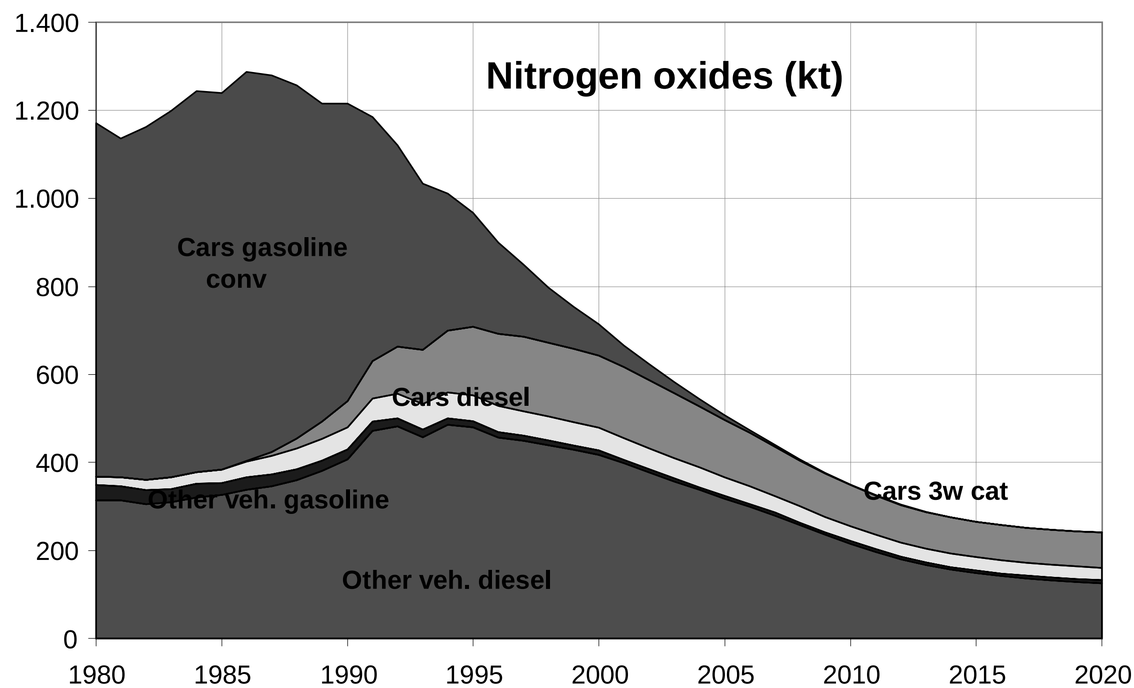
The considerable reductions that have been achieved in pollutant emissions and the projections for the years 2010 and 2020 years are illustrated in Table 2.3 and Figure 2.12:

- For France, the change in total emissions between 1990 and 1998 and the projections for the years 2010 and 2020 are set out in Table 2.3. Especially interesting is that the maximum outputs of regulated pollutants in France were generally observed in the mid-1990s or before.
- In Germany, improvements in vehicle standards are predicted to lead to significant reductions in emissions from road vehicles over the 2000-2020 period. The expected decrease of NO_x emissions is illustrated in Figure 2.12. In the short term, emissions from petrol cars will decrease rapidly, followed in the medium term by diesel cars.

Table 2.3. France: Comparative emissions, trends from 1990 to 1998 and projections for 2010 and 2020

Pollutant	Maximum observed (year)	Change 1998/1990 (%)	Change 1998/max (%)	Projection 2010	Projection 2020
SO_2	154 kt (1993)	-66%	-69%	5 kt	5 kt
NO_x	1,058 kt (1992)	-23%	-24%	369 kt	356 kt
CO	8,900 kt (1976)	-43%	-57%	1,042 kt	873 kt
VOC	1,287 kt (1981)	-37%	-41%	188 kt	164 kt
PM	71 kt (1995)	+ 15%	-10%	24 kt	16 kt

Figure 2.12. Trends and projections in NO_x emissions from road vehicles in Germany (1980-2020)



Source: German Federal Environmental Agency.

Existing vehicles

For the next 15-20 years, from the viewpoint of pollutant emissions, the presence of “old” technology vehicles in the fleet will continue to be the major problem, as they emit very high levels of pollutants by comparison with the new technology vehicles that will replace them. In the Netherlands, for instance, it is estimated that 99% of traditional pollutants emitted by the current fleet come from older vehicles not fitted with catalysts (“Euro 0”). Their high contribution also reflects that the emissions of local pollutants from cars in use deteriorate with time and mileage. This places a heavy burden on the authorities to check the emissions of vehicles in use on a regular basis.

Conclusion

The adoption of advanced emission regulations in OECD countries has contributed to a substantial reduction in total emissions for all local pollutants from motor vehicles and it is expected that this decrease will continue. In many countries, the maximum outputs of all regulated emissions were observed some years ago – generally in the early to mid-1990s. It is expected that the total emissions from passenger vehicles in 2020 will have dropped to a stable, low level. This is not only because new cars have minimal emissions and are therefore very clean in terms of local pollutants, but also because older cars without catalytic converters, which have much higher rates of air pollutant emissions, will have largely disappeared from vehicle fleets.

There is still capacity to improve the emissions performance of light-duty diesel vehicles to match that of petrol vehicles in respect of NO_x and particulate matter. A number of current vehicles with the latest technology are now equipped with advanced after-treatment systems (de-NO_x and filter traps) which have proven their efficiency in reducing both NO_x and particulate matters and their ability to reach low emissions levels similar to petrol vehicles.

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Chapter 3

GREENHOUSE GAS EMISSIONS

Abstract. This chapter describes the relationship between energy consumption and greenhouse gas emissions and the trends in fuel consumption and carbon dioxide emissions of individual vehicles. It reviews the legislative and non-legislative approaches being taken to reduce fuel consumption and limit CO_2 emissions and analyses the potential of traditional and new technologies to counter the expected increase in CO_2 emissions from road transport.

Introduction

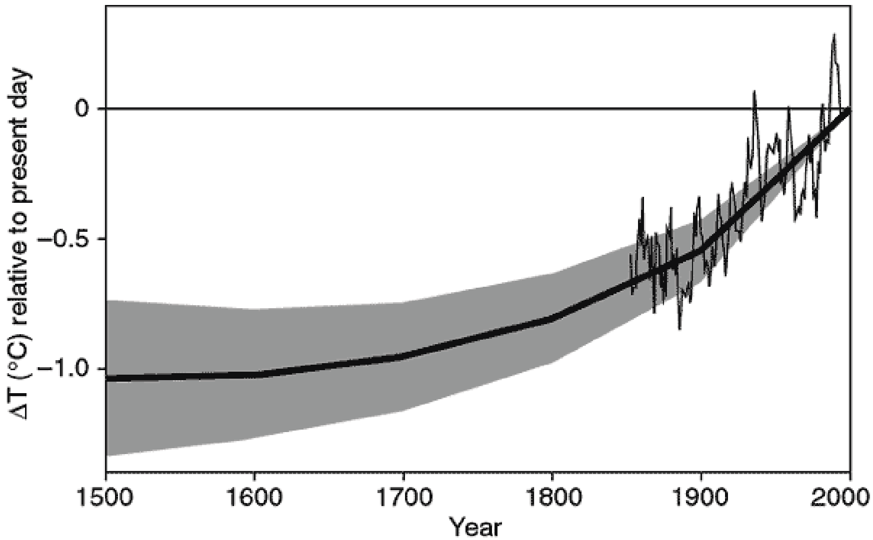
Oil reserves and the greenhouse gas effect

There are two principal reasons for examining the fuel consumption of motor vehicles: the first is the need for conservation of non-renewable fuels, and the second is the greenhouse gas effect. CO_2, which is one of the main greenhouse gases, is an inevitable product of a fossil fuel combustion process. The CO_2 emissions from a motor vehicle powered by petroleum-based fuels are directly related to its fuel consumption. Therefore, a reduction of CO_2 emissions from motor vehicles – using conventional or alternative fossil fuels – can only be achieved by a reduction in their fuel consumption.

Information on world fuel reserves can be found in publications of the International Energy Agency (IEA, 2001). In its *World Energy Outlook 2002*, in the context of projections to the year 2030, the IEA has concluded that the world's energy resources are adequate to meet the projected growth in energy demand. The IEA also concluded that oil resources are ample, but more reserves will need to be identified in order to meet rising oil demand to 2030 (IEA, 2002b).

In relation to greenhouse gases (GHGs) and global warming, the Intergovernmental Panel on Climate Change has published a number of reports on this matter (IPCC, 2001). Figure 3.1 shows the reconstructed global ground temperature estimate from borehole data over the past five centuries, relative to the present day. Shaded areas represent ± two standard errors about the mean history. Superimposed is a smoothed (five-year running average) chart of the global surface air temperature instrumental record since 1860.

Figure 3.1. Reconstructed global ground temperature over the past five centuries



Source: IPCC (2001).

United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) is an international convention that addresses issues related to the emission of greenhouse gases (GHGs). The ultimate objective of the UNFCCC is to stabilise GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The UNFCCC was adopted in May 1992, and as of December 2002 had been ratified by 186 parties. Nine conferences of the parties have been held, the most recent of which took place in Milan (Italy), in December 2003.

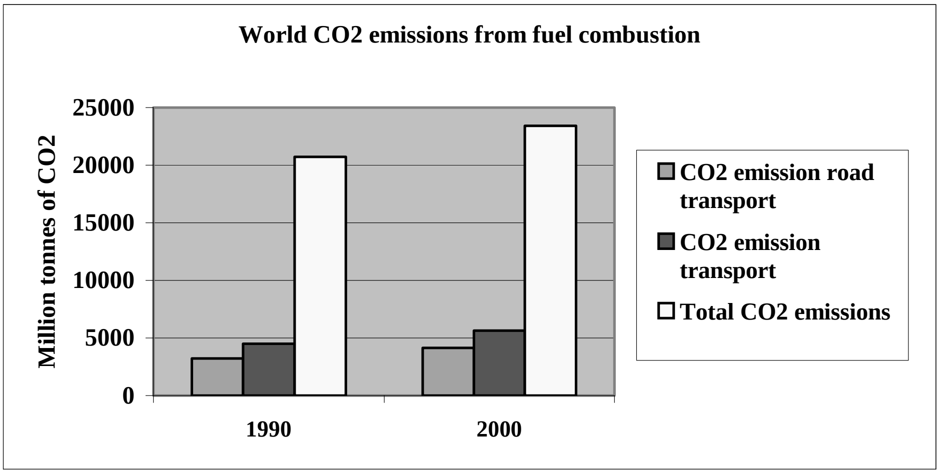
The Third Conference of the Parties held in Kyoto in December 1997 adopted the Kyoto Protocol (see below). Countries wishing to implement the Kyoto Protocol can choose to ratify it, but several countries have raised concerns with aspects of the Protocol. Issues are still being discussed, particularly with regard to a framework for meeting such goals as GHG emissions reductions by developing nations and designing and facilitating "clean development mechanisms". The countries that have ratified the UNFCCC are responsible for:

- Developing national inventories of emissions of all GHGs.
- Formulating, implementing, publishing and updating national programmes containing measures to mitigate climate change.
- Promoting and co-operating in the development, application and diffusion of technologies, practices and processes that control, reduce, or prevent anthropogenic emissions of GHGs in all relevant sectors.

CO_2 emissions

The worldwide emissions of CO_2 from fossil fuel combustion are given in Figure 3.2 (IEA, 2002a). 96% of transportation depends on petroleum-based fuels. The proportion of world CO_2 emissions emitted by transport increased from 19.3% in 1971 to 24% in 2000 and is still growing. In 2000, road transport was responsible for 18% of total CO_2 emissions worldwide and for 23% in OECD countries. Globally, the use of the different alternative fuels – such as LPG, CNG or biofuels – in the transport sector is not significant.

Figure 3.2. World CO_2 emissions



Source: IEA (2002a).

Analysis of the energy consumption of a vehicle

The breakdown of the energy consumption of a traditional mid-size family car (early 1990s) powered by a petrol engine is given as an example in Table 3.1.

Drivetrain

Engines convert the chemical energy content of a fuel into mechanical energy. This mechanical energy is used to overcome the inertia and air and rolling resistance of the vehicle and to generate electric energy to operate electric components such as lighting. However, not all of the energy is used for propulsion and auxiliary components. The greatest part of the energy content is consumed during the chemical or thermodynamic processes and to overcome friction. As is clear from Table 3.1, most of the original energy content of the fuel is transformed into heat.

Table 3.1. Energy breakdown of a traditional standard mid-size family car

Type of road		Urban	Highway
Energy content of fuel	**Energy consumption**	**100%**	**100%**
Drivetrain losses	Thermodynamic losses	60	60
	Engine losses	12	3
	Transmission losses	4	5
	Total	**76%**	**68%**
Used for components	Auxiliaries	2	1
	Accessories	1	1
	Air conditioning (when in use)	10	10
	Total	**13%**	**12%**
Used for propulsion	Air resistance	2	11
	Roll resistance	4	7
	Kinetic losses/braking - no inclination	5	2
	Total	**11%**	**20%**

Weight, drag and rolling resistance

When a vehicle is moving, several resisting forces must be overcome. Resisting forces that arise from the interaction between the vehicle, the air and the road are:

- Aerodynamic drag, which depends on the shape of the vehicle and the frontal area and is proportional to the square of the speed.
- Rolling resistance, which depends on the tyres, tyre pressure and on the quality of road and is proportional to the weight of the vehicle.
- Resisting forces related to the weight of the vehicle:
  - Inertia during acceleration, which depends on the weight of the vehicle, but also on all the rotating pieces (wheels, components of the engine and of the gearbox).
  - Gravity along a slope.

These forces are a function of the use of the vehicle and can vary considerably. At high speed, the aerodynamic resistance is preponderant (more than 75% of the total), while in urban use the inertia resistance is more than 95% of the total. As well, the absolute values of the forces differ significantly from model to model. An indication of the power required to overcome the above forces is provided in Table 3.2 for a conventional passenger car (Delsey, 1997). The table refers to a passenger car of 1 100 kg with a frontal area of 1.75m^2 and an air resistance coefficient of 0.45. The figures indicate that for urban use the weight of the vehicle is a very important determinant of the power requirements (and the fuel consumption) for passenger cars. This is also the case for delivery vans and buses.

Table 3.2. Power (kW) required to overcome various forms of resistance to forward movement of the vehicle

Use of the vehicle	Rolling	Aerodynamic	Inertia	Gravity	Total
Urban 20 km/h (mean speed)	0.7 (4.2%)	0.09 (0.5%)	15.9 (95.2%)	0	16.7
60 km/h constant horizontal	2.5 (51%)	2.4 (49%)	0	0	4.9
140 km/h constant horizontal	9.4 (24%)	30.1 (76%)	0	0	39.5
80 km/h constant slope 5%	3.7 (17.4%)	5.6 (26.3%)	0	12.0 (56.3%)	21.3

Source: Delsey (1997).

Even at constant speed, the power required to move a vehicle is dependent on the vehicle's weight and aerodynamic drag, as shown in Table 3.3. The parameters refer to two passenger-cars: Model A is a small European vehicle and Model B is a largish medium-size European vehicle.

Table 3.3. Required power at constant speeds for two models

Vehicle model characteristics

Parameters	Frontal area A (m^2)	Drag coefficient C_D	$A.C_D$	Mass (kg)
Model A	1.73	0.32	0.554	640
Model B	2.04	0.33	0.673	1 290

Power required

Constant speed	120 km/h	140 km/h	160 km/h	180 km/h
Model A	17 kW	26 kW	38 kW	53 kW
Model B	24 kW	36 kW	52 kW	72 kW

This comparison illustrates the significant increase in power needed to move a larger, heavier vehicle at the same speeds as a smaller, lighter vehicle. It also shows that the power needs of the two vehicle models are significantly different. The aerodynamic drag of the two vehicles is nearly equal, but the frontal area makes the difference in the power required to propel the vehicles at the same speed. On new passenger cars all around the world the frontal area of vehicles is increasing. So even with large improvements in the efficiency of engines, the potential gain in fuel consumption is being partly dissipated in practice.

Driving style

One of the important factors influencing motor vehicle fuel consumption is the driving style of the driver. The impact of different driving styles is demonstrated in Table 3.4 (Gense, 2000). The reference style against which other styles were compared was a "defensive driving style". In the comparison, two styles targeting fuel economy were used, the first a very slow acceleration "egg style" together with the newest Dutch version of the Swiss “ECO-DRIVE”, called “new style driving”. This “new style” combines defensive driving with a special way of accelerating and shifting gears. The environmental opposite of these styles is represented by an aggressive driving style, involving the use of high engine revolutions and power. This aggressive style involves 80% more driving dynamics (acceleration) and 20% more average engine revolutions.

Comparative results showed that the aggressive style driving increases CO_2 emissions by 30%. The new style driving was able to save 5% of fuel compared to the already environmentally friendly defensive style. (Some programmes promoting a smoother driving style claim reductions of 10-15% in fuel consumption in practice). Research has shown that drivers can further influence the fuel consumption of their vehicles by regularly checking their tyre pressure; fuel consumption can be reduced by at least 1% when adequate tyre pressure is maintained.

Table 3.4. Effect of driving style on fuel consumption and emissions
Reference for comparison: “defensive driving” style

Driving style	“Aggressive” (% change)	“New style” (% change)	“Egg” (% change)
Average speed	+3	+2	-10
Driving dynamics	+80	-8	-15
Average engine revs	+20	-7	+1
Fuel consumption	+34	-5	<1
CO_2	+30	-6	+1
CO	+750	+78	+4
HC	+280	+31	+22
NO_x	+91	+7	-18
Particles	+69	-32	-25

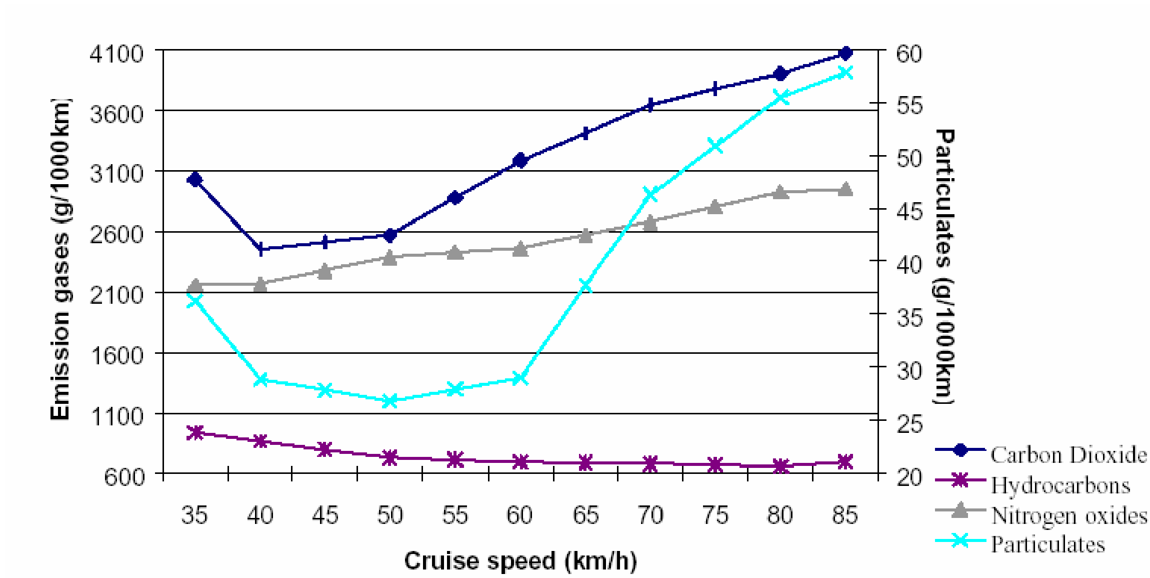
Source: Gense (2000).

Impact of traffic conditions on fuel consumption and emissions

Fuel consumption, CO_2 and other pollutant emissions are significantly affected by traffic conditions (see Figure 3.3). Traffic congestion and the stop-start driving characteristics of larger cities result in substantially higher levels of fuel consumption and emissions per vehicle-kilometre travelled (typically three times as high when average vehicle speeds are around 10-15 km per hour). Fuel consumption and CO_2 emissions are typically minimised in traffic travelling at constant speeds of around 40-50 km per hour. As Figure 3.4 also shows, emissions of particulates are minimised on a per vehicle-kilometre basis at vehicle cruising speeds between 40 and 60 km per hour.

These results suggest that some gains in fuel consumption and CO_2 emissions on a per-vehicle-kilometre basis can be achieved by management of traffic flows and measures that aim to reduce the stop-start driving associated with high levels of congestion.

Figure 3.3. Air pollutant emissions as a function of travel speed



Source: Ward *et al.* (1998).

Evolution of the fuel consumption of individual vehicles

Petrol engines

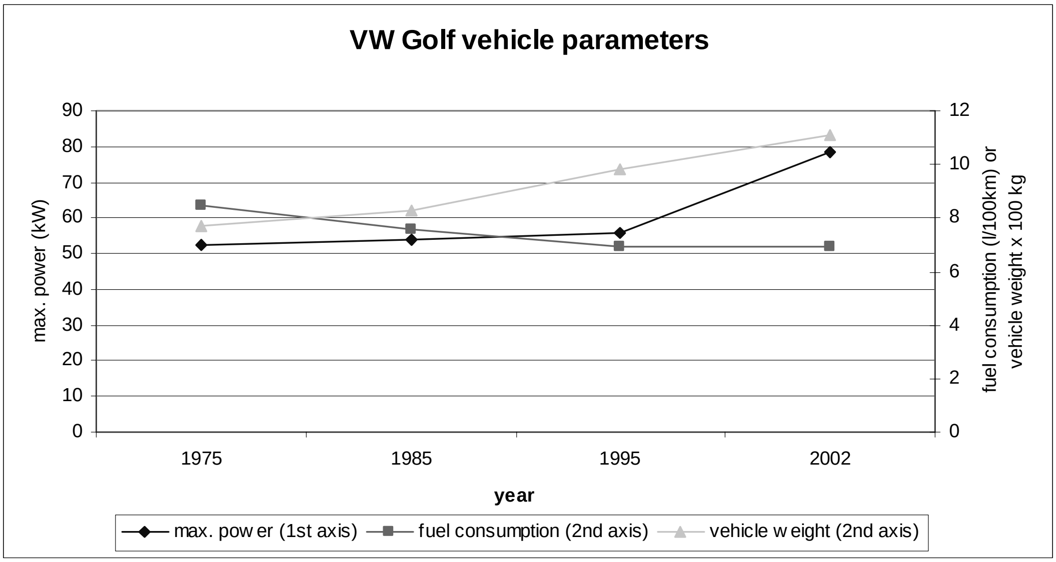
Over the last 20 years, most of the measures which have improved the energy efficiency of motor vehicles were the result of improvements in the basic engine design; examples include the use of low friction materials, optimised geometry of the combustion chamber and intake and outlet ports. For petrol cars, the switch from carburettors to electronically controlled fuel injection allowed a much greater refinement in mixture control. The large-scale introduction of multi-valve technology also contributed to significant improvements in basic engine efficiency. However, the introduction of catalytic converters increased fuel consumption slightly.

As indicated above, improvements in engine efficiency have contributed to reductions in the fuel consumption of individual vehicles. For instance, the fuel consumption of the 2002 VW Golf is 20% better than its early 1975 predecessor (see Figure 3.4). Note that this decrease in fuel consumption has been obtained despite increased power and 50% more weight.

Diesel engines

There have been further improvements in light-duty diesel vehicles, which already have a fuel economy and CO_2 emissions advantage over petrol equivalents. These improvements have been achieved through the widespread adoption over the last decade of direct injection technology, which was previously only available on heavy-duty applications. The latest trend in diesel technology is the introduction of electronically controlled injection systems, such as common rail and unit injectors, that allow flexible injection timing and rate shaping and also enable much higher pressures.

Figure 3.4. Vehicle weight versus fuel consumption, VW Golf



Influence of vehicle weight

Figures 3.5 and 3.6 illustrate the reduction that has been achieved in CO_2 emissions from passenger cars on various test cycles, together with their increase in weight. The following charts are derived from the Netherlands' "In-Use Compliance (IUC) Programme", which has been operational since the 1980s.

It can be clearly seen that prior to the introduction of catalytic converters and during their initial introduction there was a strong relationship between vehicle mass and CO_2 emissions. The development and better integration of catalysts into engine management systems in Euro 1, combined with improved engine efficiency, has led to a "decoupling" of mass and CO_2 emissions. For diesel cars, the weight increase over the years is also visible, but due to better engine design and optimisation, CO_2 emissions have fallen overall.

Figure 3.5. The relation between CO_2 emission and vehicle mass (petrol)

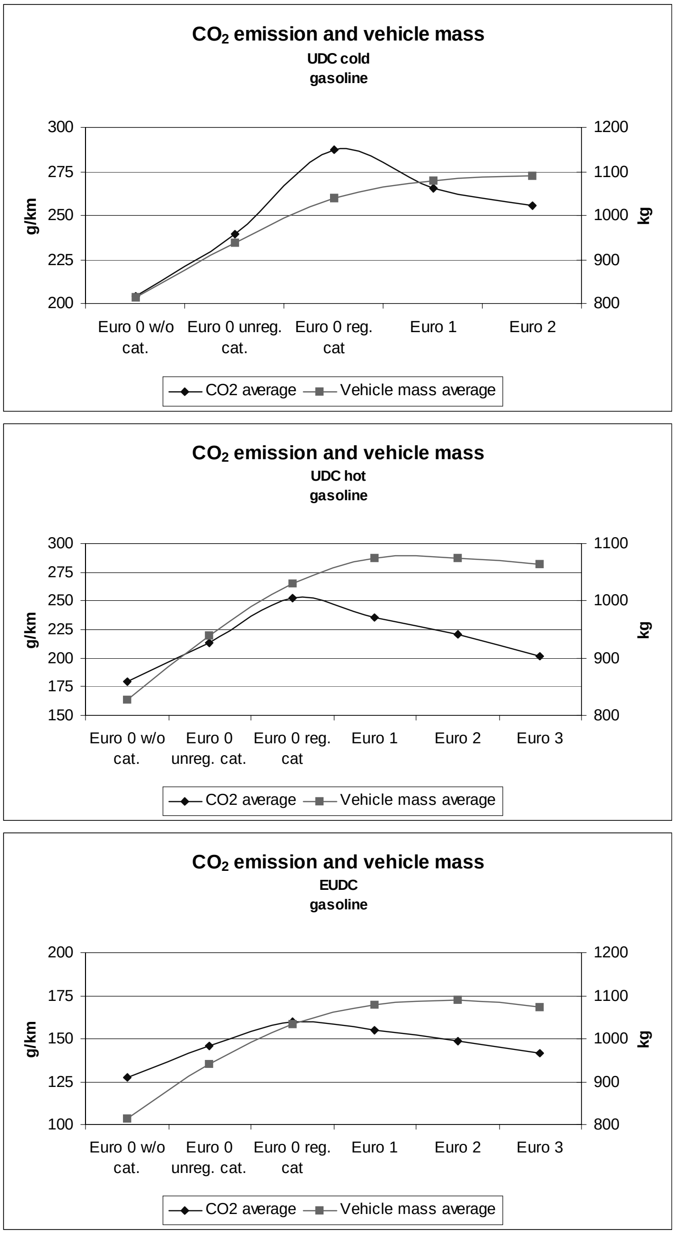
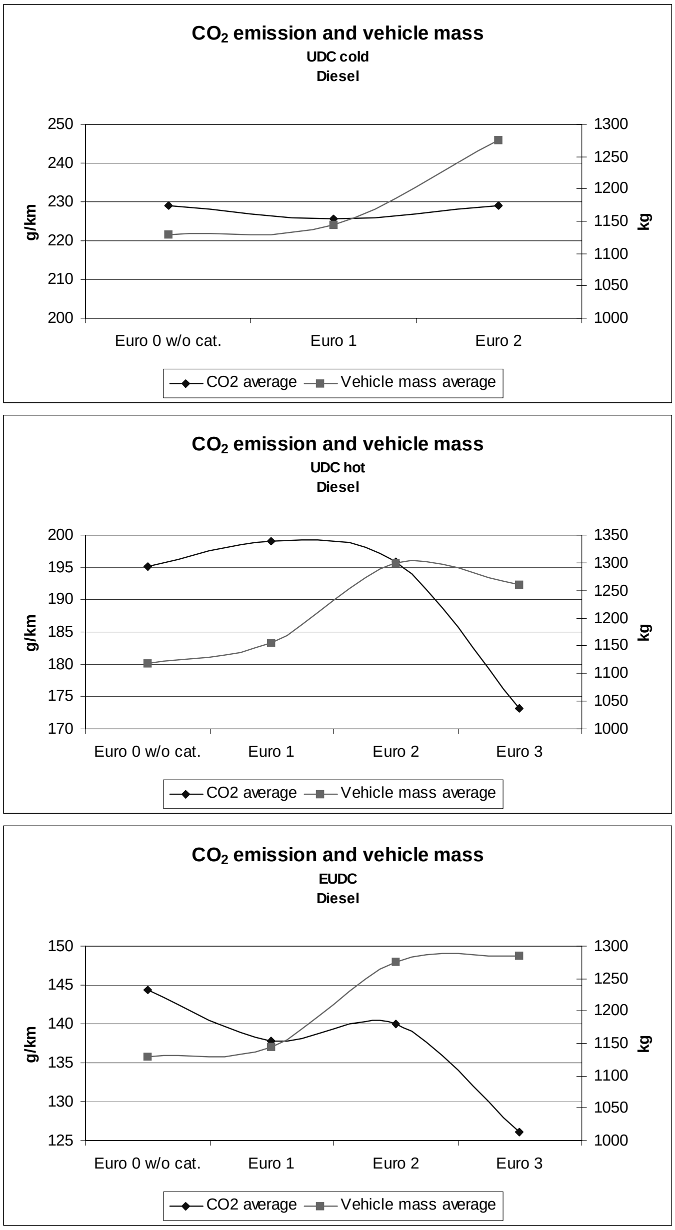


Figure 3.6. The relation between CO_2 emission and vehicle mass (diesel)



Trends in vehicle weight

Since the early 1980s, the weight of passenger cars has tended to increase. This trend has been observed in many OECD countries and has been more evident since the beginning of the 1990s.

For example, the weight of the popular Volkswagen Golf increased from 800 kg when it first appeared in the 1970s (Golf I model) to more than 1 100 kg in 2000 (Golf IV model). Similarly, the Renault 21 was replaced in the mid-1990s by the Renault Laguna I which weighed 260 kg more, and more recently by the Laguna II, which weighs an additional 60 kg. The same trend has been observed in Japan. In the United States, with the rapid development of the SUV market, around 50% of the new cars sold now weigh around 2 000 kg.

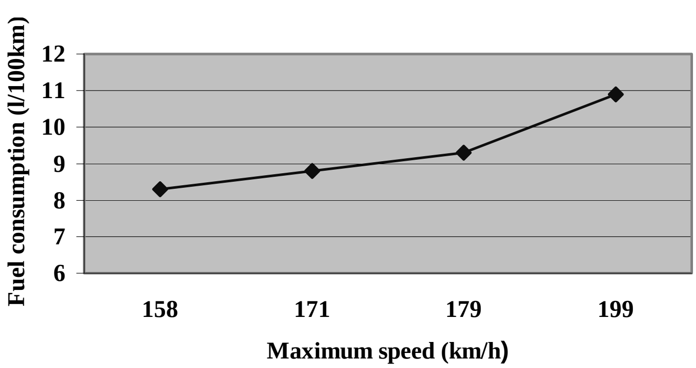
A number of factors have contributed to this trend in increasing vehicle weight and power, including:

- Improvement of the passive safety of the newer model vehicles, which increases weight.
- Improvement in the level of comfort, including increasingly widespread use of air conditioning systems (especially in Europe and Japan) and the reduction of inside noise levels (this is done principally by adding extra sound-deadening material, particularly to reduce noise at low frequencies).
- Use of more powerful engines.
- Continuing improvement in the general standard of living which allows consumers to be able to buy and operate more powerful vehicles despite their higher operating costs.

Influence of engine power on fuel consumption

Car manufacturers frequently offer a range of engines, with varying power, acceleration and top speed characteristics for the same model. Increases in engine power usually lead to increased fuel consumption. The relationship between maximum power and speed of the vehicle and its fuel consumption is demonstrated in Figure 3.7 for the Peugeot 206.

Figure 3.7. Urban fuel consumption of the same model (Peugeot 206) as a function of the vehicle's maximum speed (models with 60, 75, 88 and 135 horsepower)



History of standards[1]

Mandatory standards

The only mandatory standards for fuel consumption in the world are the US CAFE (Corporate Average Fuel Economy) Standard, the California GHG legislation and the Japanese Top Runner Programme.

United States

In the United States, the Energy Policy and Conservation Act, passed in December 1975 and amended by the Motor Vehicle Information and Cost Saving Act, requires each vehicle manufacturer to determine sales-weighted average fuel consumption figures for all passenger cars and light-duty trucks they produce. Electric cars or hybrid vehicles may be included in the average fleet calculations and a credit is given for flexible fuelled vehicles.

The standards are based on the combined city/highway fuel figures and are known as CAFE standards. For the 2003 model year, the limits were 27.5 miles per US gallon (8.6 litres per 100 km) for passenger cars (unchanged since 1990) and 20.7 miles per US gallon (11.4 litres per 100 km) for light-duty trucks. The penalty for non-compliance has been raised from USD 5.00 to USD 5.50 per mile per US gallon for each vehicle exceeding the above limits.

In April 2003, the US Department of Transportation finalised regulation to increase the fuel economy of light-duty trucks by 1.5 mpg over three years (2005: 21.0 mpg, 2006: 21.6 mpg, 2007: 22.2 mpg)[2]. Fuel economy for passenger cars, which are required to meet a fleet average of 27.5 mpg, is not affected by the new regulation.

It should be noted that sport utility vehicles, which represent around 50% of the US light-vehicle market, are considered in the CAFE regulation as light-duty trucks and are therefore not subject to the lower CAFE limit set for passenger cars but instead are subject to the light-duty truck limit.

In the United States, despite the CAFE regulations in place, the average fuel economy of new light vehicles has continued to decline. Since peaking at 22.1 mpg in 1987 and 1988, average light-vehicle fuel economy for 2001 was 20.4 mpg (11.5 litres per 100 km), which is the lowest figure since 1980. The primary reason for this decline is the increasing market share of less efficient light trucks with their increasing vehicle weight and performance.

In California, there is a law requiring automakers to reduce GHG emissions from non-commercial vehicles starting in the 2009 model year. The new law does not set specific limits or targets, but instead requires the California Air Resources Board (CARB) to develop and adopt regulations by 1 January 2005. The regulations would go into effect one year later, giving the state legislature time to review them and to introduce amendments if necessary. However, these regulations are being opposed in court by industry.

[1] More detailed information on standards can be found in Annex A.

[2] *http://www.nhtsa.dot.gov/cars/rules/rulings/CAFE/alternativefuels/background.htm*

Japan

In Japan, fuel economy standards have been set through Japan's Top Runner Programme. The average fuel economy for petrol-fuelled light vehicles in 2010 is required to be 21% lower than the 1995 level (Table 3.5). For diesel, the average fuel economy improvement required between 1995 and 2005 is 13%.

Table 3.5. Fuel economy targets in Japan

Petrol vehicles	1995 actual result	2010 target	Required improvement
Passenger car	12.3 km/l	15.1 km/l	22.8%
Truck (GVW ≤2.5t)	14.4 km/l	16.3 km/l	13.2%
Total	12.6 km/l	15.3 km/l	21.4%
Diesel vehicles	**1995 actual results**	**2005 target**	**Required improvement**
Passenger car	10.1km/l	11.6km/l	14.9%
Truck (GVW ≤2.5t)	13.8km/l	14.7km/l	6.5%
Total	10.7km/l	12.1km/l	13.1%

Note: In Japan, the average diesel vehicle sold has higher fuel consumption than the average petrol vehicle due to the fact that diesel vehicles are mostly represented in the upper weight classes.

Voluntary agreements

ACEA[3] reached a voluntary agreement with the European Commission in 1998 to reduce the average CO_2 emissions of the new cars sold to 140 g/km by 2008[4]. Similar agreements have been signed by the Japan and Korean manufacturers (JAMA[5] and KAMA[6]).

As part of this agreement, the European Automobile Manufacturers (ACEA) have adopted, on an EU-wide basis, voluntary intermediate targets for reducing the average CO_2 emissions of their new car fleet from 185 g/km in 1995 to 174 g/km in 1999 and 169 g/km in 2000 (average for the diesel and petrol fleet).

These intermediate targets have nearly been met. In terms of absolute levels, the average CO_2 emissions of new petrol-fuelled cars (representing 64% of the sales) fell to 172 g/km in 2001 (from 177 g/km in 2000), while for diesel-fuelled cars (36% of the sales) there was a reduction to 153 g/km (from 157 g/km in 2000)[7]. Since 1998, when the ACEA CO_2 Commitment was established, European manufacturers have, on average,

[3] ACEA: Association des Constructeurs Européens d'Automobiles (European Automobile Manufacturers Association). Members of ACEA are: BMW AG, DAF Trucks NV, DaimlerChrysler AG, Fiat Auto Spa, Ford of Europe Inc., General Motors Europe AG, Man Nutzfahrzeuge AG, Porsche AG, PSA Peugeot Citroën, Renault SA, Scania AB, Volkswagen AG, AB Volvo.

[4] Doc. COM/98/0495.

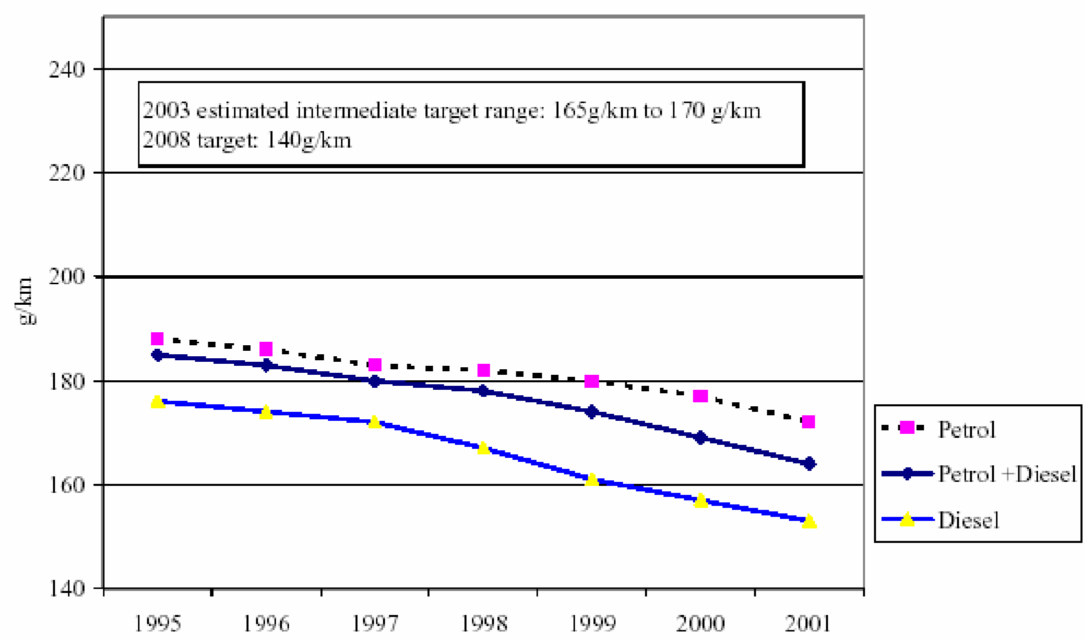
[5] Members of the Japan Automobile Manufacturers Association (JAMA) are: Daihatsu, Fuji Heavy Industries Ltd, Fuso, General Motors Japan, Hino, Honda, Isuzu, Kawasaki, Mazda, Mitsubishi Motors, Nissan, Suzuki, Toyota, UD Trucks, Yamaha.

[6] Members of the Korean Automobile Manufacturers Association (KAMA) are: Hyundai, Kia Motors, GM Daewoo, Ssangyong, Renault Samsung.

[7] In 2000, the average CO_2 emissions for new vehicles sold (both diesel and petrol) was 177 g/km x 0.64 + 157 g/km x 0.36 = 169.8 g; to be compared to 169 g/km (which is the intermediate target).

reduced CO_2 emissions by 2.5% per year (2.5% reduction in 2001). Over the 1995-2001 period, ACEA cut its average CO_2 emissions for new cars by 11.4%, with an increasing downward trend (Figure 3.8). Between 1995 and 2001, the CO_2 emissions of petrol cars went down by 8.5% and those from diesel cars by 13.1% (ACEA, 2002).

Figure 3.8. EU trends of ACEA's fleet in specific average emissions of CO_2.



Real-life fuel consumption of individual vehicles

Role of the test method

A point of contention with official fuel consumption figures is the method of measurement. Most reported fuel consumption figures are derived from the standard vehicle certification test, in which the consumption of a new vehicle is measured under standardised conditions by means of a dynamometer. Under these test conditions, all auxiliary equipment is switched off (*e.g.* in the United States and Japan). The official test results produced in this way allow comparisons to be made between different motor vehicles, and for the same vehicle, also allowing comparisons to be made between the results achieved under the test conditions for urban and extra-urban driving cycles.

However, when auxiliary equipment and accessories are in use, vehicle fuel consumption increases dramatically (increases can range from 20% to up to 100% for smaller vehicles). Fuel consumption also changes significantly in response to real-world traffic conditions. A further concern is that the official tests are not neutral with respect to type of technology. For example, all regenerative braking possibilities in electric or hybrid vehicles, even where available, are not taken into account. As a result of using the official test method, the test conditions differ markedly from those in real life. One of the further consequences is that the official results are not neutral with respect to vehicle size; the comparative results disadvantage small, very fuel-efficient cars.

A recent European Conference of Ministers of Transport study (ECMT, 2003) reviewed the research that has been undertaken on the gap between official tests and real-world driving over the last 20 years. The ECMT report indicates that there is frequently a gap of more than 20% between emissions measured during official cycles and on-road emissions. The research has confirmed the main causes of this shortfall are the inadequacy of the official cycles (which are not representative of real driving cycles), a lack of vehicle maintenance, and individual driving styles (which can differ greatly from driving styles implicit in the official tests).

Tests conducted in France on the fuel consumption in real-use conditions of a small car produced by one of the major car manufacturers and known to be very fuel-efficient showed some interesting results. While the fuel consumption according to the official test results for this small car was 3 litres per 100 km, fuel consumption of between 4.9 and 6 litres per 100 km (*i.e.* between 1.6 and 2 times the "official" figure) was observed in real conditions. The actual level depended on the acceleration needed to "follow" the flow of other vehicles. The principal reason was that, in real driving conditions, the test vehicle – which had a small engine (46kW) compared to its weight (830 kg) – needed to use a high proportion of its power to match the acceleration of other vehicles and keep up with the vehicle flow, which was highly fuel-consuming. If the additional power required for accessories (lights, windscreen wipers) was taken into account, the energy balance for the vehicle in real driving conditions was no better than that of a more powerful car.

Vehicle climate control systems

While the increased energy consumption associated with the use of an air conditioner and other accessories is not measured within the procedure of a type-approval test, such energy consumption can be quite significant. Tests have been carried out in order to establish the energy consumption and emissions of cars with the air conditioner in use. Details are shown in Table 3.6. Using an air conditioner at full load causes an increase in the fuel consumption of 27% on average. The emissions of CO and HC and particulate matter rise even more dramatically.

Table 3.6. Relative extra emissions at full load (% extra compared to no air-conditioning)

Emission type	Percentage change in emissions and fuel consumption from use of air-conditioning by road type			
	Urban	Rural	Highway	Average trip
Fuel consumption	+29	+30	+24	+27
CO_2	+28	+25	+21	+25
CO	+796	+616	+478	+605
HC	+260	+271	+114	+207
NO_x	+76	+17	+17	+31
Particles	+139	+64	+262	+159

Source: Gense (2000).

These results are of interest for two important reasons. First, the type approval data (which do not account for the use of air conditioning and other accessories) are used as an official basis for consumer information. While it is important for such consumption data to be based on standardised tests, the marketing of vehicle fuel consumption performance on the basis of official data (which does not reflect real-world driving) is potentially misleading. Many consumers do not understand the limitations of the official tests or realise that the official data are not representative of real-world driving conditions. A fairer assessment of performance from the consumer's viewpoint would identify what can be expected in practice when accessories and the air conditioner are in use and driving conditions are as they will actually experience.

Secondly, as the operation of the auxiliary systems is not factored in, the official tests provide inappropriate signals for vehicle manufacturers. This is because the tests encourage manufacturers to develop vehicles which perform best in terms of the official cycle tests, rather than vehicles that perform best in the real-world driving conditions that consumers will experience. If the tests reflected actual driving conditions, manufacturers would have an incentive to develop an optimal engine calibration strategy for low emissions that takes the additional loads from auxiliary systems into account. The EU is considering modifying the official test to include operation of air conditioning. In the United States, there is a specific cycle for assessing the outcome with the air conditioning system in use.

While these reasons are not new, they are increasingly important in the context of fuel conservation and low-emission vehicles. They are also of growing importance to consumers given the increasing use of air conditioning and accessories expected in the uture that will produce greater differences between official cycle and real use results.

Potential of traditional and new technologies

Petrol engines

CO_2 is an inevitable product of the combustion process for carbon-based fuels. Therefore, a reduction in CO_2 emissions can only be achieved by a reduction in fuel consumption.

Petrol engines offer several possibilities. One of these is to address the lower partial load efficiency that is characteristic of petrol engines, and which is caused by throttle losses. Because such engines in passenger cars operate most of the time under partial load conditions, significant gains in fuel consumption can be achieved by improving their partial load efficiency. In this respect, the following are some of the options[8] that can be considered:

- Variable valve actuation: fuel consumption can be reduced by up to 15%.
- Variable compression ratio.
- Direct injection on stoichiometric or lean mixture engines.
- Engine downsizing: through the use of smaller capacity engines, the average load on the engines increases, as does engine efficiency. Use of turbochargers or superchargers increases the power output to levels that are acceptable to consumers. However, this option is not always popular from a marketing perspective.
- Cylinder deactivation.
- Integrated starter alternator (ISA).

[8] These options are described more in detail in Annex 2.

It is difficult to estimate the reductions that can be achieved with each option, and it is still unclear to what extent certain options (or combinations thereof) will be applied in practice. Also, the cumulative reduction that can be achieved by combinations of options is not equal to the sum of the single contributions. Nevertheless, it seems reasonable to expect that if adopted, these options could lead to a reduction of fuel consumption of around 25% in the next ten years. Lowering of vehicle weight and rolling resistance could bring about further reductions.

Diesel engines

Modern direct-injection diesel engines have a specific fuel consumption that is around 25% lower than comparable modern petrol engines. Because of the difference in energy density between petrol and diesel fuels, the advantage of diesel engines in MJ/km is about 15%. The corresponding CO_2 emissions are about 14% lower compared to a petrol engine. Diesel engines do not suffer from throttle losses, but turbo-diesels (nearly all modern diesels) have the disadvantage of worse cylinder filling at low engine revolutions, because of the slow response of the turbocharger. With use of turbo-pressure regulation, major improvements are still possible. However, some offsetting of fficiency losses can be expected through the use of exhaust after-treatment systems, such as particulate filters and de-NO_x catalysts.

Downsizing and start-stop systems are also options for diesel engines, but, because of the different behaviour of diesel engines under partial load, the gains achievable are smaller than those possible in petrol engines.

Hybrid vehicles

A hybrid vehicle is equipped with at least two power sources. The most common forms of hybrids usually combine a conventional internal combustion engine and an additional power source. These additional power sources can be electric motors, hydraulic motors or mechanical flywheels. Most of the hybrid vehicles developed in recent years are hybrid electric vehicles (HEVs) equipped with an electric motor for higher efficiency and better controllability. When the vehicle is largely powered by a conventional engine and is equipped with an added electric motor and a small amount of energy storage, the vehicle is referred to as a “mild” hybrid.

HEVs can have three primary advantages over conventional vehicles: regeneration of energy during deceleration, automatic engine shutdown when the vehicle stops, and optimisation of engine drive conditions to allow the electric motor to be used wherever possible. As a consequence, HEVs achieve significantly better fuel economy than equivalent petrol or diesel vehicles and can also meet the most stringent current exhaust emissions standards more easily.

On the downside, HEVs are heavier than conventional models and require more complex engineering, mainly because they must incorporate a relatively large battery pack, an electric motor and an inverter in addition to a conventional engine. This increases their manufacturing costs. Another disadvantage is that, although designed to generate the maximum output power equivalent to that of conventional vehicles, HEVs cannot yield the maximum output over a sustained period, as the batteries lose their charge. On continuously steep roads, the fuel economy advantage of HEVs over conventional vehicles is reduced because of a drop in deceleration energy regeneration. The HEV performance can be lower also for longer trips on highways, where their electric motor may not be used. However, HEVs currently on the market have addressed these problems by increasing the output/energy density of energy storage systems, improving the motor's specific power output, and optimising the output capacity (mounted weight) according to vehicle applications and by improving their system design.

Electric vehicles

In the past decade, a range of electric vehicle models have been developed and are now commercially available. The main problems are limited range due to heavy batteries and the lack of infrastructure for charging them. In the short and medium term there appears to be no prospect of a new generation of low-cost batteries with high energy and power density. Given their performance and relative cost disadvantages, it seems unlikely that electric vehicles using current technology will be produced in large volumes.

Fuel cell vehicles

Configuration

A fuel cell is a device that is able to transform the chemical energy of a fuel into electric energy. A fuel cell concept normally consists of two major modules: a fuel cell stack and a fuel-reforming and conditioning system. The stack comprises a sequence of fuel cells. The type of reforming and conditioning system needed is dependent on the fuel used; no reforming and conditioning system is required whenever the fuel used is hydrogen.

The fuel cell process is characterised by high efficiency conversion and is virtually free of tailpipe pollutant emissions. For this reason, fuel cell vehicles are normally classified as "zero-emission vehicles". In vehicle applications, a fuel cell system using hydrogen is often favoured because no CO_2 emissions are produced during vehicle use. However, use of hydrogen fuel means the hydrogen has to be either stored on-board or produced from other fuels such as petrol, natural gas or methanol by means of a reformer.

There are three basic configurations when a fuel cell system is used in a motor vehicle (Mourad *et al*, 2001):

- The fuel cell system is the sole energy source. In this case the fuel cell system supplies all the required power and mostly operates under partial load. This approach is more energy-efficient than a petrol or diesel engine. However, if a fuel other than hydrogen is used, the relatively slow response time of the reformer may lead to problems during changes in engine load.
- The fuel cell system is part of a "series hybrid" configuration. In this case, the fuel cell generates electric power and is operated in a restricted range where its efficiency is very high. When higher power is required, the battery can assist the fuel cell in producing the necessary power output. This configuration allows regenerative braking – which lowers fuel consumption – and improves response time, particularly where a reformer is being used.
- The fuel cell acts as an "auxiliary power unit", supplying a vehicle with a conventional driveline system with extra electrical power. This approach can bring about considerable fuel savings in vehicles with high electrical power demands for the auxiliaries.

Choice of fuel

Manufacturers and public authorities face a dilemma in the choice of fuel for fuel cell vehicles.

Ideally, hydrogen is preferable. With hydrogen fuel, the system design is simple and emissions and energy efficiency are optimised, but the current on-board hydrogen storage options are either expensive or carry significant weight and space penalties (see below). In addition, the costs of developing a suitable fuel distribution network in many countries would be very large. Finally, the large-scale and generalised use of hydrogen for transport will require great care and adequate precautions to limit losses and leaks during the hydrogen production process (whether in plants or on board vehicles) or during the filling of vehicle tanks.

If petrol is chosen instead of hydrogen, the reforming and conditioning system becomes rather complicated. A fuel cell stack needs pure hydrogen, and for a reformer to produce hydrogen of sufficient purity, the petrol needs to have virtually zero sulphur content. The overall fuel cell efficiency is not optimal when petrol is used, but the ready availability of the fuel is an advantage.

With methanol, the performance is better than with petrol, but the conversion equipment is complex. Storage on-board the vehicle is, however, relatively simple. As methanol is a toxic liquid, there is an exposure risk for consumers during refuelling and a risk of pollution of subsoil water in an accidental spillage. In principle the problems are not greater than with petrol, but in practice they have led fuel cell applications in vehicles away from the use of methanol.

The final choice of the most appropriate fuel for fuel cell vehicles therefore requires consideration of range of issues, including market perspective, safety, cost and reliability of the technologies. At this stage, it is too early to predict which technology is likely to win a substantial market share, or even whether a number of fuel choices might co-exist in the marketplace.

In terms of overall performance, the potential gain in fuel efficiency from using a fuel cell as motive power for a vehicle is potentially very high, especially when pure hydrogen is used. However, when petrol or methanol are stored on-board and reformulated to provide hydrogen, the fuel efficiency is significantly reduced and becomes equivalent to a modern diesel engine, because of the losses in the reforming the fuel on board the vehicle.

Fuel storage

When hydrogen is used as the fuel for the fuel cell, solutions need to be found for storing the hydrogen on board the vehicle. Different systems for hydrogen storage are available, but they are all bulky and heavy. The main storage systems are:

- Hydrogen storage at room temperature under a pressure of 200-300 bars. High pressure steel cylinders are usually used, but for vehicle applications light-weight composite tanks with steel strengthening – which can accommodate higher pressures (600-700 bar) – are in development.
- Liquefied hydrogen storage. This would allow smaller storage volumes and lower storage weight with the same vehicle range. However, about a quarter of the fuel's energy content is lost during liquefaction of the hydrogen and other energy is lost through evaporation.

- Hydrogen storage in metal hydrides. This approach leads to significant weight increases or, when using light-weight materials such as magnesium, requires high operating temperatures (about 300^{o}C) to release the hydrogen.
- Hydrogen storage in graphite. This promising technology is at an early stage of development. In the short run, active graphite in combination with storage under pressure may be viable. In the long run, storage in nanofibres of suitable graphite looks promising.

Reformer type

Currently, two kinds of chemical processes are being evaluated: steam reforming and partial oxidation. Both processes aim to convert the current carbon-based fuels to hydrogen-based fuels that can then be used in fuel cells. The conversion could be undertaken either at a fixed location (*e.g* in a chemical factory or at a gas station) or on-board vehicles making use of reformers.

The reformers currently used in prototype vehicles are almost identical to the ones used in chemical installations, but they have much lower efficiency. Reforming is most efficient at high temperatures (300-1000^{o}C depending on the fuel type), but this requires a specially designed reformer. Currently, "steam reforming" is often used in combination with a "shift reaction". A combination of steam reforming and partial oxidation is at the centre of research interest. Partial oxidation is an exothermic process in which the carbon in the fuel reacts with oxygen to form carbon monoxide.

A significant disadvantage of reformers (when compared to hydrogen stored in a tank) is their relatively slow response to changes in load (load transients). Response times often can be as long as a few minutes. One way to overcome this problem is to incorporate a hydrogen storage capacity after the reformer, but this makes the system more complex and expensive. Another problem is the high temperature required. These limitations mean that the response times encountered when starting a vehicle with a hydrogen-powered fuel cell is relatively large compared to a petrol or diesel engine. Alternatively, if carbon-based fuels are used, the potential gain in fuel efficiency and pollutant emissions is lost.

Six types of fuel cells are currently under research and development for use in vehicles. Each has its own characteristic electrode materials, electrolytes, membranes and operation temperature. For cars and trucks, generally polymer electrolyte membrane (PEM) technology is chosen.

Production of fuel cell vehicles

To date, fuel cell vehicle technology is still in the experimental stage. Several manufacturers (including Honda, Toyota and Daimler-Chrysler) produced fuel cell vehicles in 2002 and 2003 in limited numbers. Although only several units each, the vehicles produced will help evaluate the real costs with mass production as well as any constraints in production and limitations in use. In December 2002, Japanese car makers released a small number of fuel cell vehicles to key government agencies in Japan and the United States. In February 2003, the US Environmental Protection Agency (EPA) announced that the Honda FCX was the first to be certified as a "US hydrogen fuel cell zero-emission vehicle".

Downsizing and other issues

Reducing the size and power of vehicles can produce significant savings in fuel consumption. In relation to downsizing, weight is the first factor to consider. Use of heavy vehicles leads to high fuel consumption, especially in urban areas where speeds change a lot and relatively rapid acceleration causes large increases in fuel consumption by the heaviest vehicles.

It is possible to reduce the weight of most European, Japanese or North American cars by at least 200-300 kg, using conventional and known technologies – without excessive cost, or loss of comfort or safety. When vehicles become lighter, it is also possible to reduce the power of their engines and thus reduce their fuel consumption rate by several litres of fuel per 100 km. This effect is shown in Figure 3.7, which illustrates the increasing fuel consumption of the same vehicle model equipped with more powerful engines.

For a given weight, further fuel consumption savings can be achieved by reducing the engine power – *i.e.* by having a lower "power-to-weight" ratio. For most vehicles, the power of their engines is well above the power required for the vehicles to operate effectively and move normally in traffic.

Of course, more powerful engines allow more rapid acceleration – particularly with heavy loads – and higher speeds. However, at normal driving speeds, vehicles equipped with more powerful engines have significantly higher fuel consumption than is the case for the same vehicles with less powerful engines. At the lower speeds typical of urban travel, the increase in fuel consumption with more powerful engines can be large. Changing the power-to-weight ratio is therefore a direct way of changing the fuel consumption of a motor vehicle.

Reducing the power-to-weight ratio of motor vehicles would be one of the most effective ways available to reduce vehicle fuel consumption, whatever the technology of the engine. It would have immediate benefits on both local pollutants and global emissions as new more fuel-efficient cars replace older vehicles with higher fuel consumption. Also, lower power-to-weight ratio vehicles would contribute to lower emissions over the lifetime of the vehicle – by comparison with the higher power-to-weight vehicles that would otherwise have been purchased. Nevertheless, there are limits to the benefits that can be achieved.

Reductions in the power-to-weight ratio could be pursued voluntarily, relying on public information and the agreement of vehicle manufacturers. However, the success of such voluntary approaches would then depend on consumers buying low power-to-weight vehicles in sufficient numbers to achieve the outcomes being sought. At present, although vehicle manufacturers are producing vehicle models with low power-to-weight ratios, consumers are continuing to buy increasingly more powerful and heavier vehicles with higher power-to-weight ratios.

Alternatively, should firmer action be supported, lowering the power-to-weight ratio of vehicles being sold could be pursued through regulatory or legislative means *e.g.* by specification of the maximum power-to-weight ratio that would apply to different vehicle types and weights.

While such measures would not require any technical development, they would require very strong political support, given that limitations on the power of motor vehicles being sold would be contrary to current market preferences and clearly would not be universally supported. As a transition measure, governments could give consideration to a practice adopted in some places: limiting the power-to-weight ratio of vehicles that can be driven by some driver categories – *e.g.* drivers under 25. Again, such a limitation could be expected to have safety as well as environmental benefits.

Life cycle emissions analyses

Alternative fuels

The alternative fuels which offer the capacity to reduce CO_2 emissions are those with a lower carbon content and a higher hydrogen content than petrol or diesel. Fuels that potentially can significantly reduce light-duty vehicles' tailpipe emissions of CO_2 include hydrogen, methanol, natural gas, bio-diesel fuels and also electricity. Replacing a significant share of petrol use with these fuels or electricity could produce significant reductions in CO_2 emissions from vehicle operations. Some alternative fuels also produce lower emissions of other greenhouse gases such as methane (CH_4) or nitrous oxide (N_2O).

As a fuel, LPG offers the potential of lower CO_2 emissions because it has the advantage of lower carbon content, but in reality the potential benefits are at least partially offset by the relatively higher fuel consumption of LPG engines. CNG engines offer CO_2 emissions 15-20% better than a petrol engine, but produce equivalent or higher CO_2 emissions than diesel. Given the wide availability of CNG in certain parts of the word, it is for some countries a good solution to diversify the energy supply. Regarding regulated air pollutant emissions it is expected that CNG and LPG vehicles will have emission levels that are much the same as the new very low-emission petrol vehicles. In the area of the unregulated components such as aromatics, gaseous fuels have a considerable advantage over petrol.

Other options are renewable fuels and biofuels in particular. On a life-cycle basis, biofuels can reduce CO_2 emissions by 30-60% relative to conventional fuels. Total CO_2 savings very much depend on the source of the biomass and the energy used to grow the crops (including pesticides and fertilisers) and to process and distribute the fuel. The European Commission expects that 20% of fuel will come from biomass by 2020.

Well-to-wheel analysis

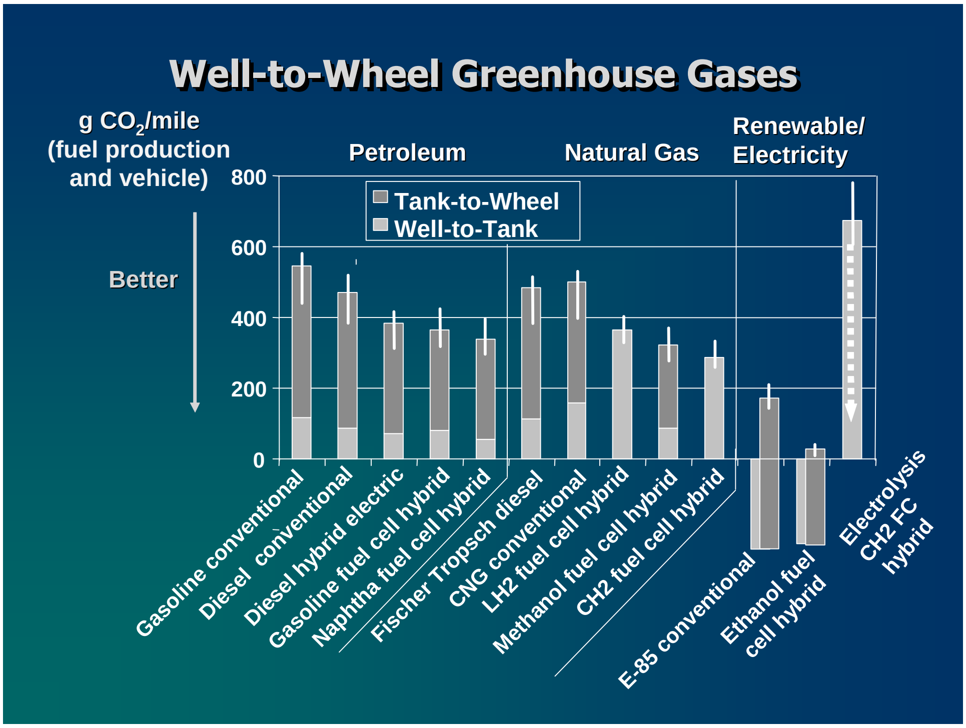
The production of some of alternative fuels generates significant GHG emissions, which can offset at least part of the reduction in tailpipe emissions they offer. A more comprehensive measure of the impact on total emissions is obtained by estimating the change in emissions measured over the "full fuel cycle", including emissions that occur during fuel production and distribution as well as during vehicle operation.

In the United States, a recent analysis (Argonne National Laboratories, 2000) using the Greenhouse Gas and Regulated Emissions from Transportation (GREET) model indicates that some alternatives to petrol offer the potential for significant reductions in direct GHG emissions from the operations of light-duty vehicles. Such fuels include ethanol, natural gas, petroleum-based and biodiesel fuels and electricity. However, producing some of these fuels generates significant GHG emissions, which would offset at least part of the reduction in tailpipe emissions they offer. To fully assess the impact on GHG emissions, it is therefore necessary to measure emissions over the full fuel cycle which includes production, distribution and vehicle operation.

Based on estimates of the GREET models of average lifetime per-mile emissions of criteria pollutants for LDV, most alternatives to petrol would reduce pollutant emissions from LDV, in some cases significantly. Most substitute fuels likely to be commercially available – except ethanol and methanol – would reduce VOC emissions significantly compared to petrol. In contrast, only biodiesel appears likely to significantly reduce emissions of NOx.

A recent study commissioned by General Motors (GM, 2001) and undertaken in co-operation with the Argonne Laboratory compared the well-to-wheel energy consumption and GHG emissions of 13 alternative fuels. Results of this analysis for GHG emissions are summarised in Figure 3.9. This work concluded that fuel cell vehicles powered by clean petrol offer greatly reduced GHG emissions compared to today's conventional powertrains and fuels. Diesel hybrid is very competitive and a clear leader among non-fuel cell powertrains/fuels. CNG does not offer significant benefit versus conventional fuels for internal combustion engine (ICE) vehicles. Methanol fuel cell vehicles do not offer significant advantage compared to petrol fuel cell vehicles. Renewable fuels and nuclear power offer the lowest GHG emissions.

Figure 3.9. Well-to-wheel greenhouse gases from alternative fuels



Source: General Motors Corporation (2001).

In Europe, the Institut Français du Pétrole undertook a similar study in 2001 to compare the CO_2 emissions of a medium-size passenger car with a range of alternative fuels. Results are given in Table 3.7. Figures in this table should only be considered as an indication of the well-to-wheel emissions, given the specific conditions that may apply to the production process of the fuels.

Table 3.7. CO_2 emissions from well-to-wheel

Energy	Origin	Engine	CO_2 (g/km) Well to tank	CO_2 (g/km) Tank to wheel	CO_2 (g/km) Well to wheel
Hydrogen (compressed)	Water (France)	Fuel cell	60	0	60
Ethanol	Corn	Spark ignition	111	0-239	111-350
CNG	Natural gas	Spark ignition	15	133	148
Hydrogen (compressed)	Natural gas (Europe)	Fuel cell	155	0	155
Diesel	Oil	Compression ignition	24	142	166
Dimethyl ether	Natural gas	Compression ignition	45	127	172
LPG	Oil and natural gas	Spark ignition	28	154	182
Petrol	Oil	Spark Ignition	42	174	216
Hydrogen (liquefied)	Natural gas (Europe)	Fuel cell	251	0	251

Source: Institut Français du Pétrole (IFP), Euroforum Congress, 7 November 2001, Paris.

Electric vehicles are commonly considered as zero-emission vehicles since they produce no tailpipe emissions. However, on a well-to-wheel basis, only those which are powered by electricity produced from zero-emission methods such as hydro-energy, wind or using nuclear energy can be classified as zero-emission vehicles. When the electricity is produced from coal, gas or oil - which is the most common source of electricity in OECD countries - the CO_2 balance is no better and often even worse than petrol or diesel vehicles.

Emissions associated with vehicle production and disposal

Of the total energy usage of a vehicle from manufacture through useful life to scrapping, 85% of the energy content is used for propulsion. The remaining 15% is used in the manufacture, maintenance and scrapping of the vehicle.

The manufacturing process requires energy and emits pollutants. In Europe, the average energy content needed to produce a vehicle is estimated to be approximately one tonne of oil equivalent per one tonne of vehicle. This value incorporates all the manufacturing operations and all materials used. As an example, data from Peugeot indicate that in 2000, the energy use for manufacturing some 2.9 million vehicles amounted to 6 260 GWh. In terms of emissions, this led to an estimated 774 000 tonnes of CO_2 emissions, 1 500 tonnes of SO_2, 900 tonnes of NO_x and 18 560 tonnes of VOCs.

For vehicles which use aluminium for the body, the net CO_2 balance is not easy to establish. It is claimed that because of its recycling properties, aluminium would perform better than steel, but this depends on the degree of recycling and on the final quality of recycled aluminium.

In hybrid or electric vehicles, the use of a large battery pack means that the energy involved to produce the battery becomes a more significant component in the overall energy input in producing the vehicle, especially with nickel-metal hydride batteries or lithium batteries which require a large number of chemical and physical treatments in their production. There is insufficient data to determine whether there is a net CO_2 reduction from the production of hybrid vehicles relative to conventional-engine vehicles. Determining the balance is complicated by the impact of the hybrid architecture of the vehicle on the size of the internal combustion engine, which is usually much smaller than an equivalent conventional vehicle. Thus, while more energy is required in the battery technology, less steel or aluminium is perhaps required to produce the engine.

For fuel cell vehicles, the manufacturing of the fuel cell stack requires precise and complex operations. It is too early to accurately determine the energy inputs required for the commercial production of fuel cell vehicles.

Given the types of technologies that might be utilised in low-emission petrol and diesel vehicles, differences in life-cycle emissions might most plausibly be associated with differences in the utilisation of precious metals for exhaust catalysts. Such catalysts typically use combinations of palladium (Pd), platinum (Pt) and rhodium (Rh) to oxidise some pollutants (CO, unburned hydrocarbons) and reduce others (NO_X). In general, a shift to low-emission vehicles might be expected to significantly increase the consumption of some or all of these metals. For example, increasing palladium use in a light-vehicle market of ten million vehicles annually by an average of ten grammes per vehicle would increase overall palladium consumption, at least in the short term, by 100 000 kg annually - nearly the total amount of palladium that was produced worldwide in 1995. This could limit the production of fuel cell vehicles.

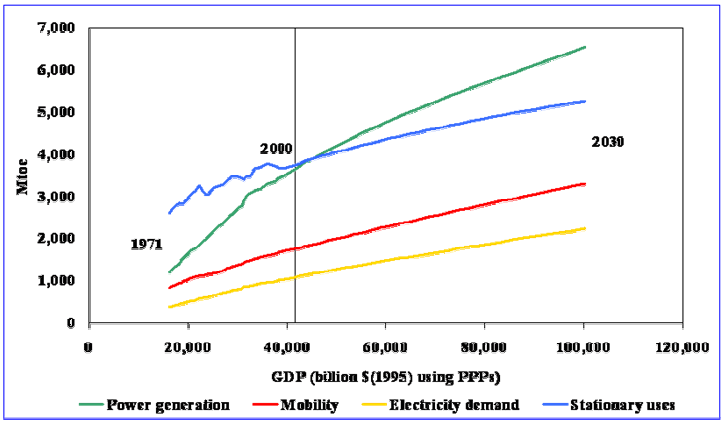
For other types of low-emission vehicles — in particular, those designed to achieve high energy efficiency — there are likely to be similar differences in life-cycle emissions related to specific components and materials. The range of possibilities regarding vehicle design, components, and materials is sufficiently wide to preclude a comprehensive set of comparisons at this time.

Outlook for 2010-2020

The IEA has projected that global primary energy demand will increase by 1.7% per year from 2000 to 2030. Fossil fuels will account for over 90% of the projected increase in energy demand. Oil will remain the single largest fuel in the primary energy mix. Oil demand is expected to grow by 1.6% per year, reaching 120 million barrels per day in 2030. Almost three-quarters of the increase in demand will come from the transport sector. The IEA has concluded that oil will remain the fuel of choice in road, sea and air transportation.

Figure 3.10 shows the trend in energy use for mobility (transport) in comparison with power generation, electricity demand and stationary uses. It shows that world energy use for both mobility and electrical services will grow in line with the expected growth in population and GDP.

Figure 3.10. Trend in energy use for mobility (transport) in comparison with power generation, electricity demand and stationary uses



Source: IEA.

For a number of years, there has been increasing concern about the worldwide outlook for CO_2 emissions. The outlook for future CO_2 emission from motor vehicles is dependent of a wide range of factors, including:

- Population growth.
- The economic development of countries and regions.
- The price of different forms of energy (crude oil, hydrogen, CNG, etc.).
- The transport policy of governments, worldwide policies on emissions, energy and trade; and the approaches taken to limiting CO_2 emissions (*e.g.* targets or standards and regulations).
- The number of cars sold and scrapped.
- Market preferences and the directions of any changes (*e.g.* continuing increases in the power and weight of the vehicles being sold, more MPV's, 4x4's.).
- The type and number of cars in operation and the distance travelled per vehicle, and vehicle occupancy.
- Technological developments (such information and communication technologies, transport innovations) that could modify patterns of demand and vehicle use.

To predict future vehicle use, energy consumption and emissions, models can be developed which will calculate the effects of the assumptions or predictions of various parameters. Examples of these calculations and projections can be found in the report *The Road from Kyoto* (IEA, 2000), which also provides a general background on approaches to CO_2 reduction.

Despite the progress in improving the fuel efficiency of new vehicles, the total CO_2 emissions from road transport are increasing. The main reasons are the growing number of vehicles, the growing number of vehicle-kilometres driven, an increase in weight and engine power and the increasing use of auxiliaries and accessories. Model year 2001 light vehicles have about the same average fuel economy as those built 20 years earlier (model year 1981), although, with the same average weight and performances as in 1981, they should show more than a 25% improvement in fuel economy (Hellman and Heavenrich, 2001). The increase in dimension and weight is the result of market changes, such as the purchase of larger and more powerful passenger cars, including more sport utility vehicles and more multi-purpose vehicles.

In 2000, the number of passenger cars worldwide was around 500 million, and the number of cars is increasing by more than 40 million every year. In the year 2020, around 1 billion vehicles can be expected to be in operation globally. The number of vehicle-kilometres travelled is expected to increase by 40% in OECD regions by 2020 for all traffic and by 32% for passenger vehicles (OECD, 2001).

In absolute terms, CO_2 emissions from transport over the 1990-2000 period increased by 8% in Sweden, 18% in Belgium and about 20% in Australia (BTRE, 2002). In Australia, CO_2 emissions from the transport sector are predicted to be 48% higher in 2010 compared to 1990 levels (AGO, 2002). The prediction for the Netherlands is illustrated in Table 3.8.

Table 3.8. Prediction of CO_2 Emissions for the Netherlands
Millions of tonnes

	1990	1995	2010		2020		2030	
			Low growth scenario	High growth scenario	Low growth scenario	High growth scenario	Low growth scenario	High growth scenario
Passenger cars	15.2	17.2	18.0	18.6	18.4	20.4	19.2	22.1
Vans	2.1	2.8	3.8	4.1	4.6	5.5	5.6	6.9
Trucks	5.5	5.7	8.8	9.7	12.1	14.7	16.3	20.9
Busses	0.5	0.6	0.6	0.5	0.6	0.5	0.5	0.5
Other	0.5	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Total	23.8	26.6	31.5	33.2	36.0	41.4	41.9	50.7

Source: RIVM, 2000. Calculations including autonomous developments plus ACEA covenant plus government CO_2 reduction measures.

Latest projections from the International Energy Agency (IEA, 2002b) anticipate a continuous increase in CO_2 emissions from transport for OECD and non OECD regions, with road transport continuing to represent 80% or more of total transport emissions (see Table 3.9).

Clearly, the increases in CO_2 emissions in these projections are a major concern, given that the policy objectives are to curtail increases and eventually reduce the level of CO_2 emissions. These projections clearly indicate that even if technology has the potential to significantly reduce CO_2 emissions on a per-vehicle basis, reductions in the order of those outlined will not be able to contain the projected increases sufficiently or ensure the necessary reduction in GHG emissions. Technological improvements therefore must be seen in wider transport strategy, including travel demand management.

Table 3.9. Expected increase in CO_2 emissions from transport: Absolute figures (million tonnes of CO_2) and percentage increases over 2000 levels[9]

	2000 Mt	2010 Mt %	2020 Mt %	2030 Mt %
World	4814	6010 +25%	7449 +55%	9024 +87%
OECD region	3326	3901 +17%	4467 +34%	4980 +50%
Non-OECD region	1488	2109 +42%	2982 +100%	4044 +172%

Source: IEA.

Conclusion

Road traffic is a growing source of GHG emissions. Efforts have been put into the reduction of fuel consumption of vehicles being produced, particularly by increasing the efficiency of the engine and components. Standard tests have illustrated that the average fuel consumption of individual cars indeed shows a downward trend. However, the absolute output of GHGs due to road transport has not followed this trend. The results obtained from more fuel-efficient engines have been largely masked by market trends toward heavier vehicles with more power and additional accessories including air conditioning. On top of this, forecasts show that a dramatic increase can be expected in many countries in the total number of vehicles and vehicle-kilometres.

Technological innovations have the potential to further reduce the average fuel consumption of individual cars and vehicle fleets in the near future. Voluntary agreements have been shown to be effective in getting the most advanced technology for controlling CO_2 emissions on the road. However, as long as carbon-based fuels are used it is unlikely that the overall growth in transport greenhouse emissions will slow. Biomass and other renewable fuels suffer from many drawbacks that seem likely to prevent them from gaining a substantial market share. It remains to be seen whether the use of hydrogen will be successful in reversing the trend in the increase of GHG emissions from the transport sector.

[9] The IEA projection takes into account government policies and measures on climate change and energy security that had been adopted by mid-2002 but does not include policy initiatives that were under serious discussion, but not enacted.

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Chapter 4

CONDITIONS AFFECTING THE WIDESPREAD USE OF LOW-EMISSION VEHICLES

Abstract. This chapter reviews the key conditions and supportive action necessary to promote wider implementation of low-emission vehicles, including fuel infrastructure requirements, production and operation costs and consumer attributes.

Fuel infrastructure requirements and safety issues

Fuel production infrastructure

Widespread production and use of low-emission vehicles (LEVs) fuelled by petrol or diesel would require minimal investments in new fuel production and distribution infrastructure. Most of this additional investment would consist of additional refining capacity or facilities required to meet the extremely low sulphur levels that petrol and diesel fuels will be required to have.

There is an international trend in many advanced countries toward the adoption of "zero" (10 ppm) sulphur fuels towards the end of this decade. Most of the additional investment to produce these fuels is in additional refining capacity, and the process is already in use in some refineries. For example, the additional energy required to produce diesel with 10 ppm of sulphur is between 2-5% of that required to produce current diesel fuel with 350 ppm of sulphur. However, the European Commission has concluded that the increase in refinery emissions of CO_2 from producing 10 ppm sulphur fuels was significantly offset by the reduction in vehicle CO_2 emissions which is achievable from the adoption of vehicle technologies which reduce fuel consumption (European Commission, 2001).

Currently, diesel represents almost 50% of all transport fuel consumed in Europe. To increase diesel production, it would be necessary to modify the refinery process, and more energy is required to modify the structure of hydrocarbon molecules. An increase of 10% in the diesel proportion would increase the proportion of crude intake from 8.5-9.5% for refinery energy use (from Shell International Petroleum Company – ImechE, 1992). Some other models indicate different values depending on the process, crude oil quality, etc., but costs are consistently higher when the diesel fuel proportion exceeds 50%.

For *alternative fuels*, the extent and cost of required investments in new or expanded fuel production, storage and distribution infrastructure are likely to vary. At one extreme, the ready adaptability of the petrol delivery infrastructure to be used for diesel or alcohol fuels would minimize the investment in fuel distribution infrastructure necessary to support widespread replacement of petrol by these fuels. Some modifications are necessary for handling alcohol fuels (particularly methanol).

In addition, significant expansion of fuel production facilities would be necessary to support the widespread use of alcohol fuels, while existing refining capacity should be readily adaptable to increased diesel production.

The infrastructure required for *electric vehicles* would include that needed for additional generation and transmission capacity, together with installation of charging facilities in households and at a significant number of employment sites, public facilities or retail locations.

Widespread use of *natural gas* as a transportation fuel would require significant expansion of production facilities and pipelines, as well as large investments to modify retail fuelling stations to dispense natural gas. Pressurization of the storage and distribution systems required for widespread use of compressed natural gas or liquefied petroleum gas would further increase the capital investments required for these fuels. The long distance transport of natural gas is more costly than oil. In natural gas pipelines, there is a potential risk of leaks and it is necessary to recompress the gas all along the pipes. When transported by sea vessels as liquefied natural gas (LNG), there is an additional energy cost to liquefy the gas.

Biofuels present interesting possibilities as they can be blended with normal petrol or diesel fuels and can also be used directly in conventional vehicles. However, it is important to take into consideration the land surface needed to obtain large quantities of biofuels. Depending on the biomass source, the production of three tonnes of ethanol (equivalent to 1.8 tonnes of petrol) or of three tonnes of diester (equivalent of three tonnes of diesel fuel) requires 10 000 m^2 of land. For instance, to meet France's transport fuel needs, more than 25% of the France's land area would be required, displacing regular agricultural activities, if 100% of the fuel was to come from biomass. Other methods for ethanol or methanol production (*e.g.* from cellulose) are possible but appear to be relatively expensive.

It is also possible to produce petrol or diesel from natural gas. This is known as the Fisher Tropsch process and requires very large capital investments. It is very energy-intensive, consuming around 30% of the initial energy content of the gas.

Hydrogen can be obtained principally from processing natural gas, coal or oil, or by the electrolysis of water. Once it is produced, it has to be transported to retail stations in the form of compressed or liquefied hydrogen. Liquefaction requires significant additional energy.

Distribution infrastructure requirements

A ubiquitous retailing or other distribution infrastructure – comparable to that now offered by the established networks of retail petrol and diesel stations (over 100 000 in the United States alone) – would also be required to allow any alternative fuel to replace a significant fraction of petrol use. Refuelling with an alternative fuel would need to approach the convenience now afforded by petrol retailing stations, including a large number of locations, safety, speed and ease of refuelling, convenient opening hours, availability of ancillary services such as vehicle repair, and options for self service (possibly accompanied by driver education in safe fuelling procedures). Achieving this level of convenience would require refuelling facilities to be available in a range of locations, including densely developed urban areas, remote recreational locations and at occasional points along highways in sparsely populated regions.

The existing fuel infrastructure in many countries has been developed over nearly a century, with many of the facilities being constructed when land was readily available and there was less concern about potential environmental impacts. Investments in new or replacement infrastructure will face far greater limitations with regard to available land in and near developed areas, as well as more detailed regulations for their design and operation to ensure user safety, health and environmental protection. Siting of fuel production, storage, and retailing facilities is likely to be subject to more protracted public procedures than in the past, while applicable regulations and permissions and authorities may fall under the jurisdiction of a variety of federal, state, and local agencies. Safety, health and environmental concerns – and the public's perception of how facility designs and operating procedures respond to these concerns – can have major impacts on the acceptability of new facilities, their location, and their final costs.

Recognising these potential impediments to establishing an entirely new fuelling infrastructure, the most likely scenario for creating an expanded distribution network for certain alternative fuels would perhaps entail installation of separate storage capacity and delivery equipment for these fuels at existing petrol/diesel stations. For fuels such as ethanol and diester, which are liquid at ambient temperature, appropriate modifications might allow some existing gasoline storage tanks and pumps to be converted for use with these fuels. In contrast, the physical properties of other alternative fuels such as natural gas or hydrogen require specialised capabilities such as pressurised storage and closed-coupling transfer systems to vehicles' fuel tanks, and might require construction of new, dedicated fuelling facilities to provide these capabilities.

Fuel and feedstock production demands

In addition to the required investments in new infrastructure and higher production costs some alternative fuels, there are other potential impediments to the use of alternative fuels and their widespread substitution for petrol and diesel. These include possible difficulties in increasing the production of alternative fuels that are currently available on only a limited scale, expanding their distribution and retailing networks to duplicate (or at least approach) the ubiquitous availability of petrol, and extracting or importing increased supplies of the feedstock necessary to produce some alternative fuels.

Because total petrol production is so large, the fuel production demands to replace even a modest fraction of petrol use with an alternative fuel could require major investments to fund the increases in refining or production capacity that would be required for most fuels, as well as in storage and distribution infrastructure, and retail or home fuelling facilities.

Potential hazards of fuel production and distribution

Both conventional fuels and alternative fuels present potential safety, health and environmental hazards. These include risks of fire or explosion in fuel processing and distribution, as well as potential hazards to human health from repeated or prolonged contact with fuels or their vapours. Potential environmental damages arising from fuel production, storage or distribution from normal vehicle operation and refuelling, or from accidental fuel releases occurring at any point in the production, distribution, and fuel use cycle are another important concern.

Even if these risks can be controlled and it can be demonstrated that none of the alternatives to petrol and diesel are inherently more dangerous than the conventional fuels they would replace, it is necessary to:

- Consider the specific physical, chemical and toxic parameters of the alternative fuel.
- Assess the potential risks for the workers involved in their production and distribution.
- Assess the hazards for vehicle owners using these fuels.

Specific safety standards would therefore need to be developed in conjunction with the deployment of the new technologies in order to address the issues above and create an operational framework where the risks can be reduced at least to the same level of conventional vehicles and fuels.

Infrastructure, production and operation costs

Major elements of alternative fuel costs

Substituting alternative fuels for petrol and diesel entails three categories of additional costs:

- First, expanding the use of most alternative fuels requires increased capital investments in facilities for the production or extraction of the feedstocks, as well as refinement and distribution.
- Second, the production cost of alternative fuels themselves may be higher than petrol or diesel and lead to increased vehicle operating cost measured on a per-vehicle-kilometre basis.
- Third, producing vehicles with the ability to operate on alternative fuels may involve higher costs than manufacturing conventional petrol or diesel-powered vehicles; examples are the high-pressure tanks required for CNG, LPG or hydrogen.

Fuel infrastructure costs

Additional capital costs for delivery infrastructure are likely to vary widely among the alternative fuels. At one extreme, the ready adaptability of the present infrastructure for the use of alcohol fuels (ethanol or methanol) would result in very low incremental costs. Although necessary modifications for handling alcohol fuels (particularly methanol) increase the necessary investments in fuel infrastructure compared to those for diesel fuels, they remain relatively modest by comparison to those for most other fuels. For electric vehicles, the distribution network already exists and costs are limited to the installation of charging facilities in households and at public or retail facilities. European experience indicates the costs are modest if a slow charging process is used (EUR 100 to EUR 200 per charging facility – charging time of six hours per car). If using a quick-charging process, costs are significantly higher (EUR 10 000 per facility – charging time of half an hour per car).

At the opposite extreme, extensive pressurized fuel storage and distribution systems would be needed for CNG, LPG or hydrogen, which would require significant additional capital investments. Costs are dependent on the nature of the installations (private or public) and the charging process. For a public distribution facility capable of refuelling 100 vehicles per day, the following estimates are an indication: EUR 45 000 for an LPG installation, EUR 300 000 for a CNG installation and EUR 450 000 for cryogenic fuels (LNG or hydrogen).

Fuel production costs

Some fuel production costs have been reported by the US Energy Information Administration in its *Annual Energy Outlook 2000* (Table 4.1). Results indicate that, compared to petrol on an energy content basis, CNG and petroleum-based diesel are expected to remain less costly to produce. In contrast, production costs for alcohol fuels (methanol and ethanol), LPG, and bio-diesel are projected to significantly exceed those for petrol. Future costs for electricity generation and transmission are projected to make electricity by far the most costly alternative to petrol as an energy source for LDV.

In Europe, the results are similar, but are dependent on the technical level of refinery facilities, the availability of fuels on the market, and on the sulphur content limit for diesel fuel. The production costs for petrol and diesel (with very low sulphur content) are not very different in Europe because of the large market for diesel passenger cars in addition to commercial diesel vehicles. As already mentioned, diesel represents almost 50% of all transport fuels consumed in Europe. To increase diesel production to respond to a potential higher demand of diesel engines, it would be necessary to modify the refinery process and costs are consistently higher when the diesel fuel proportion exceeds 50% of the final fuel production.

Table 4.1. US Energy Information Administration fuel price forecasts for the year 2010

Fuel	Feedstock	Fuel cost/gallon (2000 USD, excluding taxes)	Fuel cost/million Btu (2000 USD, excluding taxes)
Petroleum diesel	Petroleum	0.77	5.95
CNG	Natural gas	--	6.52
Biodiesel (B20)	Petroleum/sov	0.93	7.40
Gasoline	Petroleum	0.88	7.64
Methanol (M85)	Natural gas	0.61	9.22
LNG	Natural gas	0.69	9.46
LPG	Petroleum/natural gas	0.92	10.94
Electricity	Projected US mix	--	13.47
Ethanol (E85)	Corn	1.26	15.37

Vehicle construction and maintenance costs

For vehicles that use non-petroleum liquid fuels at ambient temperature (ethanol, bio-diesel fuel) and are equipped with internal combustion engines and conventional mechanical drivetrains, the cost of construction is similar to that of petrol or diesel vehicles. In contrast, vehicles that run on gaseous fuels or electricity and/or that have non-conventional drivetrains, (*e.g.* hybrid electric) cost more to produce than equivalent vehicles using conventional engines fuelled with petrol or diesel.

The additional cost is around 10% for LPG vehicles and 15-20% for CNG vehicles when compared to a similar petrol or diesel vehicle. The additional costs arise principally from the pressurized tanks and safety control devices (valves, sensors, electronics, etc.)

and are not likely to decrease (tank production is now quite large and no significant decrease in cost can be expected through market growth). Vehicles operating on compressed hydrogen as fuel for conventional engines could be expected to have similar costs to a CNG vehicle, although no data is available.

With hybrid vehicles, the incremental cost will depend on the type of hybrid architecture. The additional cost could be less than 5% with a mild hybrid system (perhaps in mass production in 2004-2005), but more than 30% with a full hybrid system (such as the Toyota Prius).

For fuel cell vehicles, it is more difficult to evaluate the additional cost as the technology is still at an experimental stage. However, the vehicle manufacturers anticipate that in mass production, it should not be more than 10-20% of the current price of petrol or diesel vehicles. However, fuel cell vehicles are far from being produced in large quantities, and the estimated production cost of the current vehicles (from approximately EUR 150 000 to 300 000, minimum) constitutes a significant obstacle to a rapid development of the technology.

Vehicle manufacturers are aiming to keep the maintenance cost of these alternative fuel and new technology vehicles (new fuels, new drivetrains) to a level similar to that of conventional vehicles. Otherwise, market acceptance will be severely limited. As an example, the market failure of electric vehicles is, in part, a consequence of the high maintenance cost of batteries (due to short battery life).

Operating costs

The IEA has found that the costs for incremental fuel economy improvement per unit oil saved (or CO_2 reduced) in conventional vehicles is in general much lower than for advanced technologies or alternative fuels.

Differences in operating costs experienced by road users would depend mainly on the tax set by governments for alternative fuels.

In terms of the overall impact of changes in costs, research has found that the money devoted by households to road travel is fairly constant over time. Therefore, it can be expected that higher costs will reduce the distance travelled while lower operating costs will usually lead to increases in distance travelled. Such increases could offset the potential gains in fuel consumption and emissions.

Consumer attributes

Consumer acceptance of different types of low-emission vehicles could widely vary based on a range of factors, many of which are difficult to effectively characterise. Based on market trends, consumers appear to value a wide range of different features, with some of the key ones being safety, quality/reliability, economy, low fuel consumption, driving characteristics/road holding, environmental friendliness, value for money, advanced technology, comfort/luxury, interior space, compact external dimensions/handling/manoeuvrability, motoring enjoyment, completeness of equipment, multiple utility, large boot, design of interior, shape/external styling, high performance, car with “personality”, etc.

Currently, conventional vehicles can achieve practical driving ranges of more than 500 km (600 to 800 km in Europe with many diesel models), climb long grades without loss of speed, accelerate quickly, and carry and tow considerable loads. They can offer a high degree of occupant protection and, in most cases, can be designed to handle well even in adverse conditions (wind, snow, etc.). They are capable of providing high levels of comfort, *e.g.* passenger compartment heating and cooling.

Therefore, the alternative fuel and new technology vehicles would have to offer similar levels of comfort, convenience and performance as a conventional vehicle if they are to gain a significant share of the market. Even discounting the additional costs, many alternatives to conventional vehicles are likely to be disadvantaged based on one or more of these consumer acceptance factors. For instance, electric vehicles are capable of acceleration rates comparable to conventional vehicles, but use of this acceleration must be quite limited to preserve vehicle range. The performance of electric vehicles is also limited in cold weather and there is little prospect of heating or cooling the passenger compartment, given the energy required to do so. Consumers also place a high value on the time necessary for refuelling as well as on the fuel availability and the vehicle range.

The most promising alternative to conventional vehicles would appear to be hybrid vehicles. A hybrid vehicle's combination of a small conventional engine and batteries for electric power provides an effective means to significantly reduce CO_2 emissions, while producing very low levels of harmful emissions and offering most of the benefits of an equivalent conventional vehicle. It is however necessary to pay careful attention to the design of the engine to ensure that normal demands for air conditioning, steep climbs and carrying loads can be met.

Fuel and technology transitions and pathways – limits

When analysing all the possibilities, there are a myriad of fuel and vehicle technology alternatives that might plausibly be combined into overall vehicle/fuel systems to deliver vehicles with very low emissions and very low levels of fuel consumption. Table 4.2 illustrates a range of possible independent options. Of course, some combinations will not be possible or realistic.

Other parameters can also play an important role, including reduction of vehicle weight, downsizing of the engine and a decrease in the maximum allowable speed. Reducing weight and maximum speed could potentially result in lower pollutants and CO_2 emissions at a lower cost using conventional systems, without the need to adopt more complex technological approaches, but such measures run counter to the trends in consumer preferences for larger and more powerful vehicles.

Conclusions

The potential to reduce emissions of road vehicles depends on available vehicle technologies, fuel choices and associated issues such as refuelling infrastructure.

In the short to medium term, improving the performance of conventional vehicles offers greater potential than the use of new technologies and fuels. It is possible to achieve a very low level of local pollutant emissions and significantly lower CO_2 emissions, and this would be more cost-effective with improved conventional vehicles than with advanced and complex alternative technology systems.

Table 4.2. Potential fuel and vehicle technology combinations

<table>
<tr><td colspan="3">Body/chassis construction
Conventional steel unibody
Steel space frame with polymer composite panels
Aluminium unibody
Aluminium space frame with polymer composite panels
Polymer composite unibody</td></tr>
<tr><td>Fuel feedstocks
Coal
Petroleum
Natural gas
Biomass
Nuclear/water
Hydroelectric/water
Wind/water
Solar/water</td><td colspan="2">Fuels
Gasoline
Diesel
Ethanol
Methanol
Liquefied petroleum gas
Dimethyl ether
Naphtha
Compressed natural gas
Liquefied natural gas
Hydrogen</td></tr>
<tr><td>Energy conversion
Spark-ignition ice
Compression ignition ice
Atkinson/miller cycle
Two-stroke ice
Stirling cycle
Turbine
Fuel processor
Pem fuel cell</td><td>Drivetrain
Electronically controlled mechanical gearbox
Continuously variable transmission
Power assist parallel hybrid
Dual mode parallel hybrid
Range extend parallel hybrid
Series hybrid</td><td>Peak energy storage
Lead-acid
Nickel-metal hydride
Lithium-ion
Lithium-polymer
Ultracapacitor
Advanced flywheel</td></tr>
</table>

There are therefore considerable advantages in continuing to focus on petrol and diesel LEVs, at least in the short to medium term. Facilities to manufacture such vehicles are already well established as are maintenance facilities and practices. Components such as on-board diagnostics, catalysts and improved fuel management systems are well proven and do not dramatically increase new vehicle prices. “Cleaning up” petrol and diesel fuel requires some capital investment that increases the price of these fuels, but not to an extent that that petroleum may lose its competitive advantage relative to other fuels and feedstocks. In contrast, expanding the use of alternatives to petrol or diesel for use as low-emission vehicle fuels would require significant new capital investments in production and distribution facilities.

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Chapter 5

STRATEGIES FOR PROMOTING LOW-EMISSION VEHICLES[1]

Abstract. This chapter reviews strategies being implemented in OECD countries for promoting the use of low-emission vehicles. It analyses the role of a variety of incentives and other measures and how they can impact users' choices. It also highlights the need to better inform the public on the fuel consumption and emissions performance of vehicles in real use, via labels, guides and other supporting material.

Role for governments

In many OECD countries there is the technical capacity to make considerable improvements in the emissions and fuel consumption performance of the motor vehicles currently being produced. However, in the absence of appropriate market signals, consumer trends are towards larger, heavier vehicles with increased power. These trends have tended to offset improvements in engine efficiency and thus average fuel consumption has shown little improvement in the past ten years in most regions (see for example BTRE, 2002a). The one major exception is a number of European countries where there were improvements in the late 1990s (IEA, 2001).

To understand government's role in implementing a broad strategy for the promotion of the use of low-emission vehicles (LEVs), it is useful to consider the overall objectives of reduced pollutant emissions and fuel consumption in the context of other possible approaches. Developing an effective policy intended to reduce urban air pollution and/or greenhouse gas (GHG) emissions from the transport sector is a complex question, which may require action on a number of levels. The difficulty is in determining at what levels government action is likely to be most effective.

Reductions in emissions could potentially be delivered through a range of policies, covering:

- Land use planning.
- Transport infrastructure.
- Modal choice and modal transfer (*e.g.* to public transport, carpooling, etc).
- Vehicle and transport system technologies.
- Pricing of fuels, vehicles and transport infrastructure use (road pricing, parking charges, etc.).

[1] Further information can be found in Annex D.

- Vehicle standards.
- Emission reduction targets.

To date, policy makers have largely focused on vehicle and fuel-based measures, as these are often simpler and less politically sensitive than measures which directly impact vehicle use, such as road pricing – even if the evidence suggests that pricing vehicle use may be very effective. In addition, measures which would require significant changes to existing urban infrastructure, including the location of schools, offices, factories, houses, etc., are often difficult to implement.

While LEVs are not a total solution to the problem of local pollutant and greenhouse emissions, the widespread adoption of LEVs – particularly very low-emission vehicles operating on fuels with a lower life cycle carbon content – would offer the capacity to deliver significant reductions in emissions from the transport sector, even in an environment of increased transport activity. A "clean" vehicle is easier to obtain than alternative approaches such as re-arranging land use so that houses are closer to work-places or increasing the density of urban development. While other measures are aimed at reducing vehicle use, some will obviously enhance the benefits of LEVs, which have been favoured as they can deliver improvements largely independently of other measures.

In addition, measures based on vehicle design have less impact on everyday life, compared, for example, to controls on vehicle use. So, from a political perspective, it is a good starting point to promote clean and low-emission vehicles. Active promotion of vehicles with good environmental performance may also increase public awareness of the impact of vehicles on urban air quality and the greenhouse effect.

Governments can play a variety of roles in facilitating increased market penetration of LEVs (Van Zuylen and Weber, 2001), including:

- A neutral "hands-off" approach, in which the market is left to direct the change.
- A monitoring role, where governments track changes in key air quality parameters and assess the environmental performance of the vehicle fleet.
- As an R&D agent, where the government itself undertakes research on relevant issues, or provides financial support to external bodies to undertake such research.
- As an innovation agent, where governments provide incentives to encourage innovation and the development of new technologies.
- As an implementer, where governmental bodies implement measures in their own domain.
- As a developer, where governments steer the developments of technologies.
- As a regulator, where governments set minimum standards which are designed to improve the environmental performance of new vehicles.
- As a leader in promoting the deployment of new technology, through fleet selection policies favouring vehicles with better environmental performance.

In addition, governments can play a key role in educating and informing the consumer as to the environmental performance of vehicles.

The choice between a regulatory or non-regulatory approach is often a key decision for governments, which can take the lead by indicating what their environmental expectations are in relation to the vehicle fleet, and by setting clear performance targets (Energy Foundation, 2002).

The consideration of further steps is best undertaken by transport, energy and environment administrations in close co-operation with key stakeholders in other government agencies, key industry sectors, vehicle user groups and the wider community. Governments can play an effective role in this process by facilitating interaction and discussion between the various interest groups. This process is a sometimes known as *constructive technology assessment*, a form of co-operation in which the details and value of a technology emerges in an interactive process. The European Auto-Oil programme is an example of such a process (EC, 2000).

One approach gaining some support is for governments to provide the conditions to allow the market to choose the best technology (UK Department of Transport, 2001; Besseling and Schlösser, 2001). Under this approach, the government role is to:

- Undertake technology assessment and rule making.
- Create conditions to give new technologies a chance, by removing legislative barriers that do not make sense in light of the new technology.
- Have a type approval system that can accommodate new technologies.
- Have a test method developed that is able to test environmental benefits and/or drawbacks.
- Support independent assessments of various technologies. It is imperative that tests be carried out in real-world situations in order to establish reliable information that consumers can use to make the best of the new technology.
- Develop appropriate standards to address any adverse environmental impacts of new technologies, including potential hazards of new fuels and vehicle technologies.
- Develop appropriate safety regulations before new technologies are put on the road (if accidents occur due to the lack of safety, it may set back new technology for years).
- Provide financial and other incentives to facilitate technology innovation and support vehicles with demonstrated improvements in environmental performance.

Promoting LEVs by means of incentives

The role of incentives

There is widespread recognition of the need for more appropriate frameworks for transport taxes and charges in order to promote greater efficiency, fairness and sustainability for the transport sector and for the economy as a whole. Many OECD governments have taken steps over recent years to improve the efficiency of transport charges and taxes, including, for example, differentiating charges in relation to emissions of local air pollutants and CO_2. Transport taxes and charges would be most effective if they were applied as closely as possible to the points of decision making by consumers on matters such as vehicle purchases and use.

In the absence of direct taxes and charging based on actual usage and actual vehicle emissions, governments have generally pursued an alternative approach based on a range of incentives and taxes that can be applied relatively easily in a political and administrative sense. Incentives for LEVs to date have been largely economic, targeted on alternative fuels and technologies (such as LPG or CNG fuel and electric vehicle technology) and designed to send an environmentally linked price signal to consumers. The logic behind this is that in many markets, price competition on the sale of vehicles and fuels is very intense, and thus any measure which impacts on the overall price can potentially influence consumer choice.

A range of measures have been taken which are not directly aimed at the vehicle as such, but rather serve to encourage the supply of low-emission vehicle technologies. These measures include incentives for cleaner fuels (usually low sulphur diesel and petrol) and support for alternative fuel production and infrastructure.

In addition to the economic instruments, some measures aimed at linking vehicle use/access and environmental performance are also being developed.

The key objectives of LEV incentives (direct or indirect) are to:

- Have an immediate and direct impact on consumer demand for LEVs.
- Accelerate the introduction of LEVs into the new vehicle fleet.

Well-directed incentives for LEVs can encourage manufacturers to supply a more appropriate range of LEVs to the market. In the case of countries with advanced emission standards, such incentives are likely to be targeted at vehicles that meet future tighter standards and new technologies such as hybrids. In countries where the minimum mandatory standards are less stringent, incentives are likely to encourage vehicle manufacturers to supply more advanced conventional technology vehicles to the market. Most manufacturers are now part of global companies with a product range which includes such LEVs.

LEV taxation incentives

The most common incentive used to date by countries to favour LEVs – however they are defined – is the setting of different rates of vehicle purchase or annual taxes/charges based on compliance with different levels of emissions performance or fuel/technology type.

There is limited information available to assess the impact of these taxation measures on the uptake of LEVs. In some cases, (*e.g.* United Kingdom) this is because the schemes are relatively new and it is too early to assess the impact on consumer purchasing behaviour. However, data from a number of European countries suggest that schemes to provide vehicle tax reduction for vehicles meeting future emission standards ahead of the mandated date have been very effective. For example, the ECMT (2000) reported that:

- In Germany, under the annual vehicle tax incentive scheme which commenced in mid-1997, the proportion of low (Euro 3) emission passenger cars in the fleet increased from less than 1% to 70% of new vehicle sales within one year, even though the Euro 3 standard was not mandatory until 2000.
- In Switzerland, earlier experience with tax incentives for vehicles fitted with catalytic converters led to an increase in the proportion of such cars in those cantons applying the incentives, compared to the national average.

- In the Netherlands, a policy of purchase tax incentives led to around 70% of heavy goods vehicles meeting the Euro 2 standards ahead of mandatory compliance, representing the highest proportion in Europe at that time.

The Swedish Environmental Protection Agency (SEPA, 1997) also reported that the introduction of a lower vehicle tax in 1993 based on emissions standards led to 75% of new vehicles in Sweden in 1996 meeting better than minimum standards.

In general, while the range of quantitative analysis of environment based vehicle charges is limited, qualitative assessment suggests that such incentives can be effective in accelerating the uptake of LEVs (ECMT, 2000) if:

- The vehicles are readily available. This is particularly important in smaller countries, or those with no significant vehicle manufacturing base, as the economies of scale dictate that manufacturers are not likely to respond to ambitious incentives based on advanced technology in such markets.
- The availability of the incentive is promoted and supported by information programmes (to the point where new vehicle retailers promote the vehicles on the basis of their reduced tax and environmental performance).
- Fuel prices do not fall to the point where reduced vehicle running costs encourage an increase in vehicle use.

Conversely, the impact is likely to be reduced if:

- There are consumer anxieties (perceived or real) regarding particular technologies or fuels.
- The fuelling infrastructure is not widely available to support the vehicle’s operation.
- The tax incentives are too low to induce a change in purchasing behaviour.

Some examples of incentives that have not delivered expected benefits include:

- Electric vehicles: despite considerable tax incentives and subsidies in many countries, the adoption of electric vehicles has been very low. It would appear that the financial incentives have been largely insufficient to offset the technological and functional limitations of electric vehicles.
- In Austria, an earlier policy to impose a tax increase on vehicles without catalytic converters, which was designed to increase the number of catalyst equipped vehicles in the fleet, only led to a 5-10% take-up by consumers. It was concluded that the policy was largely unsuccessful because of uncertainties at that time over the durability of catalyst-equipped vehicles, the limited availability of unleaded petrol and the low monetary incentive (ECMT, 2000).

Changes to fixed vehicle taxes, whether at time of purchase or as an annual tax, are reported to have relatively low implementation costs, few negative side effects and are likely to be quite effective, particularly if supported by information measures (ECMT, 2000). In setting the level of taxes, governments need to assess whether the aim is to partially or fully offset the additional production costs for a LEV (which may just lead to a later technology vehicle maintaining its price relativity with comparable vehicles meeting minimum standards), or whether greater incentives are introduced to give the vehicles a competitive advantage.

In assessing purchase vs. annual vehicle taxes, the ECMT report (ECMT, 2000) concludes that purchase taxes, particularly when they represent a significant proportion of the vehicle price, are likely to have a more significant impact on vehicle selection than the annual taxes. Conversely, a Japanese report (Kashima *et al.*, 1999) concluded that changes to taxation on the "possession" of vehicles (*i.e.* annual taxes) are more effective in reducing CO_2 emissions than changing purchase taxes The best approach may depend on the culture and prevailing circumstances in the country concerned.

Both purchase and annual tax incentives can be applied in a revenue-neutral manner (by offsetting revenue losses on LEVs with increases in taxes on higher emission vehicles). To maintain revenue neutrality, the criteria for setting the differential tax rates needs to be adjusted as the proportion of vehicles in the fleet qualifying for lower rates increases. Japan, for example, has taken a revenue-neutral approach in its "green" vehicle tax policy, whereby the revenue losses from vehicles meeting better than specified target standards for both fuel consumption and emissions are offset by increases in tax on vehicles over a specified age (13 years for petrol vehicles and 11 years for diesel vehicles). The ECMT (2000) reports that in the European context, revenue-neutral approaches were "well accepted"; however, it is not clear whether this would likely be the experience in all countries.

Incentives for LEV use

Many economic analyses suggest that broader strategies targetong vehicle use are likely to be effective market measures to reduce total emissions from the vehicle fleet in the longer term, particularly in relation to GHG emissions. Such measures, including fuel taxation, carbon taxes and road pricing are being implemented or considered in a number of countries. However, as LEVs are the focus of this report, only measures which are specifically aimed at supporting their use are considered in detail.

Low-emission zones

Low-emission zones (LEZs) are being introduced in a limited number of countries in an effort to avoid traffic congestion and reduce pollution in concentrated population areas (*e.g.* central business districts). LEVs are given unrestricted access to these zones, while other vehicles are either denied access, or have restricted accessonly. Thus these zones indirectly serve as an encouragement to purchase eligible LEVs. To date, the focus of LEZs has been on commercial vehicle access, with no restrictions on private vehicle use.

Access to high-occupancy vehicle lanes

In a number of US states, vehicles meeting a combination of stringent Californian and national emission standards are granted access to high-occupancy vehicle lanes even if the vehicle has no passengers (normally at least two persons must be inside the vehicle). Currently this access is only available to zero-emission (electric) vehicles, some CNG and LPG-fuelled vehicles and fleet-owned vehicles with exhaust standards certified to the Federal ILEV (inherently low-emission vehicles) category. Exhaust standards for ILEVs are equivalent to those for ULEVs and SULEVs[2] with additional evaporative emission controls (ARB, 2001). These very strict criteria have led to some criticism as being unnecessarily limiting and not supportive of other LEVs, including petrol/electric hybrids

[2] ULEV and SULEV are Californian standards where U = ultra and SU = super ultra.

(Brauer, 2001). In areas of high traffic congestion, access to such lanes could clearly be used as an incentive for the purchase of LEVs.

Access on high pollution days

In some cities, access restrictions to central parts of the city are placed on conventional vehicles in periods of high air pollution. In Italy, for example, when pollution levels in Rome and other large cities reach a specified level, cars are granted restricted access on an odd/even number plate basis, and if the air pollution reaches an even higher level, only public transport vehicles may enter. Under such conditions, vehicles classified as having a "minimal environmental impact" can continue to travel in restricted zones.

Parking concessions

In a number of US states and some European and Japanese cities, zero or owemission vehicles have access to free/discounted parking in areas where parking fees are charged for conventional vehicles. To date, all zero-emission vehicles are electric, and thus free recharging facilities are also often provided at some parking places.

Clean fuel incentives

Although not aimed directly at LEVs, incentives for cleaner fuels can facilitate the development of LEVs by removing barriers to the adoption of vehicle technologies which may be adversely affected by particular fuel parameters. In conventional fuels, the key fuel parameter in this context is sulphur, which can severely limit the adoption of a range of emission control technologies necessary to meet advanced emission standards, and which may assist in reducing fuel consumption. These technologies include catalysts, particle traps, direct injection systems and on-board diagnostics.

Many countries have incentives for cleaner conventional fuels and a number of alternative fuels. The earliest experience with this in Europe was the introduction of incentives for the supply of unleaded petrol (ULP) which led to its rapid adoption in many countries. More recently, the major focus has been on financial incentives for the production of ultra-low sulphur (50 ppm) diesel and "sulphur-free" (<10 ppm) diesel. Recent research by the European Commission (EC, 2001) has concluded that a move to 10 ppm sulphur petrol and diesel would be cost-effective, and a decision has been made to mandate these fuels from 2009. Some EU member states are likely to offer incentives for early supply of 10 ppm fuels (ahead of the mandatory date).

Evidence from the United Kingdom, Germany and Sweden indicates that reducing the taxation levels on cleaner diesel fuels can lead to a very rapid shift in production from high to low sulphur fuels. For example, in the United Kingdom, the excise incentive for ultra-low sulphur diesel (introduced via an increase in excise on diesel with >50 ppm sulphur) led to the market share of ULSD rising from under 20% in November 1998 to effectively 100% by August 1999 (HM Treasury, 2000).

The potential for rapid adoption of cleaner fuels with more favourable tax treatment means that governments need to carefully consider the structuring of such support to ensure that potential revenue losses from the increased market share of the clean fuel are addressed. The United Kingdom and Germany addressed this issue by increasing the excise on high sulphur fuels, rather than lowering the excise on low sulphur fuel.

A recent report (ECMT, 2001) indicates that the case for incentives for ULSD has been well established, and incentives introduced in a number of countries have been very effective in accelerating ULSD’s market share. The evidence indicates that incentives are most effective in accelerating uptake of lower sulphur fuels where the excise reductions are reflected in lower pump prices. The size and timing of the incentive are also critical, and need to be determined in light of each country’s particular circumstances. The report argues that the cost-effectiveness of incentives for sulphur-free fuels is yet to be determined, but nevertheless governments should look to encourage sulphur-free fuels as they would assist petrol-engined vehicles in maximising fuel efficiency while still meeting the Euro 4 emission standards, and assist diesel vehicles in meeting the particle limits in Euro 4 and the NO_x limits in Euro 5.

Infrastructure incentives

A number of countries consider that there is merit in supporting vehicles fuelled by alternative fuels such as liquefied petroleum gas (LPG) and natural gas (NG), because of benefits in reduced emissions such as particulates. Wider adoption of alternative-fuelled vehicles, particularly gaseous fuels, is often constrained by the limited refuelling infrastructure. Many governments therefore support the development of such infrastructure through subsidies and other measures.

For current technology vehicles, the principal infrastructure limitations apply to NG. In many countries, LPG is widely available and facilities have been largely funded by commercial interests. NG fuelling infrastructure tends to be very expensive and in some countries the reticulated gas network to supply such stations is also limited – sometimes only available in larger cities. Thus in many countries to date, NG fuelling infrastructure is limited to major depots where public transport or commercial fleets can refuel. To encourage wider use of NG as a transport fuel, many countries provide subsidies or other financial incentives for NG fuelling infrastructure. These countries include Argentina, Australia, Germany, Iran, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Pakistan, Switzerland, the United Kingdom, the United States and Venezuela.

Fuelling infrastructure will also play an important role in emerging technologies such as fuel cells, if they are fuelled by hydrogen. The decision to design vehicles for on-board hydrogen storage (which necessitates the installation of supply infrastructure) or to use technology to produce hydrogen on board the vehicle by reforming of liquid fuels will be significantly affected by the cost and feasibility of new hydrogen supply infrastructure.

Conclusions on the role of incentives

One reason for market intervention through incentives for low-emission vehicles is that in most countries, the market currently functions imperfectly and there are no explicit charges for actual usage - and therefore the real pollution of vehicles during use. Without government incentives, vehicle purchase decisions will continue to be made in ways that do not take full account of the longer-term social and environmental impacts.

Also, in the absence of any policy intervention by governments, the available evidence suggests that the potential environmental benefits of new vehicle technologies – in both conventional and new forms – are unlikely to be fully realised. With particular regard to GHG emissions, the trend in many countries towards higher power and larger vehicles is offsetting the benefits of increased engine efficiency. Regulation of local pollutant emissions via mandatory maximum emission standards has been an effective tool in delivering reductions in air pollutant emissions from motor vehicles and therefore in achieving air quality benefits. The impact of the standards can be enhanced by bringing forward compliance through market-based measures.

An effective set of incentives, together with a well-informed consumer, offer considerable potential to accelerate the uptake of LEVs in the new vehicle fleet. While the particular incentives need to be tailored to each country's specific circumstances, the available data suggest that differentiated vehicle and fuel taxes, based on environmental performance, can be cost-effective in increasing the proportion of LEVs on the market. Governments can also play a leadership role by adopting purchasing policies favouring LEVs.

Promoting LEVs: the role of public information

Introduction

The previous section explored a range of incentives being adopted around the world to encourage and accelerate the adoption of conventional, alternative fuel and new technology LEVs on the vehicle market. As highlighted earlier, the effectiveness of any incentive promoting low-emission vehicles is, in part, reliant on public awareness of the specific incentive and, more generally, the environmental rationale for the incentive.

There are currently two principal methods used to deliver information to consumers on the emissions and fuel consumption performance of motor vehicles:

- Vehicle labelling.
- Information guides.

The overall aim of both is to improve consumer choices and ultimately improve the environmental performance of the vehicle fleet. Information programmes aim to achieve this by:

- *Raising consumer awareness* of the impacts of vehicle on the environment and hopefully influencing their purchase decision in favour of a model with better environmental performance. When purchasing a new vehicle, consumers – whether individuals, government or business – take into consideration a number of factors including price, performance, safety, reliability and resale value. The priority currently placed on emissions and fuel consumption varies from country to country, but is usually lower on the list of priorities than these other factors.
- *Increasing market demand* for low-emission, low fuel-consumption models, thus encouraging manufacturers to place greater emphasis on environmental performance in the design of vehicles. Model-specific information on environmental aspects provides a means of product differentiation around which manufacturers can compete. In the absence of this information, the vehicle industry rarely tries to compete on the basis of environmental performance.
- *Providing support* for related LEV policies. Information programmes can provide important support for other measures that governments might consider in promoting LEVs, such as economic/taxation incentives and fleet purchasing policies. If measures are to be taken to encourage manufacturers to supply vehicles with better environmental performance ahead of mandatory standards, identifying those vehicles to consumers (individual, government or corporate) is critical to the success of such measures.

Labels

A number of reports (BTE, 1996; Raimund, 1999; Boardman *et al.*, 2000) suggest that labelling can be effective in influencing consumers to purchase more fuel-efficient vehicles. The research suggests that labels are most effective when:

- They are not overloaded with information.
- The information on the label is presented in a form that is simple and readily understood by the consumer.
- Their format is similar to energy labelling schemes used for other goods (where applicable).
- They provide model-specific information relative to the performance of other models of a similar class, rather than across the whole fleet.
- They do not operate in isolation – that is, they are part of a broader information and incentives strategy.

A recent Australian report (BTRE, 2002b) noted that there is very little data available to assess the impact of labelling on consumer behaviour, and ultimately CO_2 emission reductions. The report did note, however, that while labelling may not deliver significant emissions reductions, it was a very low cost measure. UK research (Boardman *et al*, 2000) concluded that fuel consumption labelling could reduce CO_2 emissions from the car fleet by around 2.7%, while Raimund (1999) estimates a reduction of 4-5% from the label alone.

There is some debate about the reliability of the CO_2 value reported on labels, as CO_2 results derived from standard vehicle certification tests may not be reflective of "real world" driving. Some labels, such as the US label, attempt to address this by including a corrected value as well as the standard test value. Nevertheless, the principal purpose of labelling is to provide a comparative assessment on the basis of a standard test, and thus even if the reported value may under-represent fuel consumption for an "average" driver, it is still of value in informing consumers about the relative performance of particular models. Most labels also have a "disclaimer" to warn consumers that actual fuel consumption will depend on how the vehicle is driven, the load it is carrying, road and traffic conditions, etc.

Guides

While labels can play an important role in informing consumers of the environmental performance of vehicles, they are unlikely to be effective in isolation. In particular, it is likely that many consumers decide on the particular model they intend to purchase prior to arriving in a vehicle showroom, and unless information is provided earlier, a label – by itself – is unlikely to change the purchasing decision.

Consequently, greater emphasis is now being placed on providing information to consumers on the environmental performance of vehicles earlier in their decision-making process.

Guides on the environmental performance of vehicles are a growing means of delivering this information. Most guides cover at least fuel consumption and noxious emissions, with others also covering CO_2 emissions, vehicle noise, life cycle assessments and operating costs. These guides are largely Internet-based, with some countries also providing “hard copy” versions. The guides are provided by both government and non-government organisations

Scope of guides

Guides have the potential to provide a much larger range of information than a label, but nevertheless, like labels, an effective guide should not overload the consumer with information and should present it in a form which is simple and readily understood by a lay reader. Additionally, if the guide is Internet-based, it should be designed to ensure that the information can be obtained quickly with a minimum of steps (mouse clicks).

There are a number of variables that could be considered in evaluating the environmental performance of vehicles. These include:

- Emissions of regulated pollutant gases and particulates (noxious emissions).
- CO_2 emissions.
- Emissions of other greenhouse gases.
- Fuel consumption.
- Emissions during manufacturing and recycling of vehicles and fuel.
- Noise.

As the principal environmental impacts of motor vehicles are their contributions to urban air pollution and GHG emissions, measures of these impacts are the minimum that should be presented in any guide.

The benefits of including other measures of environmental performance such as vehicle noise and life cycle assessments are less clear, and there is considerable debate on how to assess the latter. The guide published by American Council for an Energy Efficient Economy[3] (ACEEE) is one of the few guides to attempt to address life cycle impacts, and in the absence of more detailed data, it uses vehicle mass as a surrogate for manufacturing impacts.

A number of guides also provide information on the annual cost of operating a particular vehicle model. In most cases this is simply based on average annual fuel consumption figures and an assumed fuel price. In the case of the ACEEE guide, there is also an annual cost assigned based on estimated human health impacts.

Ranking vehicles on environmental performance

Ranking motor vehicles according to environmental performance is helpful to consumers and an important prerequisite for encouraging shifts in purchasing patterns. Any policy that promotes LEVs depends on the ability to identify them to the consumer. Ranking a vehicle’s environmental performance can be done in two main ways:

- *Overall:* comparing a vehicle against all other vehicles, regardless of size or type.
- *Within class:* comparing vehicles within a defined class.

[3] See *http://www.greenercars.com/indexplus.html*

An overall fleet ranking has the advantage of providing a "true" measure of a vehicle's performance relative to the whole fleet. However, it does not take into account consumer tendencies to make selections from within particular classes. UK research (Boardman *et al*, 2000) has shown that when consumers begin to define what they need from a new vehicle, most set about on a period of research which seems to be divided into two distinct phases:

- Decision on a class or classes of vehicle.
- Screening choices within the class.

The biggest challenge for environmental rating schemes is to address the widely held assumption that motor vehicles of a similar size have similar environmental impact (Boardman *et al*, 2000). The IEA, for example, concludes that consumers are often unaware of the significant variability in fuel consumption within vehicle classes (see Table 5.1). Overall fleet comparisons have a limited ability to highlight differences between vehicles in the same class.

Table 5.1. Best and worst European fuel consumption by market class (model year 2000)

Vehicle class	Percent difference between best and worst in class	
	Worst vs. best diesel vehicle	Worst vs. best petrol vehicle
Compact	122%	59%
Mid-size	133%	63%
Large	106%	54%

Source: IEA (2001).

The delivery medium

Guides can be "delivered" to the consumer in paper form or on the Internet. The important consideration is that consumers need access to the guide before going to the showroom, as otherwise the information is less likely to influence their purchase decisions. This objective tends to favour the use of the Internet, as it is difficult and more costly to identify and distribute paper guides to prospective consumers prior to their arrival in a showroom. The Internet also offers the advantages of ready updates and lower maintenance costs. Regardless of the delivery mechanism, ongoing and regular information updates are essential to ensure the guide's relevance and value to the consumer.

In further support of the Internet approach, analyses of Internet statistics (NUA, 2001) indicate that consumers are increasingly going online to research their next car purchases and that the traffic to European car Web sites more than doubled between April 2000 and March 2001. In the United States, 45% of consumers who intend to buy a car carry out research on the Internet. The automotive category is now the fourth most popular on-line shopping category and one-quarter of all visitors to automotive Web sites are looking to buy a new car. In the United Kingdom, it is estimated that almost 500 000 car purchasing decisions will be made on-line by 2004, representing 20% of the national new car market.

Conclusions on information strategies

A number of reports have pointed to the importance that information plays in supporting strategies to encourage consumers to purchase LEVs and thereby increase their proportion in vehicle fleets. There are considerable variations in emissions and fuel consumption - even in conventional vehicles and within vehicle types - but if consumers are unaware of such differences, they are unable to factor environmental performance into their vehicle purchasing decisions.

Internet-based guides, supported by vehicle labelling, appear to be the most cost-effective means to deliver this information to consumers. To be effective, both guides and labels need to present information accurately and in a form which is readily understandable to consumers.

Need for a comprehensive, integrated approach

This chapter has outlined a range of possible strategies and implementation issues that need to be addressed in promoting conventional, alternative fuel and new technology low-emission vehicles.

One of the important conclusions of the report is that government and industry have relied heavily on development of engines and technology in conventional motor vehicles to reduce the emissions of local pollutants in new vehicles. Substantial progress has been made by manufacturers in meeting more stringent standards and targets that have been set, on a per-vehicle basis. Currently, conventional vehicles with the latest engine and exhaust after-treatment technology are “near clean” in terms of the regulated local pollutants.

However, one of the most important issues raised in this report is that reliance on technological developments alone may not be able to resolve the rapid increases in GHG emissions that have been forecast for the next 10 to 20 years. While manufacturers include vehicles with lower mass and engine power in their product, market trends as reflected by consumer purchases are clearly in the direction of larger more powerful vehicles. In the absence of appropriate pricing signals and explicit taxes on GHG emissions, these trends seem likely to continue.

For this reason, consideration must be given to comprehensive approaches that involve all key stakeholders including consumers and a range of policy measures. Integrated policy approaches will be needed in order to have a significant impact on current and anticipated trends and patterns of motor vehicle purchases and use. In addition to policies aimed at improving the technical fuel efficiency of conventional vehicles, policies and other actions should promote other changes which could have a significant impact. Government policies should include a focus on appropriate taxes and charges; they might also include measures aimed at controlling congestion and improving traffic conditions to minimise vehicle emissions, and possibly modifying behaviour in favour of more environmentally and socially sustainable approaches. Consumers should be encouraged to apply their heightened environmental awareness to their decisions on vehicle purchase and use.

In its *World Energy Outlook 2002*, the IEA analysed the likely impact of a combination of policies involving improved fuel efficiency, increased use of alternative fuels and vehicles, and reducing travel demand growth and switching to less energy-intensive modes. The IEA concluded that total OECD oil demand would be half a million barrels a day less in 2010 than in their “Reference Scenario”. This could rise to 3.6 million barrels a day less by 2030, which would represent 6.2% of the total primary oil demand in the three regions in the Reference Scenario in 2030.

While this would be a significant change, the possible reduction needs to be seen in the context of the increases anticipated in the Reference Scenario. As outlined in Chapter 3, without the policy changes being tested, the IEA expects that oil consumption in transportation in OECD countries will increase from 1185 million of tonnes in 2000 to 1 773 million tonnes in 2030 – an increase of close to 50%. Over the same period, the IEA expects the world oil consumption in transportation to increase from 1 696 million tonnes to 3 195 – an increase of 88%.

The IEA analysis underlines how difficult it will be to achieve the policy objectives that have been adopted, *i.e.* containing the GHG increases that are currently expected and eventually reducing the levels of GHG emissions. It reinforces the fact that consideration must be given to all measures which are likely to be cost-effective and publicly supported. It also reinforces the need for comprehensive transport approaches integrated across transport modes and sectors of the economy.

Nevertheless, the vehicle-based measures outlined – which aim to achieve significant reductions in emissions on a per-vehicle basis – remain one of the most reliable approaches and can continue to make an important contribution to achieving overall policy objectives.

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TECHNICAL ANNEXES

Annex A

STATUS REPORT ON INTERNATIONAL REGULATION OF VEHICLE EMISSIONS, GREENHOUSE AND ADVANCED TECHNOLOGY VEHICLES

Vehicle emission legislation

UN/ECE

Background

On 20 March 1958, an agreement was signed by several European countries under the auspices of the United Nations Economic Commission for Europe (UN/ECE). This Agreement (known as the 1958 Agreement) introduced type approval and reciprocal recognition of approval for motor vehicle equipment and parts for countries applying regulations annexed to the Agreement. Currently some 47 countries, as well as the European Union itself, are Contracting Parties to this Agreement. Accession to the Agreement is open to all member states of the United Nations.

All the technical work to develop the ECE Regulations is undertaken by the World Forum for Harmonization of Vehicle Regulations (known as Working Party WP29) and its Groups of Experts. The development of these regulations meets a continuing need to improve road safety and to reduce the damage to the environment at a time of continuing growth of motor vehicle traffic. To date, some 113 regulations have been adopted and subsequently amended or supplemented in response to the concerns of society and to the changing technology.

The list of existing Regulations, including those addressing vehicle emissions can be found at *http://www.unece.org/trans/main/wp29/wp29regs.html*.

Current situation

The UN/ECE’s role in vehicle standards regulation is to produce model standards which may be adopted by member nations, but it has no power to enforce compliance. Nevertheless, there is a commitment to harmonise the ECE Regulations with the vehicle standards set by the European Union (EU) and among Contracting Parties to the UN/ECE 1958 Agreement. In the EU this activity gives rise to Directives which are binding to EU member states. In the UN/ECE the resulting Regulations are available for implementation by the Contracting Parties if they so wish. Other countries such as the United States, Japan, Canada and Australia, China and South Africa also take part in the activities of WP29 UN/ECE and to a varying extent UN/ECE Regulations are adopted in these and other markets.

The Working Party transmits, for consideration and preparation, the different proposals for draft Regulations and amendments to existing Regulations to its Meetings of Experts. The group of experts responsible for emissions regulations and greenhouse related measures is the *Meeting of Experts on Pollution and Energy (SC1/WP29/GRPE*).

In relation to air pollutant emissions, the UN/ECE Regulations set limits on emissions from all road vehicles, including cars, trucks, buses and motorcycles. The regulations cover vehicles operating on all the mainstream fuels (petrol, diesel, LPG and NG). While the regulations do not set limits on greenhouse emissions, they do provide a standard set of test procedures for determining both fuel consumption and CO_2 emissions from vehicles.

A range of activities are underway in the GRPE to improve the emissions performance of vehicles, including:

- The reduction of emission limits under existing ECE Regulations, including:
  - Reduction of the limit values contained in the ECE Regulation N° 83 for light vehicles.
  - Drawing up new driving cycles and emission limit values, especially for goods vehicles, buses and motorcycles (ECE Regulations N° 49 and N° 40).
- Progressing methodological issues with the measurement of fine particulates in vehicle exhaust, including:
  - Method of determination of fine particulates.
  - Evaluation and testing of equipment.
  - Assessment of numerical quantity measurement techniques in lieu of mass measurement.
  - Limit value of particulates in the exhaust.
- Determination of the requirements for the type approval test of low-emission vehicles related to new technologies, specifically:
  - Hybrid vehicles.
  - Vehicles with fuel cells using hydrogen.

European Union

Background

Emissions regulations in Europe were formulated in the 1970s and early 1980s primarily by the UN/ECE process outlined above. In its early years, the European Union generally adopted regulations which were technically identical with the ECE equivalents. This position has changed over time, with the European Community, now the European Union, gradually assuming a major role in formulating automotive emissions standards. UN/ECE is now unlikely to adopt any proposal which has not been agreed within the EU.

European Union regulations, published as Directives, have the force of law within EU member states under the provisions of the Treaty of Rome. EU countries may not prohibit the marketing of vehicles which comply with the provisions of the Directives, but may prohibit vehicles which do not comply. With the introduction of the “Consolidated Emissions Directive” in June 1991, implementation became mandatory for the 15 EU member states and was no longer left to the discretion of individual national governments.

Of these EU members, Austria, Denmark, Finland and Sweden were signatories to the “Stockholm Agreement” of July 1985 in which these countries, together with Canada, Norway and Switzerland, agreed to adopt 1983 US standards. These countries also adopted heavy duty limits based on UN/ECE regulations. Having joined the EU in 1994, Austria, Finland and Sweden were allowed a four-year transition period to harmonise legislation, ending on 1 January 1999. Austria and Finland, together with Norway and Switzerland, have adopted most of the EU Directives. Sweden retained US limits based on federal test procedures. The Czech Republic, Hungary and Poland have adopted EU environmental regulations. Other countries are in the process of adopting these environmental regulations.

- ECE publications and regulations can be found at *http://www.unog.ch.*
- EC publications and regulations can be found at *http://www.europa.eu.int*.

Current status

The base directive governing emissions from light vehicles is 70/220/EEC. The amending directive 98/69/EC (which is technically equivalent to ECE R83/05) set the new emission limits for 2000 and 2005 (known as the Euro 3 and Euro 4 standards). Emission limit values are presented in Table A.1.

Table A.1. Mandatory exhaust emission limits in the European Union

			Reference mass (RW) (kg)	Limit values								
				Mass of carbon monoxide (CO)		Mass of hydrocarbons (HC)		Mass of oxides of nitrogen (NOx)		Combined mass of hydrocarbons and oxides of nitrogen (NOx)		Mass of parti-culates(1) (PM)
				L1 (g/km)		L2 (g/km)		L3 (g/km)		L2+L3 (g/km)		L4 (g/km)
Category		Class		Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Diesel
A (2000) Euro 3	M(2)		All	2.3	0.64	0.20	-	0.15	0.50	-	0.56	0.05
	N_1(3)	I	RW ≤ 1305	2.3	0.64	0.20	-	0.15	0.50	-	0.56	0.05
		II	1305 < RW ≤ 1760	4.17	0.80	0.25	-	0.18	0.65	-	0.72	0.07
		III	1760 < RW	5.22	0.95	0.29	-	0.21	0.78	-	0.86	0.10
B (2005) Euro 4	M(2)		All	1.0	0.50	0.10	-	0.08	0.25	-	0.30	0.025
	N_1(3)	I	RW ≤ 1305	1.0	0.50	0.10	-	0.08	0.25	-	0.30	0.025
		II	1305 < RW ≤ 1760	1.81	0.63	0.13	-	0.10	0.33	-	0.39	0.04
		III	1760 < RW	2.27	0.74	0.16	-	0.11	0.39	-	0.46	0.06

(1) For compression ignition engines. (2) Except vehicles of which the maximum mass exceeds 2 500 kg. (3) And those category M vehicles which are specified in note 2.

Directive 98/69/EC also introduced a number of other changes in addition to the revised emission limits which effectively increased the stringency of the standards even further. These changes are outlined in Table A.2.

Table A.2. Additional technical requirements of directive 98/69/EC

Test cycle for tailpipe emissions	Emissions measured over a revised test cycle, *i.e.* the previous (Euro 2) dynamometer test cycle minus the first 40 seconds of engine idle where there was no emissions sampling.
Revised weight classifications for light commercial vehicles	Class I RW ≤ 1,305 kg Class II 1,305 < RW ≤ 1,760 kg Class III 1,760 kg < RW
Cold start test	New test at cold temperature (-7°C) with limits of 15 g/km for CO and 1.8 g/km for HC. Measured over the urban part of the test cycle only. Cold test to be introduced for new type approvals from 1 January 2002.
Evaporative emissions	New procedure with higher and longer temperature excursions to better represent the vehicle heating cycle over a diurnal period. Evaporative limit remains at 2 g/test.
Durability	Remains at 80 000 km or five years (whichever is sooner) for stage 2000 (Euro 3) but increases to 100 000 km or five years (whichever is sooner) for stage 2005 (Euro 4).
OBD (On-Board-Diagnostics)[1]	The Commission shall report on application dates of OBD requirements and make appropriate proposals on extending the scope of OBD to other vehicle systems (covering active and passive safety) and regarding the replacement and retro-fit parts market.
In-use compliance	The emphasis of the revised test is now on the manufacturer to carry out periodic audits of vehicles in service. The authority can check the audit and require confirmatory testing if necessary. The scope of the audit, the checking of the audit and the statistical procedure for testing vehicles have been examined and the Commission is in the process of making a proposal through technical adaptation.
Extension of approvals to vehicles of category M_2 and N_2	Commission to study and put forward proposals no later than 2004 and to apply in 2005.
Reference fuels	The Commission has to make a proposal to set the specifications for sulphur, aromatics and oxygen content of petrol and sulphur content of diesel such that they represent the market average of these specifications – this will be applicable for the testing of vehicles by the 2005 (*Euro 4*) emission limits.

[1] On-Board Diagnosis is a computer control system that allows an automatic diagnosis of the pollutants emitted by the vehicle. First requirements for OBD were introduced in 2000 and they are now progressively installed on all new vehicles.

Recently, other directives have been adopted, including:

- Directive 1999/102/EC – Application dates and technical adaptation in relation to the OBD requirements.
- Directive 2001/1/EC – Dates of application of OBD to vehicles using gaseous fuels (LPG or NG).
- Directive 2001/000/EC Cold start emission limits for category N1 vehicles.
- Directive 2002/80/EC concerning the replacement of catalytic converters.

EU fuel quality standards

In the European Union, fuel quality is governed by the Directive 2003/17/EC (which modifies the former 98/70EC Directive), which specify the environmental properties of petrol and diesel fuels.

Key fuel parameter limits for commercial petrol and diesel in Europe are specified in Table A.3 below.

Table A.3. Key fuel parameter limits for commercial petrol and diesel in Europe

1 January 2000 mandatory petrol quality	Max. 150 ppm sulphur, 1% benzene, 42% aromatics
1 January 2000 mandatory diesel quality	Max. 350 ppm sulphur
1 January 2005 mandatory petrol quality	Max. 50 ppm sulphur, 35% aromatics
1 January 2005 mandatory diesel quality	Max. 50 ppm sulphur content
1 January 2009 mandatory petrol quality	Max. 10ppm sulphur content
1 January 2009 mandatory diesel quality	Max. 10ppm sulphur content

ppm = parts per million.

Vehicle emissions legislation in the United States[2]

History of reducing tailpipe emissions

1970-1975: The first standards

In 1970, Congress passed the Clean Air Act, which called for the first tailpipe emissions standards. The pollutants controlled were carbon monoxide (CO), volatile organic compounds (VOC), and oxides of nitrogen (NO_x). The new standards went into effect in 1975 with a NO_x standard for cars and light-duty trucks of 3.1 grams per mile (gpm).

1977-1988: Tightening atandards for the first time

In 1977, Congress amended the Clean Air Act and tightened emission standards again in two steps. First, between 1977 and 1979, the NO_x standard became 2.0 gpm for cars. Then in 1981, the NO_x standard for cars was reduced to 1.0 gpm. Effective in 1979, pursuant to the Clean Air Act requirements, EPA tightened standards for light-duty trucks to 2.3 gpm. Effective in 1988, EPA then set the first tailpipe standards for heavier trucks at 1.7 gpm and revised the standard for lighter trucks to 1.2 gpm.

[2] Units are given as in the US legislation.

1990-1994: Tier 1

In 1990, Congress again amended the Clean Air Act, further tightening emission standards. The NOx standard was set at 0.6 gpm for cars, effective in 1994. The new standard called “Tier 1” was a 40% reduction from the 1981 standard. For trucks, the new standard ranged from 0.6 to 1.53 gpm, depending on the weight of the vehicle.

The Clean Air Act Amendments of 1990 also require EPA to assess the air quality need, cost effectiveness, and feasibility of tighter emission standards for the 2004 model year and beyond.

1998: Voluntary agreement for cleaner cars

In 1998, the Federal Administration, the auto industry and the northeastern states struck a voluntary agreement to put cleaner cars on the road before they could be mandated under the Clean Air Act. The new cars are called national low-emission Vehicles (NLEV). NLEV cars operate with a NO_x standard of 0.3 gpm, a 50% reduction from Tier 1 standards. The NLEV agreement also calls for a 0.5 gpm NO_x standard for lighter trucks only, a 17 percent reduction from Tier 1 requirements for these vehicles. In 1998, as required by the Clean Air Act Amendments of 1990, EPA issued the Tier 2 Report to Congress. The report contains strong evidence of the need, cost-effectiveness and feasibility for tighter tailpipe emission standards in the future beginning in 2004. In 1998, EPA also determined that sulphur reductions in petrol were needed to enable the full performance of low emission-control devices.

1999: Development of Tier 2 for implementation in 2004

In 1999, EPA proposed Tier 2 tailpipe emissions standards beginning in 2004 the first time both cars and light-duty trucks are subject to the same national pollution control system. The new standard is 0.07 gpm for NOx, a 77-86% reduction for cars and a 92-95% reduction for trucks beyond the NLEV agreement. EPA also proposes a reduction in average sulphur levels to 30 parts per million (ppm) (maximum of 80 ppm) to achieve the full performance of vehicle emission control technologies.

As part of these new standards, EPA has included several measures to ensure maximum flexibility and cost-effectiveness. These flexibilities include:

- Allowing averaging to meet both the car emission and gasoline sulphur standards.
- Allowing extra time for larger vehicles between 6 000 and 8 500 pounds and smaller refiners to meet their respective standards.
- Allowing for a market-based credit trading-and-banking system for both industries to reward those who lead the way in reducing pollution.

The US NO_x Standards are summarised in Table A.4.

Table A.4. US NO_x emission standards

Cars

Year	1975	1977	1981	1994	1999	2004-09
NO_x standard (gpm)	3.1	2.0	1.0	0.6	0.3	0.07
NO_x reduced (from previous standard)		35%	50%	40%	50%	77%

Smaller SUVs, minivans, and light trucks (under 6 000 pounds)

Year	1975	1979	1988	1994	1999	2004-09
NO_x standard (gpm)	3.1	2.3	1.2	0.6	0.5	0.07
NO_x reduced (from previous standard)		26%	48%	50%	17%	86%

Larger SUVs, vans, and heavier trucks (between 6 000 and 8 500 pounds)

Year	1988	1994	2004-07	2008-09
NO_x standard (gpm)	1.7	1.53	0.2	0.07
NO_x reduced (from previous standard)		10%	87%	65% or 95% from 1994 standard

- Additional documents on emission standards for cars and light trucks are available from the EPA Internet server at *http://www.epa.gov/otaq/ld-hwy.htm.*
- Information on the Tier 2 standards is available on the Tier 2 home page at: *http://www.epa.gov/otaq/tr2home.htm.*

2000: Adoption of the 2007 standards for heavy-duty vehicles

In 2000, the United States adopted emission standards for new model year 2007 heavy-duty diesel engines and the fuel sulphur rule. The adopted emission standards are 0.01 g/bhp-hr[3] for particulate matter (PM), 0.20 g/bhp-hr for nitrogen oxides (NO_x), and 0.14 g/bhp-hr for nonmethane hydrocarbons (NMHC). The PM standard will take full effect in 2007, while the NO_x and NMHC standards will be phased in for diesel engines between 2007 and 2010. Compared with today's standards, the new rule represents a 95% reduction in the NO_x level (currently at 4 g/bhp-hr; an intermediate standard of 2.4 g/bhp-hr of combined NO_x+NMHC takes affect in 2004) and an 80-90% reduction in PM emission (currently at 0.1 for truck engines and 0.05 g/bhp-hr for urban buses).

- More information can be found at *http://www.epa.gov/otaq/hd-hwy.htm.*

California Air Resources Board

The state of California has always been a world leader in emission control legislation and has generally adopted limits more severe than the federal (Clean Air Act) limits which apply in the rest of the United States. California has thus introduced more stringent standards for light duty vehicles and trucks, with the progressive introduction of low, ultra-low and zero-emissions Vehicles, although the introduction of the latter has been delayed. There are also proposals for hybrid electric vehicles with suitably low emissions to be classified as equivalent zero-emissions vehicles (EZEVs). The California Air Re-

[3] g/bhp-hr : gram per brake horsepower per hour. 1bhp-hr = 0.75 kW-hr.

source Board (CARB) has developed an extension of its LEV programme to apply to heavy-duty vehicles.

- More information on the Californian emission legislation and standards can be found at *http://www.arb.ca.gov/.*

Vehicle emissions legislation in Japan

Japan announced revised emissions standards in 1989, which were progressively introduced from 1991 to 1998. The authorities also imposed age limits on vehicles registered within metropolitan areas. There are plans to apply new more stringent limits on diesel vehicles of less than 12 tonnes together with a new durability test. Regarding new emissions controls, the Central Environment Council issued a report entitled “Future Policy for Motor Vehicle Exhaust Emissions Reduction (Fifth Report)”on 16 April 2002.

The Japanese 10-15 driving cycle is used for these vehicles to determine the hot start exhaust emissions and fuel economy. The Japanese 11-mode test procedure is used to evaluate cold start gaseous emissions.

For commercial vehicles, a long-term regulation is already in force and the new short-term long-term regulations have been prepared. Pollutant emissions for these vehicles are measured using the Japanese 13-mode test procedure, which consists of steady-state modes.

The Japanese emission regulation values for diesel, petrol and LPG vehicles can be found at and *http://www.env.go.jp/policy/hakusyo/img/215/tb2.1.2.10.gif* (in Japanese only) and *http://www.env.go.jp/*.

An overview is given in Table A.5. New standards were introduced in 2003 for trucks, buses and special diesel vehicles but are not shown in this table.

Table A.5. Japanese motor vehicle exhaust emission standards

Category			Test mode	Components	Current regulation		
					Enforcement year	Standard value	
Petrol/LPG motor vehicles	Passenger cars	4-cycle and 2-cycle	10.15M (g/km)	CO	2000	1,27	(0,67)
				HC	2000	0,17	(0,08)
				NOx	2000	0,17	(0,08)
			11M (g/test)	CO	2000	31,1	(19,0)
				HC	2000	4,42	(2,20)
				NOx	2000	2,50	(1,40)
	Trucks and buses	4-cycle mini-size motor vehicles	10･15M (g/km)	CO	2002	5,11	(3,30)
				HC	2002	0,25	(0,13)
				NOx	2002	0,25	(0,13)
			11M (g/test)	CO	2002	58,9	(38,0)
				HC	2002	6,40	(3,50)
				NOx	2002	3,63	(2,20)
		2-cycle mini-size motor vehicles	10･15M (g/km)	CO	1975	17,0	(13,0)
				HC	1975	15,0	(12,0)
				NOx	1975	0,50	(0,30)
			11M (g/test)	CO	1975	130	(100)
				HC	1975	70,0	(50,0)
				NOx	1975	4,00	(2,50)
		Light-duty vehicles (GVW□1.7t)	10･15M (g/km)	CO	2000	1,27	(0,67)
				HC	2000	0,17	(0,08)
				NOx	2000	0,17	(0,08)
			11M (g/test)	CO	2000	31,1	(19,0)
				HC	2000	4,42	(2,20)
				NOx	2000	2,50	(1,40)
		Medium-duty vehicles (1.7t＜GVW □2.5t）	10･15M (g/km)	CO	2001	3,36	(2,10)
				HC	2001	0,17	(0,08)
				NOx	2001	0,25	(0,13)
			11M (g/test)	CO	2001	38,5	(24,0)
				HC	2001	4,42	(2,20)
				NOx	2001	2,78	(1,60)
		Heavy-duty vehicles (2.5t＜GVW)	G13M (g/kWh)	CO	2001	26,0	(16,0)
				HC	2001	0,99	(0,58)
				NOx	2001	2,03	(1,40)

Table A.5. Japanese motor vehicle exhaust emission standards *(continued)*

Category			Test mode	Components		Current regulation: Enforcement year	Current regulation: Standard value	
Diesel motor vehicles	Passenger cars		10･15M (g/km)	CO		2002	0,98	(0,63)
				HC		2002	0,24	(0,12)
				NOx	Small	2002	0,43	(0,28)
					Medium	2002	0,45	(0,30)
				PM	Small	2002	0,11	(0,052)
					Medium	2002	0,11	(0,056)
	Trucks and buses	Light-duty vehicles (GVW□1.7t)	10･15M (g/km)	CO		2002	0,98	(0,63)
				HC		2002	0,24	(0,12)
				NOx		2002	0,43	(0,28)
				PM		2002	0,11	(0,052)
		Medium-duty vehicles (1.7t＜GVW □2.5t)	10･15M (g/km)	CO		1993	2,70	(2,10)
				HC		1993	0,62	(0,40)
				NOx		1997-1998	0,97	(0,70)
				PM		1997-1998	0,18	(0,09)
		Heavy-dutyvehicles (2.5t＜GVW)	D13M (g/kWh)	CO		1994	9,20	(7,40)
				HC		1994	3,80	(2,90)
				NOx	DI	1997-1999	5,80	(4,50)
					IDI			
				PM		1997-1999	0,49	(0,25)

Notes:

1. Carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), particulate matter (PM).
2. The value 2.70(2.10) indicates 2.70 as the maximum permissible value for the vehicle and 2.10 as the average value for the vehicle type.
3. 10·15-mode (10·15M) represents a typical driving pattern in urban areas. 11-mode (11 M) is typical driving pattern of cold-started vehicle travelling from suburbs to the urban centre.
4. For diesel motor vehicles, the "small-size vehicles" are vehicles with an equivalent inertia weight (EIW) of 1.25t (vehicle weight of 1.265t) or less, and the "medium-size vehicles" are vehicles with EIW of more than 1.25t (vehicle weight of 1.265t).
5. “MTM” and “ATM” stand for manual transmission and automatic transmission, respectively.

Test cycles

European test cycles

The first European regulation from the 1970s ECE 15 defines an urban test cycle to be used for emission measurements. The cycle was devised to be representative of city-centre driving and has a maximum speed of only 50 km/h. The complete first ECE 15 emissions procedure consists of three tests: Type I, II and III.

Type I emission test cycle

The ECE 15 mode driving cycle was repeated four times without interruption. This gave a total test cycle time of 780 s, a total distance of 4 052 km (2 516 miles) and an average speed of 19 km/h (11.8 mph). In Regulation ECE 83 (which replaced the former N°15) an Extra Urban Driving Cycle (EUDC) with a maximum speed of 120 km/h was added.

Characteristics		ECE 15 cycle	EUDC cycle
Distance	km	4 x 1.013 = 4.052	6.955
Time	S	4 x 195 = 780	400
Average speed	km/h	19	62.6
Maximum speed	km/h	50	120
Acceleration	% time	21.6	-
Acceleration	m/s^2 max.	-	0.833
Deceleration	% time	13.6	
Deceleration	m/s^2 max.	-	1.389
Idle	% time	35.4	-
Steady speed	% time	29.3	-

Type II test

Warmed-up idle CO test, conducted immediately after the fourth cycle of the Type I test; tailpipe sampling probe.

Type III test

Chassis dynamometer procedure for crankcase emissions (idle and 50 km/h constant speed modes). The system is certified if the crankcase operates at partial vacuum (as in PCV systems), or if crankcase emissions meet specified standards.

US test cycles

Since 1972 the US exhaust emission test procedure has been based on a transient cycle representative of driving patterns in Los Angeles (the LA-4 Cycle). The original 1972 test procedure (US-72) was a two-phase test covering 7.5 miles in almost 23 minutes. From 1975 onward, the procedure was modified in such a way that Phase I is repeated after a 10-minute hot soak, to form a third phase. The total test length was thus extended to 11.09 miles and the time to 31 minutes, plus 10 minutes for the hot soak. Emissions are measured using a constant volume sampling (CVS) system, and collected in three bags, for each phase of the test.

The Highway Fuel Economy Test (HWFET) cycle is used to measure fuel economy for the CAFE standards but is also used to measure NO_x emissions.

Fuel consumption and CO_2 regulations

European Union

There are currently no legal fuel consumption or CO_2 limits for motor vehicles within the European Union. However, the EU Council of Ministers has called on numerous occasions for measures to reduce greenhouse gas (GHG) emissions from transport. Such calls have received even greater emphasis since the Kyoto Protocol was signed in December 1997.

Previous proposals for legislation on vehicle fuel economy have always run into difficulties, particularly because larger cars would be disadvantaged. Additionally, such legislation would require fiscal incentives and taxation policies which would be both complex and cut across the principle of subsidiarity. However, on 2 July 1996, the EU Commissioners for the Environment and for Industry issued a public invitation for the motor industry to begin discussions "with a view to concluding an agreement at European level on the improvement of vehicle fuel efficiency". This resulted in a voluntary agreement (29 July 1998) for vehicle manufacturers to reduce the fuel consumption of their products by 25% compared to 1995, and to achieve a target of 140 g/km CO_2 emissions for the fleet average of new car sales in the EU by 2008.

The European Union and the Kyoto Protocol

The Kyoto Protocol commits the industrialised countries to legally binding emissions reductions of greenhouse gases by 2008-2012 and the EU is in the process of developing a strategy to meet its protocol commitments. The EU Commission's communications on climate change [COM(98)353 of 3 June 1998] was announced as "a first step in such a strategy" and put a series of questions to the Council of Ministers. A key point is that member states have the major responsibility for meeting the Kyoto reduction target. The EU, as a signatory of and future party to the Protocol, has the responsibility to ensure that member states' actions are consistent with the treaty and that their obligations are met. It also has an important role in complementing and supporting the member states with common and co-ordinated policies and measures. The achievements made were reviewed at an environmental conference held in The Hague, the Netherlands, in late 2000.

Passenger cars

The average fuel consumption of passenger cars improved during the 1970s and early 1980s, due, in part, to fuel price increases. However, this trend has reversed in recent years, with heavier and more powerful cars increasing in popularity. The weight increase is partly due to improved vehicle safety requirements. The European Commission considers that reductions in average fuel consumption of the vehicle fleet can be arrived via two principal measures: technical improvements to the vehicles and by increased consumer preference towards the purchase of more fuel-efficient vehicles.

The strategy to reduce CO_2 emissions from passenger cars by improving their fuel economy was set out in COM(95)689 final of 20 December 1995 and the subsequent Council conclusion of 25 June 1996. The objective was to achieve a fleet average CO_2 emission value of 120 g/km by 2005 (or 2010 at the latest) for all new cars. This objective could be met by a series of complementary measures:

- An environmental agreement with the automotive industry, under which the industry would commit itself to reducing the average CO_2 emissions of new cars sold.
- Fiscal measures (vehicle taxation).
- A consumer information scheme "to influence the market".

The European Commission also proposed legislation for a monitoring system on the average CO_2 emissions from cars. This was published as the Decision of EP and Council 1753/2000/EC of 22/06/00. Item (1) was the subject of discussions between the European Commission, ACEA *(Association des Constructeurs Européens d'Automobiles* – European Automobile Manufacturers Association) and importers which resulted in a series of commitments:

- No later than 2000, some manufacturers will introduce models emitting 120 g CO_2/km or less. (This has happened, as more than 10 models emitting less than 120 g of CO_2/km— most of them with a diesel engine — were available on the market in 2003).
- A target fleet average for new car sales of 140 g CO_2/km will be achieved by 2008. According to ACEA, this represents an average CO_2 reduction of 25 % compared to 1995.
- In 2003, ACEA will review the potential for achieving the Community's goal of 120 g CO_2/km by 2012.
- For 2003, ACEA considers an estimated target range of 165-170 g CO_2/km to be "appropriate".

Details of the final agreement between the European Commission and ACEA were published "implementing the Community Strategy to reduce CO_2 Emissions from cars: an Environmental Agreement with the European Automobile Industry". A monitoring system will be set up to follow the development of the average CO_2 emissions on new passenger cars and will address any problems which might arise in achieving the CO_2 objective of the agreement.

Similar agreements were concluded between the European Commission and the Japan Automobile Manufacturers Association (JAMA) and the Korean Automobile Manufacturers Association (KAMA). The ACEA, JAMA and KAMA contain the same quantified CO2 emission objective for the average of new passenger cars sold in the European Union, i.e. 140 g CO_2/km (to be achieved by 2009 by JAMA and KAMA and by 2008 by ACEA).

United States

CAFE standards

The Energy Policy and Conservation Act, passed in December 1975, and amended by the Motor Vehicle Information and Cost Saving Act, requires each vehicle manufacturer to determine sales weighted average fuel consumption figures for all passenger cars and for all light duty trucks produced by them. Electric cars or hybrid vehicles may be included in the fleet average calculations and a credit is given for flexible fuelled vehicles. The standards are based on the combined City/Highway fuel figures and are known as the CAFE (Corporate Average Fuel Economy) standards.

The first year for which the standards were established for passenger cars was model year (MY) 1978 at a level of 18.0 miles per gallon (mpg); the standards increased to 19.0 mpg for MY 1979 and 20.0 mpg for MY 1980. The Act directed NHTSA to establish and promulgate standards administratively for MYs 1981, 1982, 1983 and 1984, and to specify fuel economy requirements for MYs 1985 and thereafter at 27.5 mpg. The fuel economy standard for light trucks was established for MY 1979 at 17.2 mpg for two-wheel drive models and 15.6 mpg for models equipped with four-wheel drive. Several changes in characterizing light truck fleet composition were made over the years, including mandatory and optional calculation of combined two-wheel and four-wheel drive configurations in combination with domestically produced vehicles and "captive" imports, which are vehicles produced outside of the United States that are marketed under a domestic manufacturer's nameplate; optionally calculated domestic and import fleets; and finally single fleet calculations. Passenger vehicle calculations also changed over the years, and current calculations are made for manufacturers import fleets and the domestically produced fleet. Table A.6 summarises the history of fuel economy standards for both passenger cars and light trucks from the program's inception through MY 2002, the latest year for which targets have been set.

The limits for 2002 are 27.5 mpg for passenger cars. For light-duty trucks CAFE has been established through model year 2004 at 20.7 mpg. In April 2003, the US Department of Transportation finalised a regulation to increase the fuel economy of light-duty trucks by 1.5 mpg over three years (2005:21.0 mpg, 2006:21.6 mpg, 2007:22.2 mpg). Fuel economy for passenger cars, which are required to meet a fleet average of 27.5 mpg, is not affected by the new regulation. The penalty for non-compliance has been raised from USD 5.00 to USD 5.50 per mile per US gallon for each vehicle exceeding the above limits.

- More information can be found in the latest EPA "Light-Duty Automotive Technology and Fuel Economy Trends Report (1975-2003) at *http://www.epa.gov/otaq/fetrends.htm* and/or on DOTs National Highway Traffic Safety Administration Web site at *http://www.nhtsa.dot.gov/cars/rules/rulings*.

California's regulation to control CO_2 emissions from motor vehicles

In July 2002, the governor of California signed into law a bill requiring automakers to reduce GHG emissions from non-commercial vehicles starting in the 2009 model year. The new law does not set specific limits or targets, but instead requires the California Air Resources Board (CARB) to develop and adopt regulations by 1 January 2005. The regulations would go into effect one year later, giving the state legislature time to review them and introduce amendments if necessary.

The law stipulates that CARB's regulations must achieve "the maximum feasible and cost-effective reduction" of GHGs from motor vehicles. The regulations also must be flexible, allowing automakers to comply through alternative means so long as they achieve the same or greater emission reductions. The regulations will provide emission reduction credits to automakers that reduce emissions in their vehicles before 2009, starting with the 2000 model year. Automakers will be able to report emissions reductions to the California Climate Action Registry.

Table A.6. Fuel economy standards for passenger cars and light trucks
(miles per gallon)

Model year	Passenger cars	Light trucks (1)		
		Two-wheel drive	Four-wheel drive	Combined (2), (3)
1978	18.0(4)	...	...	...
1979	19.0(4)	17.2	15.8	...
1980	20.0(4)	16.0	14.0	...(5)
1981	22.0	16.7(6)	15.0	...(5)
1982	24.0	18.0	16.0	17.5
1983	26.0	19.5	17.5	19.0
1984	27.0	20.3	18.5	20.0
1985	27.5(4)	19.7(7)	18.9(7)	19.5(7)
1986	26.0(8)	20.5	19.5	20.0
1987	26.0(9)	21.0	19.5	20.5
1988	26.0(9)	21.0	19.5	20.5
1989	26.5(10)	21.5	19.0	20.5
1990	27.5(4)	20.5	19.0	20.0
1991	27.5(4)	20.7	19.1	20.2
1992	27.5(4)	...	...	20.2
1993	27.5(4)	...	...	20.4
1994	27.5(4)	...	...	20.5
1995	27.5(4)	...	...	20.6
1996	27.5(4)	...	...	20.7
1997	27.5(4)	...	...	20.7
1998	27.5(4)	...	...	20.7
1999	27.5(4)	...	...	20.7
2000	27.5(4)	...	...	20.7
2001	27.5(4)	...	...	20.7
2002	27.5(4)	...	...	20.7
2003				20.7
2004				20.7
2005				21.0
2006				21.6
2007				22.2

1. Standards for MY 1979 light trucks were established for vehicles with a gross vehicle weight rating (GVWR) of 6 000 pounds or less. Standards for MY 1980 and beyond are for light trucks with a GVWR of 8 500 pounds or less.

2. For MY 1979, light truck manufacturers could comply separately with standards for four-wheel drive, general utility vehicles and all other light trucks, or combine their trucks into a single fleet and comply with the standard of 17.2 mpg.

3. For MYs 1982-1991, manufacturers could comply with the two-wheel and four-wheel drive standards or could combine all light trucks and comply with the combined standard.

4. Established by Congress in Title V of the Motor Vehicle Information and Cost Savings Act.

5. A manufacturer whose light truck fleet was powered exclusively by basic engines which were not also used in passenger cars could meet standards of 14 mpg and 14.5 mpg in MYs 1980 and 1981, respectively.

6. Revised in June 1979 from 18.0 mpg.

7. Revised in October 1984 from 21.6 mpg for two-wheel drive, 19.0 mpg for four-wheel drive, and 21.0 mpg for combined.

8. Revised in October 1985 from 27.5 mpg.

9. Revised in October 1986 from 27.5 mpg.

10. Revised in September 1988 from 27.5 mpg.

The new law prohibits CARB from imposing additional fees and taxes on any motor vehicles, fuels, or vehicle miles travelled, and the board cannot ban sales of any type of vehicle, require reductions in vehicle weight, or change speed limits.

Because California accounts for approximately 10% of the US new car market, the new regulations are expected to affect vehicles offered throughout the country - especially if other states adopt similar regulations. Several opponents of the new law have however indicated their intent to challenge it in federal court.

- More information can be found at *http://www.arb.ca.gov/cc/cc.htm*.

Japanese fuel economy standard

In Japan, the fuel economy standard has been enforced by the top-runner method. The government has set targets to improve the average fuel economy for the petrol fuelled light vehicles by 21.4% in 2010 compared to the 1995 level. For light-duty diesel vehicles, the average fuel economy is to be improved by 13.1% in 2005 compared to the 1995 level. To determine the fuel economy, the Japanese 10-15 driving cycle has been used. The fuel economy targets in Japan are given in Table A.7.

Table A.7. Fuel economy targets in Japan

Petrol	**1995 actual result**	**2010 target**	**Improvement**
Passenger car	12.3 km/l	15.1 km/l	22.8%
Truck (GVW≤2.5t)	14.4 km/l	16.3 km/l	13.2%
Total	12.6 km/l	15.3 km/l	21.4%
Diesel	**1995 actual result**	**2005 target**	**Improvement**
Passenger car	10.1 km/l	11.6 km/l	14.9%
(GVW≤2.5t)	13.8 km/l	14.7 km/l	6.5%
Total	10.7 km/l	12.1 km/l	13.1%

Note: In Japan, the average diesel vehicle sold has higher fuel consumption than the average petrol vehicle due to the fact that diesel vehicles are mostly represented in the upper weight classes.

Other countries

Legislation in other countries – where it exists - tends to follow (or adapt) US, European or Japanese standards and test methods.

New approaches and regulations for hybrid and hydrogen-fuelled vehicles

A.3.1. Type approval of hybrid vehicles

Under the UN ECE process, the GRPE is undertaking work to develop appropriate standards and procedures to enable effective type approval for hybrid vehicles. The aim of this work is to:

- Ensure continuity and coherence between regulations for a vehicle operating solely on an internal combustion engine to a vehicle utilising an electric motor.
- Ensure hybrid vehicles regulations take into account their potential to produce very low exhaust emissions of both air pollutants and greenhouse gases.

In May 2001 the GRPE formed a working group on hybrid vehicles to:

- Develop an appropriate set of definitions governing hybrid vehicles.
- Identify categories of hybrid electric vehicles (HEV).
- Identify and prioritise the amendments of existing ECE regulations.
- Establish principles of test methods for measuring emissions and fuel consumption of hybrid vehicles.

Work is progressing on these measures and reports on the current state of play can be obtained by examining the reports of the GRPE meetings and associated documents at: *http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grperep.html*.

Hydrogen-fuelled vehicles

Hydrogen has been identified in the United States, Japan and Europe as having the potential to be a clean transport fuel in the longer term. A small number of hydrogen fuelled vehicles using fuel cell technologies are already on the road in these three regions.

In Europe, the European Integrated Hydrogen Project (EIHP) was established in 1998 to enhance the safety of hydrogen vehicles and to facilitate the approval of hydrogen vehicles.

The current EC Directives for emissions, fuel consumption and engine power cannot be met by hydrogen-fuelled vehicles because of the absence of a standardised reference fuel and the absence of a procedure for testing the engine power. In addition, requirements regarding the safety of the hydrogen on board storage system are yet to be determined. In the interim, each country is applying their (often different) national requirements regarding the safety of the hydrogen onboard storage system.

EIHP Phase 1 (1998 - 2000)

The objectives of Phase 1 were to:

- Create a European database of existing regulations and codes of practice.
- Contact other pertinent authorities outside Europe.
- Identify weak spots in today's technology.
- Define the areas requiring regulation.
- Create a basis for an ECE regulation for hydrogen vehicles.

At the end of Phase 1, the EIHP partners had developed two drafts for new ECE regulations, one for the onboard storage system for liquid hydrogen and one for the onboard storage system for gaseous hydrogen.

Phase 2 (2001 -   )

The draft regulations developed in Phase 1 are presently in the submission process to the relevant European regulatory bodies. The aim is for these regulations to be suitable for harmonisation at a global level. By applying these draft regulations to the design and approval of fuel cell vehicles with direct onboard hydrogen storage they will address not only hydrogen related vehicle components and systems, but also safety requirements, refuelling procedures and periodic inspections.

For the relevant hydrogen refuelling infrastructure components and systems, for which existing standards, codes of practice and regulations are only partly identified, the applicable national standards and regulations will be identified and necessary requirements for new draft standards and possibly draft regulations for approval will be developed. These activities among others will also comprise refuelling procedures, safety aspects, periodic inspections and the layout of refuelling stations. The interface between the refuelling station and the vehicle (receptacle and nozzle) will be an important issue. The capacity for EU-wide harmonisation will be evaluated. It will also be investigated to what extent certain elements of the refuelling systems are suitable for harmonisation on a global regulatory scale, *e.g.* components.

Comparative risk and safety analyses with respect to the release of hydrogen in confined and semi-confined environments, such as tunnels, garages, refuelling stations, and inner city streets will be undertaken. These shall provide data in sufficient depth in order to enable the partnership to define the required inputs for hydrogen-related standards and regulations.

To date, Phase 2 has led to the development of:

- A draft harmonised regulation for hydrogen-fuelled road vehicles.
- Draft procedures for periodic vehicle inspections (roadworthiness).
- Draft standards and periodic inspection procedures for the relevant refuelling infrastructure, subsystems and components.

Adoption of these draft regulations and standards would maximise the potential to reduce costs for both the vehicle and infrastructure industries in bringing hydrogen fuelled fuel cell vehicles into service. The regulations can provide a legal framework for approving the operation of hydrogen-fuelled vehicles on public roads and refilling at public refuelling stations. In addition, harmonised standards will facilitate trade in vehicle and infrastructure components in the medium and long term.

European regulations on liquid hydrogen onboard storage systems

An informal group of GRPE (Informal Group Hydrogen/Fuel Cell – Vehicles) is currently working on regulations of liquid hydrogen onboard storage systems and fuel cell vehicles. All presentations and documents concerning the informal group are available at the EIHP Web site, *www.eihp.org*).

US future approach, PNGV programme and FreedomCAR

In the United States, transportation accounts for nearly one-third of CO_2 emissions, with cars and light trucks contributing over half of that total. The "Partnership for a New Generation of Vehicles" (PNGV) was a 10-year joint research and development programme between the EPA and General Motors, Ford and Chrysler. It was announced in September 1993 and had the following objectives:

- Improve US competitiveness in vehicle manufacturing.
- Implement fuel efficiency and emissions technology for use in conventional vehicles.
- Develop a vehicle to achieve up to three times the fuel efficiency of a current comparable vehicle.

The National Research Council recommended restructuring the PNGV programme because of developments and advancements in related fields:

- Automobile fuel economy is declining as SUV market share increases.
- Significant R&D progress has been achieved.
- Industry partners have announced they will introduce hybrid technology in production vehicles within the next few years.
- Other PNGV technologies (*e.g.* lightweight materials) are being introduced in conventional vehicles.
- Substantial programmes similar to PNGV are underway around the world.
- Full fuel efficiencies associated with PNGV technologies will not be realized in large numbers until breakthroughs render them more cost-competitive.
- Re-evaluation is appropriate as PNGV approaches the end of a ten-year project.

In 2002, FreedomCAR replaced and improved upon the PNGV programme. The Department of Energy and the Big Three automakers (Ford, General Motors and DaimlerChrysler) announced a public-private partnership to develop hydrogen economy of the future. For this programme, called FreedomCAR (CAR stands for cooperative automotive research), the government and the private sector will fund research into advanced, efficient fuel cell technology which uses hydrogen to power automobiles without creating any pollution. FreedomCAR will focus on technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and the hydrogen-supply infrastructure to support them. FreedomCAR also will continue to support for petroleum-dependant technologies that have the potential to reduce oil consumption and environmental impact.

In evaluating the former PNGV programme, the US Department of Energy and auto industry partners agree that public/private partnerships are the preferred approach to R&D, as highlighted in the President's National Energy Plan, but the co-operative effort must be refocused in order to:

- Aim at longer range goals with greater emphasis on highway vehicle contributions to energy and environmental concerns.
- Move to more fundamental R&D at the component and subsystem level.
- Assure coverage of all light vehicle platforms.
- Maintain some effort on nearer term technologies that offer early opportunities to save petroleum.
- Strengthen efforts on technologies applicable to both fuel cell and hybrid approaches, *e.g.* batteries, electronics, and motors.

Strategic approach

- Develop technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and ensure the hydrogen infrastructure to support them.
- Continue support for other technologies to dramatically reduce oil consumption and environmental impacts.

- Instead of single vehicle goals, develop technologies applicable across a wide range of passenger vehicles.

Technology-specific 2010 Goals[1]

- To ensure reliable systems for future fuel cell powertrains with costs comparable with conventional internal combustion engine/automatic transmission systems.
- To enable clean, energy-efficient vehicles operating on clean, hydrocarbon-based fuels powered by either internal combustion powertrains or fuel cells.
- To enable reliable hybrid electric vehicles that are durable and affordable.
- To enable the transition to a hydrogen economy, ensure widespread availability of hydrogen fuels, and retain the functional characteristics of current vehicles.
- To improve the manufacturing base.

The Japanese ministerial statement on a comprehensive strategy for "environmentally friendly vehicles"

The Ministerial Conference on Transport, held in Tokyo in January 2002, stated that the benefits that motor vehicles have brought us have also been accompanied by negative side effects. According to the statement, further improvements in vehicle emissions, noise and fuel efficiency must be made, aiming for sustainable development, although regulations have been successfully implemented. Additional technical improvements are also necessary to substantially decrease GHG and pollutant emissions, and to lower noise levels.

Future policies include the discussion of the environmentally friendly vehicle (EFV) concept, the role of government in the development and dissemination of EFVs, the availability of appropriate fuels, and international co-operation and harmonisation of standards throughout the world. In the context of these policies, an international conference on environmentally friendly vehicles was held in Tokyo in January 2003, and delegates supported the initiative for harmonisation of EFV standards and test procedures under the Global Agreement within the framework of the United Nations/Economic Commission for Europe/World Forum for Harmonisation of Vehicle Regulations.

Annex B

TRADITIONAL AND NEW TECHNOLOGIES

Introduction

This annex provides further information complementary to the policy report, primarily expanding on Chapters 2 and 3. It describes and assesses conventional and new technologies focusing on their impacts on:

- Traditional pollutants that are harmful to public health and the environment. These pollutants include carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides (NO_x) and particulate matter (PM).
- Emissions that have an effect on the climate, the so-called greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).
- Fuel economy in light of the limited natural resources of oil.

Reduction of regulated air pollutants

Since the early 1970s, major efforts have been put into the reduction of the emission of pollutants through the tightening of legislation on new vehicles. This section describes the evolution of traditional engines that resulted from these legislative changes as well as the results that have been achieved.

Evolution of traditional engines

Legislation restricting the emission of pollutants from passenger cars first emerged in California where air quality problems were considered quite severe. The first measures to be taken on petrol-fuelled cars were improved carburettor settings and the application of exhaust gas recirculation. However, throughout the 1970s, these measures were not sufficient to meet the tightening emissions standards, which led to the introduction of catalytic converters. To prevent catalytic converter damage, lead-free fuel was introduced as well, which also eliminated motor vehicle contributions to the lead pollution of the environment.

The first catalysts were of the unregulated (oxidising) type. The engine mixture was not optimised for the functioning of the catalysts. Because a catalytic converter has the highest reactivity for CO, VOC and NO_x for a fixed engine mixture (when the mass of air is 14.7 times the mass of petrol, *i.e.* $\lambda = 1$), a closed loop system with an oxygen-sensor became the mainstream system on petrol passenger cars in the 1980s, most commonly with an engine management system and electronic fuel injection. Consequently, the carburettor disappeared from passenger cars. Further tightening of the emissions limits led to increased catalysts reactivity and more refined engine control systems; in addition, cold start and evaporative emissions became proportionally more important and needed to be strictly controlled.

In Europe, this evolutionary path lagged approximately ten years behind the United States and the first catalytic converters emerged in the late 1980s under tax incentive programmes in several countries. Not until the 1992 "Euro 1" legislation did the application of closed loop controlled three-way catalysts become the industry standard.

For diesel engine passenger cars, the main issues related to local pollution are reductions of NO_x and particulate matter. Until now, car manufacturers have managed to meet the U.S. and European limits through increased diesel pump and injector refinement, higher pressures and/or exhaust gas recirculation. A limited number of car manufacturers now equip their vehicles with particulate filters. Although CO and VOC emissions from diesel-fuelled cars are naturally rather low, the tightening European legislation in the 1990s led to a widespread use of oxidation catalysts in diesel vehicles.

Results

To illustrate the reduction in emissions of local air pollutants from passenger cars, this section is illustrated with figures which show the results of the Dutch In-Use Compliance (IUC) programme that has been running since the 1980s. The same trends have been observed in most OECD countries. Results are shown for CO, VOC, NO_x and particulate matter (PM_{10}, diesel only). The height of the bars indicates the spread of the emissions measured. Table B.1 shows the technology classes that were included in the IUC analysis.

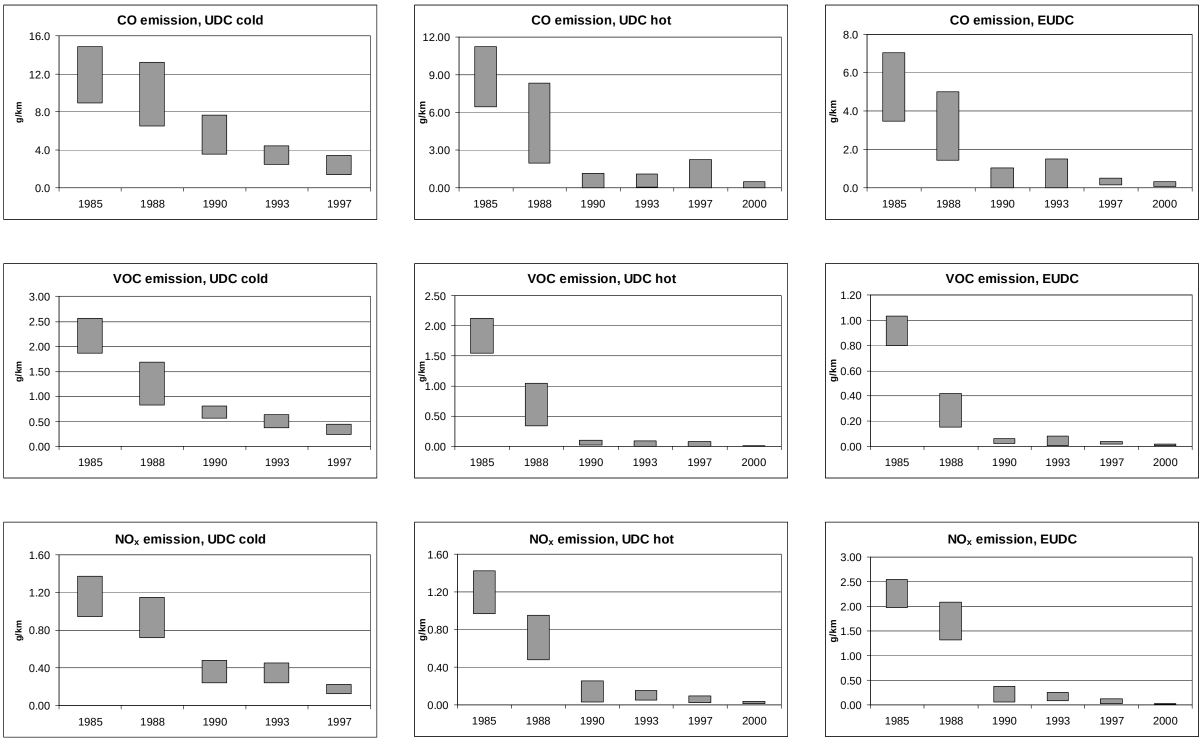
Table B.1. Technology classes included in the IUC analysis

Model year	Petrol	Diesel
1985	Pre Euro 1 ("Euro 0") cars with a catalytic converter	
1988	Pre Euro 1 ("Euro 0") cars with a unregulated catalytic converter	Pre Euro 1 ("Euro 0") cars without an oxidation catalyst
1990	Pre Euro 1 ("Euro 0") cars with a regulated catalytic converter	
1993	Euro 1 cars with a unregulated catalytic converter	Euro 1 cars without a oxidation catalyst
1997	Euro 2 cars with a regulated catalytic converter	Euro 2 cars with or without an oxidation catalyst (depends on vehicle)
2000	Euro 3 cars with a regulated catalytic converter	Euro 3 cars with an oxidation catalyst

In the Dutch IUC programme emissions are measured from various driving cycles:

- Urban Driving Cycle (UDC) with cold start (up to Euro 2).
- Urban Driving Cycle (UDC) with hot start.
- Extra Urban Driving Cycle (EUDC) with hot start.

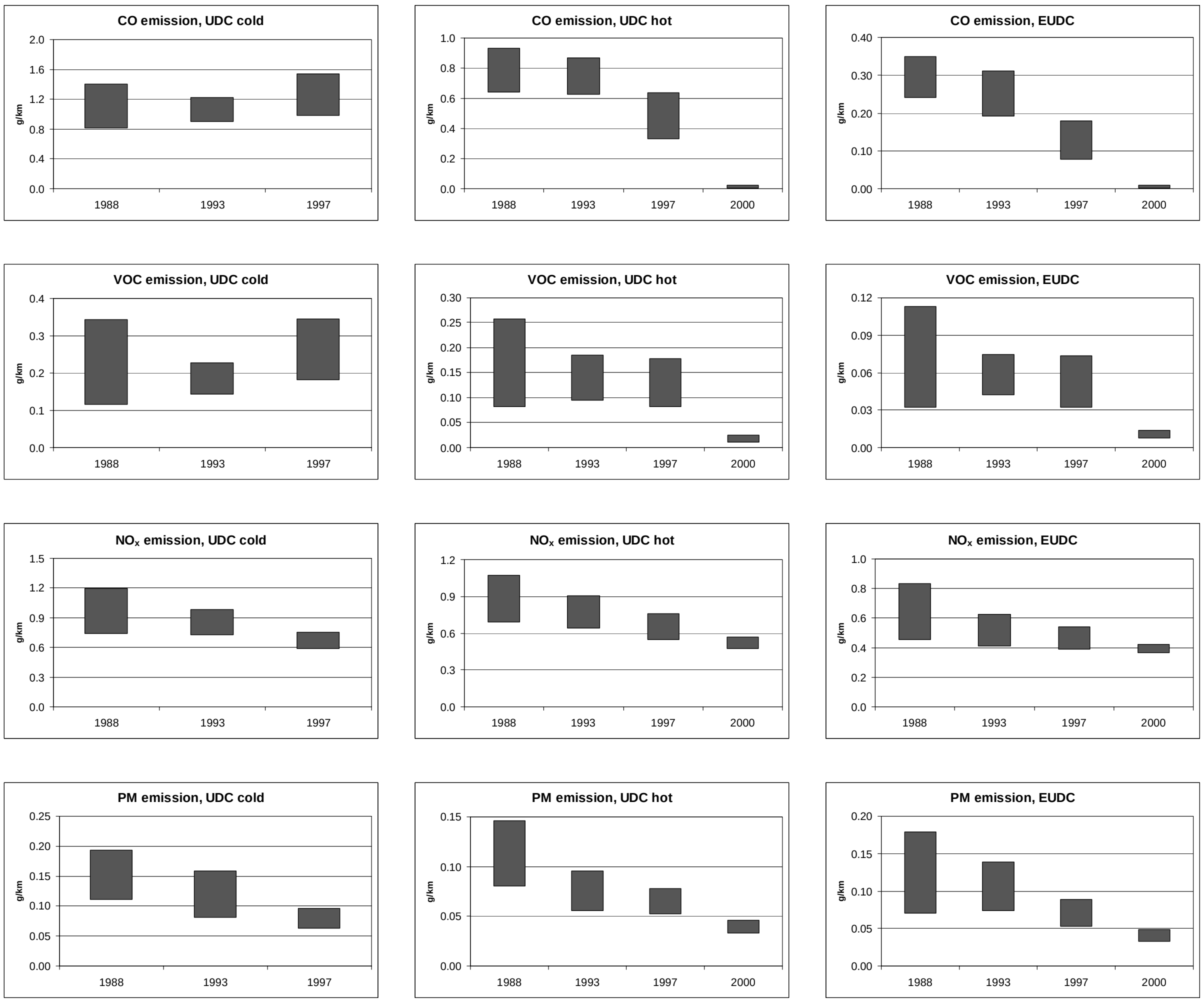
Figure B.1. Emission reduction of passenger cars (petrol)



Source: Dutch In-Use Compliance Programme, 1987-2002.

These figures clearly show that emissions of NOx, CO and VOC have dropped dramatically since the introduction of three-way catalysts and with Euro 3 standards. Emissions have decreased to such low levels that it has become difficult to accurately measure them. These figures also show that the cold start effect is becoming more and more important.

Figure B.2. Emission reduction of passenger cars (diesel)



Source: Dutch In-Use Compliance Programme, 1987-2002.

For *diesel* passenger cars (Figure B.2), the introduction of oxidation catalysts have led to a considerable decrease in CO and VOC emissions. The reduction of NO_x and particulate matter shows a more gradual decrease, leaving enough room for further improvements in the coming years with the introduction of Euro 4 standards in 2005.

Reduction of greenhouse gas emissions

Energy breakdown of a traditional vehicle

The chemical energy content of a fuel is harnessed by the engine to produce mechanical energy. This mechanical energy is used to overcome the inertia and air and rolling resistance of the vehicle and to generate electrical energy to operate electric components such as lighting.

Not all of the energy is used for propulsion and auxiliary components. Part of the energy is consumed during the chemical or thermodynamic processes and to overcome friction. The breakdown of the energy consumption of a conventional model year 2000

European mid-size family car powered by a petrol internal combustion engine (ICE) is given as an example in Table B.2. This breakdown is also presented for advanced vehicles later in this annex.

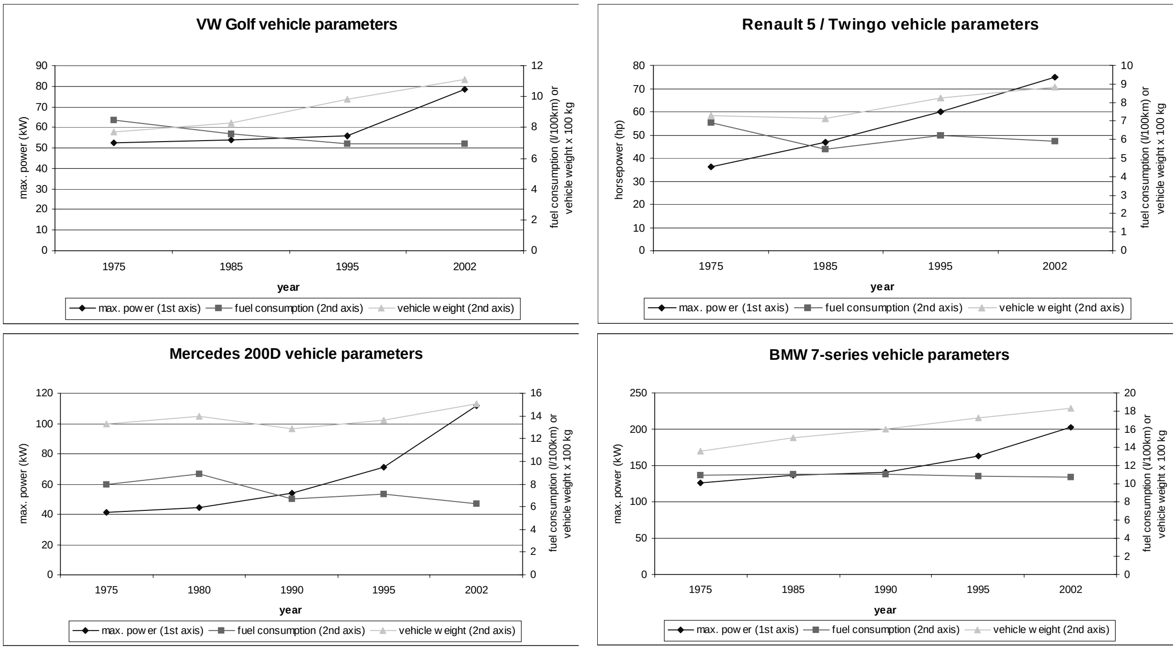
Table B.2. Energy breakdown of a traditional standard midsize family car

Type of road		**Urban**	**Highway**
Energy content of fuel		**100%**	**100%**
Drivetrain losses	Thermodynamic losses	60	60
	Engine losses	12	3
	Transmission losses	4	5
	Total	**76%**	**68%**
Used for components	Auxiliaries	2	1
	Accessories	1	1
	Air conditioning (when in use)	10	10
	Total	**13%**	**12%**
Used for propulsion	Air resistance	2	11
	Roll resistance	4	7
	Kinetic losses/braking, no inclination	5	2
	Total	**11%**	**20%**

As shown in Table B.2, most of the original energy content of the fuel is transformed into heat. Over the years, much has been done to improve the engine efficiency which has increased with the use of lean-burn engines and direct injection. The fuel consumption of individual vehicles has not decreased at the same pace because, among other factors, the vehicle weights have increased.

However, overall, the fuel consumption of vehicles has decreased, despite the increase in vehicle weight and maximum power (Figure B.3). According to ECE Regulation tests, the fuel consumption of the 2002 VW Golf was 20% better than its predecessor of 1975 – despite the recent model being 44% heavier.

Figure B.3. Vehicle weight versus fuel consumption (based on manufacturer specifications)



Technical parameters influencing fuel consumption

The fuel consumption of a vehicle depends on the efficiency and the driveline of the engine, auxiliaries, regeneration or not of braking energy, the weight of the vehicle, the aerodynamics of the vehicle, the drag caused by windows and luggage carriers, and the accessories such as air conditioners, lighting, audio installation, defrosters, etc.

The energy produced by the engine is of course used for propulsion and auxiliaries. This section analyses the energy used for propulsion and auxiliaries and the performance of the vehicle. This analysis focuses on the tank-to-wheel efficiency and cannot be used alone for studies on CO_2 emissions because well-to-tank efficiencies play an important role (see Chapter 3).

An important factor influencing fuel consumption is the performance of the engine, which is generally proportional to its displacement (see Figure B.4).

Figure B.4. Vehicle performance and fuel consumption of a vehicle at different engine displacements (based on manufacturer specifications)

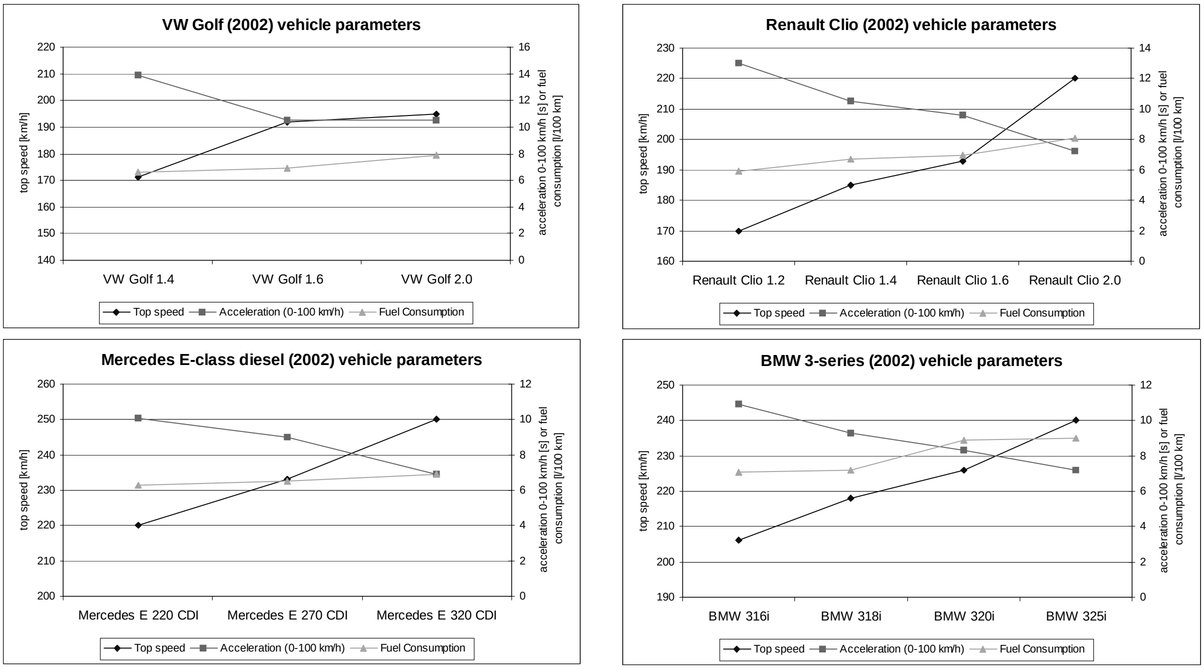
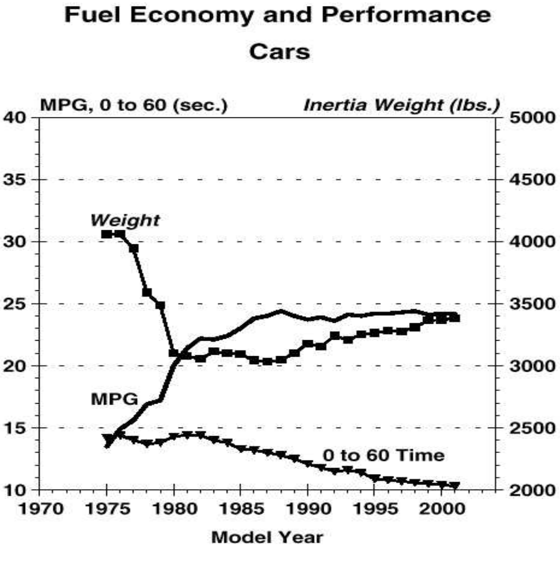


Figure B.4 illustrates that the smallest engines with the lowest fuel consumption deliver more than adequate performance for use in today's traffic conditions.

Figure B.5 illustrates the trend in performance, weight, and adjusted fuel economy for U.S. passenger cars. It shows increasing weight and performance over roughly the last two decades, while fuel economy remains near constant (Hellman and Heavenrich, 2001).

Figure B.5. US fuel efficiency and performance of cars by model year



More efficient technologies continue to enter the vehicle fleet and while the additional power and accessories being sought by consumers have led to increasing vehicle weight and acceleration, the fuel economy of current vehicles is not being increased. In the United States, model year 2001 light vehicles have about the same average fuel economy as those built 20 years earlier in model year 1981. Based on accepted engineering relationships, however, if the 2001 light vehicle fleet had the same average weight and performance as in 1981, it could have achieved more than 25% higher fuel economy (Hellman and Heavenrich, 2001).

Evolution of traditional engine technologies

The efforts put into improving fuel economy of passenger cars recognise the decreasing oil reserves in the world and respond to concerns about conservation and supply raised broadly for the first time during the oil crisis in the 1970s. In the 1990s, concerns about global warming due to CO_2 emissions reinforced strongly the necessity for more fuel efficient cars. In response, during the last decade, car manufacturers have made significant efforts to improve the fuel economy of cars by optimising engine efficiency. Most of these measures have involved improvements in the basic engine design, such as the use of low friction materials and optimised geometry of the combustion chamber and intake manifolds and outlet canals.

In *petrol cars,* the switch from carburettors to electronically controlled fuel injection allowed greater refinement in mixture control. Also, the large-scale introduction of multi-valve technology led to significant improvements in basic engine efficiency. However, the introduction of catalytic converters led to an increase of fuel consumption because of the switch from the common 'lean' λ=1.1 setting to a λ=1 setting for optimal catalytic reactivity. In addition, the slightly increased exhaust backpressure due to the catalyst contributes to higher fuel consumption.

Diesel cars, which already have a fuel economy and CO_2 emission advantage over petrol cars, benefited during the last decade from the introduction of direct injection, which was previously only available on heavy-duty applications. The latest trend in diesel technology is the introduction of electronically controlled injection systems, such as common rail and unit injectors, that allow flexible injection timing and rate shaping, but also enable much higher pressures. Today, some high efficiency state of the art diesel engines do not even produce enough heat for heating the cabin under cold conditions, making the use of additional electrical heaters necessary in very cold regions.

Generally, the more widespread use of automatic transmissions on passenger cars has had an adverse effect on fuel economy.

Drag, rolling resistance and weight

Drag, rolling resistance and weight are major parameters influencing fuel consumption, which are explained in the policy report.

Energy consumption of auxiliaries and components

In-vehicle climate control systems

Accessories generally have only accounted for a moderate part of the fuel consumption. However, traditionally, accessories did not include an air conditioner or an auxiliary heater. Modern cars are increasingly equipped with an air conditioner. In addition, modern diesel cars with highly efficient engines require additional heating and are equipped with an auxiliary heater.

Air conditioner systems

The power that is required for operating a conventional in-vehicle air conditioner system can be split up into two specific parts. The first part is the power required to propel the air conditioner's compressor. The second is the electrical power required for the fans that force air through the condenser and the evaporator. Besides the ambient temperature, the preset or desired interior temperature, the amount of air recirculation, the ambient humidity and the vehicle's insulation against cold and solar radiation are important factors that influence the fuel consumption and CO_2 emissions as well as the emissions of local pollutants.

Air conditioners can also be used to demist the vehicle windows. This is often required just after a cold start when the ambient temperature is low and the relative humidity is high. The moisture in the air that enters the air conditioner is condensed at the cold surface of the condenser. The air that has been cooled down at the condenser needs to be heated up to a comfortable temperature to enter the vehicle's cabin. It is clear that additional heating is required here.

In order to establish the energy consumption and emissions of cars that have the air conditioner switched on, a test was carried out by TNO (Gense, 2000). The measurements were carried out with the air-conditioner switched fully on by making sure that the preset temperature of 20°C in the car was not reached during the test. This is a worst case situation. In practice, this full load situation only occurs at very high ambient temperatures or during the cool down period of the interior, until a stabilised temperature is reached and the load is reduced to a level that suffices for keeping the interior temperature at the desired level.

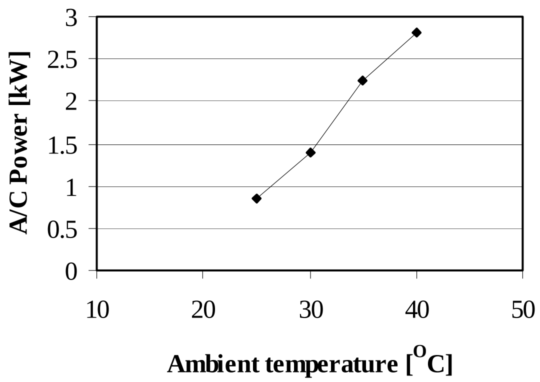
Using an air conditioner at full power caused an average increase of the fuel consumption of 27% over the five cars tested. The emissions of CO and HC and particulate matter rise even more dramatically.

Table B.3. Relative extra emissions due to the air conditioner at full load compared to the same vehicle without air conditioning (percentage)

Track type	Urban	Rural	Highway	Average trip
Fuel consumption	+29	+30	+24	+27
CO_2	+28	+25	+21	+25
CO	+796	+616	+478	+605
HC	+260	+271	+114	+207
NO_x	+76	+17	+17	+31
Particles	+139	+64	+262	+159

Other researches have shown that the additional fuel consumption and thus additional CO_2 emissions are to a certain extent proportional to the ambient temperature. Figure B.6 shows the results of a research undertaken by UTAC/INRETS (Barbusse, Clodic and Roumégoux, 1998).

Figure B.6. Ambient temperature versus airco power



Another aspect of the use of in-vehicle climate systems is the additional weight of those systems. This additional weight adds to the vehicle energy consumption because the inertia of the system requires extra energy during acceleration. The additional fuel consumption due to weight amounts to approximately 0.03 to 0.06 litres/100 km for such systems.

In addition to the increase in fuel consumption, there is an increase in tail pipe emissions. The explanation lies in the relationship between engine load and the calibration strategy of the engine and motor management system. Especially at idling and low driving speeds, the additional power required for the air conditioner system can add a relatively large amount of load to that already required for driving. The calibration of the engine and motor management is not always optimised for this situation.

New technologies are being developed for air conditioner systems. Some developments are focussed on making the system more efficient in terms of energy consumption. Other developments are pushed by the fact that the use of alternative refrigerants - with a lower GWP (Global Warming Potential) than the currently used refrigerants – often requires a different system configuration due to the differing specifications of the alternative refrigerants.

Current developments of air conditioning systems focus on:

- Component weight reduction.
- Increasing compressor efficiency through variable displacement or engine speed independent propulsion (electrical).
- Increasing temperature control accuracy by means of intelligent control.
- Heat pumps.
- Absorption systems.
- Thermal storage.
- Use of refrigerants with lower GWP. This often requires a non-conventional system configuration.
- Secondary loop systems.

Auxiliary heaters

Auxiliary heaters can also increase emissions and fuel consumption. As discussed, modern diesel vehicles, which have very efficient engines, do not have enough surplus heat to support the heating system. An additional heating device is therefore necessary for a quicker warm-up of the engine and/or for the supply of heat to the interior of the vehicle. For these two purposes, an electrical heating device can be mounted in the engine's cooling circuit, or a fuel-fired heater can be integrated in the cooling circuit using a heat exchanger. Both can make the engine heat up more quickly and thus allow a quicker warm-up of the interior. (It should be mentioned that a quicker warm-up of the engine leads to a slight decrease in fuel consumption during the engine heat up period. It is not clear however, to what extent this compensates for the additional fuel consumed by the devices that are necessary to achieve a quicker heat up). Another alternative is a system composed of an electrical heater mounted in the airflow, which is directed into the vehicle's cabin.

Both the electrical system and the fuel-fired system consume additional energy - either directly as the fuel for the heater or indirectly via the electric energy from the vehicle's generator (that is propelled by the engine). Other systems are being developed as well. One such well known system is the friction heater. The friction of oil between a rotating plate and a fixed plate causes the oil to heat up. A heat exchanger takes care of the heat distribution to the engine's coolant. This system is propelled directly by the vehicle's engine and thus requires additional energy for its operation.

Other equipment

New vehicles are equipped with a wide variety of electrical equipment which enhances their comfort and safety. In a modern car, the power requirement of such electrical equipment is around 1000 Watts (1 kW). In the near future, increases in power requirements of up to 5 kW can be expected, depending on the amount and functions of the equipment that is used in the vehicle. Some sources suggest requirements could be as high as 12 kW by 2010. Electrical systems of 42 volts are being developed to meet anticipated requirements and diminish dissipation losses.

Future on-board equipment requirements could include more computer power for rapidly increasing control and status-report functions throughout vehicles and a range of additional equipment such as: computer-controlled power-assisted active suspension; electrically actuated brakes and power-to-wheel distribution; steer-by-wire; video rear-view mirrors, collision avoidance radar; electrically actuated doors with safety locking assurance; electrically propelled a/c compressors for engine-off use; night vision lighting enhancement; complete mobile office with functions such as internet, fax, phone and GPS functions; TV, video and internet access to all passenger seats; cabin preconditioning with heating/cooling when parked; refrigerators and coolers; catalyst heating; active exhaust noise reduction; cooled/heated seats/steering wheel; auto tinting mirrors/windows; active vehicle distance control; active suspension; fully variable valve timing; automated manual shifting; e-pump; variable compression systems; electrical adjustable seats; rear head rest fold away; parking mirror fold away, and many more.

Most of these functions are either in development or already offered in the leading model series of current model cars. These functions all require additional electric energy. In order to provide this energy, the need for highly efficient engines and intelligent management systems for the complete electrical system is urgent. A more efficient alternator or an auxiliary power unit (APU) could supply the electrical power. A fuel cell can also act as an APU and achieve fuel savings, in particular for vehicles where high electric power is needed.

Conclusions

The energy consumption requirements of auxiliary equipment and the impact on vehicle emissions is not captured by the official test cycles and is therefore not measured within the procedures of a type approval test. This is unfortunate given type approval data may be used as a principal basis for consumer information and consumer comparisons. For a fair comparison of vehicle performance, information should be provided to the consumer on the environmental performance of vehicles in real use when the air conditioner or other accessories are switched on. This would also provide an incentive for vehicle manufacturers to develop more efficient systems for real use rather that test cycle purposes and to develop optimal engine calibration strategies for achieving low vehicle emissions that takes the additional loads expected from auxiliary systems in real use into account.

Improvements in traditional vehicles[1]

Improvements in petrol engines

Reduction of exhaust emissions

The emissions performance of spark ignition engines is currently based on a closed loop $\lambda=1$[2] fuel mixture in combination with a three-way catalytic converter. Control of the fuel mixture is achieved by means of an oxygen sensor in the exhaust system and an electronic control unit. This is a relatively slow system. The electronic control unit therefore uses optimised feed forward calculations, which are fine-tuned through the feedback of the oxygen sensor. Based on its signal, the air-to-fuel ratio varies around the stoichiometric value, at which value a three-way catalytic converter reaches an optimal efficiency (>99%). However, almost every engine also uses mixture enrichment in certain high load conditions. This approach which is called full-load enrichment leads to a significant increase in CO and VOC emissions. Recent analyses show that the remaining end-of-pipe emissions can be attributed to the following sources:

- Cold start.
- Lambda excursions.
- Effect of real surrounding temperatures.
- Off-cycle.
- Warm conversion efficiency of catalyst.

[1] The information presented in this section is drawn from a survey conducted by TNO Automotive, published in 2003.

[2] $\lambda=1$, when the mass of air is 14.7 times the mass of petrol.

Lambda excursions

Fast load variations to which the electronic control unit cannot compensate quickly can result in so-called *lambda-excursions*. During these lambda-excursions, the efficiency of the catalyst is dramatically reduced, resulting in very high emissions. Lambda-excursions can also occur under situations that are not encountered under type-approval tests, such as aggressive driving styles and use of air-conditioning (see previous sections).

These fast effects can be addressed by refinement of the feed-forward calculations. This requires a very detailed and reliable model of the specific processes and the development of both the engine electronics and some dedicated software. Another method, which is already in use in some current cars, is the decoupling of the throttle-pedal and throttle valve by means of electronic throttle actuation. The throttle valve can then not be opened faster than the electronic control unit can handle in order to optimise the emissions.

In addition to speeding up the calculations, improvements can also be gained by decreasing the number of situations where the control strategy deliberately deviates from the $\lambda=1$ strategy - the so-called "off-cycle" emissions situations when the strategies used do not fall within those required by the official test procedures (and the official test-cycles). Under off-cycle situations, the engine is not calibrated for low emissions, but for optimal driveability. An example, especially applicable for smaller engines, is full load enrichment.

Cold start

A three-way catalyst functions with full efficiency when it is hot. Therefore, during a cold start the reactivity of the catalyst is limited until it has reached its optimal temperature. Shortening the time that elapses before the catalyst reaches its working temperature ("catalyst light-off") can be achieved by catalysts that are mounted very close to the engine's exhaust manifold. Lowering the "light-off" temperature is another measure able to reduce cold start emissions.

Another aspect that plays a role at low temperatures (below 20°C) is enrichment of the mixture. Such enrichment is needed because of the poor vaporisation of fuel at low temperatures. More fuel is added to the mixture to have enough fuel vapour to start the combustion process. However, this prevents the catalyst oxidising CO and VOC emissions, even when it is hot. This problem can be solved by equipment that helps the fuel to vaporise, such as electric intake manifold heaters. Also secondary air injected before the catalyst can help reduce the remaining CO and VOC emissions, as is applied in the Ford Focus for example.

Reducing cold-start emissions is above all a matter of forcing manufacturers to pay attention to this problem. This can be done by adding a cold start test at –7°C to the type approval procedure, as is now the case with the Euro 3 regulations.

Expected emissions reductions

Significant further reductions of the real-world emissions of CO, VOC and NO_x are technically feasible for petrol engines. With incremental improvements to the engine control system and the exhaust after-treatment system, reductions of 80% or more (depending on the type of emissions) might be achieved compared to Euro 3, with a relatively limited increase of the production costs.

For advanced non-stoichiometric engines, it is difficult to quantify the achievable emission levels due to the limited availability of technical data. These engine technologies might play an important role in achieving fuel consumption and CO_2 emission reduction. A trade-off between engine efficiency and emission performance is necessary and must be assessed for these engine types.

The actual level of emissions of future passenger cars with petrol engines will be determined by the evolution of emissions legislation. The extent of future incentives and possible legislation on CO_2 emissions will strongly influence the applied engine technologies and therefore the reduction potential for other exhaust gas emissions.

Fuel consumption and CO_2 emission

CO_2 is an inevitable product of a fossil fuel combustion process. Therefore, a reduction in CO_2 emission can only be achieved by a reduction in fuel consumption. With stoichiometric spark ignition engines, there is a range of possibilities as described below.

Improvement of partial-load efficiency

Low partial-load efficiency is characteristic of spark engines and is caused by throttle losses. Due to the fact that the engines in passenger cars most often operate under partial-load conditions, significant gains in fuel consumption can be achieved by improving their partial-load efficiency. In this respect, the following options can be considered:

- *Variable valve actuation.* In its most advanced form, this technology allows for the creation of a Miller cycle, thus eliminating the throttle losses. CO_2 reduction of up to 15% can be achieved. This option is on the brink of a large-scale introduction and is already being applied by several manufacturers.
- *Variable compression ratio*. This technique does not address the throttle-losses, but reduces efficiency losses resulting from incomplete charge. This option is rather complicated and a wide application is not expected in the short-term.
- *Direct-injection* on stoichiometric engines reduces the thermal losses and lowers the combustion temperature because it enables the fuel to vaporise in the combustion chamber with the heat of the intake air. Small reductions of the fuel consumption are achievable, but significant gains can be achieved under ‘lean’ ($\lambda>1$) conditions, as discussed later.
- *Downsizing*. Through the application of smaller capacity engines, the average load will increase. Application of charging (turbocharger or supercharger) increases the power output to a level that is acceptable to users. However, this option is not yet widespread.
- *Cylinder disconnection*. This option, which is suited to larger engines, increases load and efficiency on the cylinders that remain connected.
- *Integrated starter alternator (ISA)*. An ISA system enables a fast shut-down and starting of the engine, therefore enabling start-stop mode. Especially in city driving, significant reductions in fuel consumption are achievable. An ISA also enables a “mild hybrid” setting (discussed under the “hybrid vehicles” section).

Expected fuel consumption reduction

It is difficult to estimate for each option the reductions that are achievable. Also, the reductions that can be achieved by combinations of options are not equal to the sum of the individual reductions. It is still unclear to what extent certain options (or combinations of options) will be applied in practice. However, it is reasonable to expect that through application of certain of the options, a reduction of fuel consumption in the order of 25% is achievable in the next 10 years. To achieve further reductions, improvements need to be sought via lowering the vehicle weight and rolling resistance.

Alternative fuels

Alternative fuels with a lower carbon content and a higher hydrogen content offer the potential to reduce CO_2 emissions. This concerns mostly hydrogen and natural gas. For this purpose, the German manufacturer BMW has developed several prototypes that solely use hydrogen in the engine.

LPG offers less CO_2 advantages because the gain of a lower carbon content is in practice offset by a higher fuel consumption. Regarding regulated emission components, it is expected that CNG and LPG vehicles will have emission levels that are very little different from the very low-emission petrol vehicles. In the area of the unregulated components such as aromatics, gaseous fuels will have a considerable advantage over petrol.

Other options are the so-called durable fuels – including bio-fuels. Because of the partial recycling of CO_2, net CO_2 emissions from use as a vehicle fuel can be much lower. Bioethanol, for instance, could achieve an average greenhouse gas savings of between 50 and 65% compared to conventional petrol. Significant advances in biofuels technology are being made which offer to make possible the utilisation of low-value feedstocks at much higher conversion efficiencies. The technologies can be broadly characterised as:

- "Ligno-cellulosic" technologies: Enzyme-based hydrolyse of cellulose-rich biomass (*e.g.* straw, forest waste).
- Gasification of Fischer-Tropsch technologies: the application of heat and pressure to break down biomass into synthetic gas which is then reformed into ethanol or other road fuels.

Improvements in diesel engines

Reduction of exhaust emissions

The end-of-pipe emissions of modern diesel passenger cars (without de-NO_x catalysts and particulate filters) can be attributed to the following operations:

- Cold start.
- Effect of real surrounding temperatures.
- Off-cycle operation.
- Warm emissions.

In order to reduce fuel consumption, diesel engine technology has already switched to direct injection. However, direction injection can have negative impacts on emissions, especially NO_x and particulate matter (PM).

Under current emissions legislation, diesel engines are already equipped with oxidation catalysts (reduction of VOC and PM) and exhaust gas recirculation for reduction of NO_x. Further emission reductions have been recently made possible by optimising the shape of the combustion chambers, increasing injection pressures, accurate injection timing and rate shaping.

For further reductions, however, in order to meet future emission legislations, other measures will be needed. Even optimised oxidation catalyst reactivity and cooled and electronically controlled exhaust gas recirculation will not be sufficient in this respect. In order to lower NOx and PM from diesel engines to the level of petrol cars, techniques such as de-NO_x systems and particulate filters are inevitable. These options are discussed briefly.

CO and VOC

CO and VOC emissions of diesel engines are naturally very low, and can be reduced to near zero by means of an oxidation catalyst. However, during cold start conditions the VOC emission can reach significant levels. Oxidation catalysts also oxidise the soluble organic fractions (SOF) of particulates.

NO_x

Relatively high NO_x emissions are characteristic of diesel engines. Application of exhaust gas recirculation reduces NO_x emission, but not as effectively as a three-way catalyst on a petrol fuelled car. A three-way catalyst is not possible under lean conditions, and therefore special measures have to be taken. The following options exist:

- *Passive de-NO_x catalyst*, which uses engine output VOCs to reduce NO_x emission. The VOC concentration can be increased for instance by post-injection on a common-rail system. The conversion efficiency is however rather low.
- *Active de-NO_x catalyst*, which uses VOCs that are added separately to the exhaust gas to reduce NO_x emissions. This system requires extra components, slightly increases fuel consumption, has a rather variable efficiency and is not yet often used.
- *Selective catalytic reduction catalyst*, which uses a selective reductant, such as urea to reduce NO_x emissions. The urea is injected separately into the exhaust gas. The conversion efficiency is rather high. However, because of the need for a separate urea tank and a separate control system it consumes a lot of space on board the vehicle and will therefore mainly be applied on heavy duty applications. This system is insensitive to sulphur in the fuel.
- *NO_x storage catalyst*, which temporarily stores the NO_x during lean operational conditions and removes the stored NO_x during short rich conditions (regeneration). Regeneration occurs through post injection of fuel, and requires an advanced electronically-controlled diesel injection system. Because of the rich periods there is also a slight fuel consumption penalty. The conversion efficiency is rather high however, but low sulphur fuel is required because of its high sensitivity.

Particulate matter (PM)

Reducing the emission of particulate matter to the level of petrol engines can only be achieved through use of particulate filters. On heavy duty applications, particulate filters have already proven themselves, but on light duty applications additional problems arise due to the relatively low engine loads, which in turn cause plugged filters. The following options exist:

- Active particulate filter

Particulate filters need to be regenerated after some time to prevent clogging. Regenerating of filters would occur automatically when the exhaust gas would have a sufficiently high temperature of above 500°C. In practice, these temperatures are seldom reached, because of the low-engine loads. Therefore, additional measures are needed in order to actively initiate the regeneration, which can include:

- Forcing extra heat to the exhaust gas ("afterburning", electric heating, or post injection of fuel).
- Lowering the regenerating temperature by using an additive in the fuel (fuel-borne catalyst).
- Rinsing the filter after removing it.

- Passive/continuous regenerating filter

Passive or continuous regenerating filters are also known as Continuously Re-generating Traps (CRT). This type of filter operates in the same manner as an active filter, only the regeneration occurs continuously. Burning the particulates can occur at a lower temperature by using NO_2 as an oxidising agent, instead of oxygen. To increase the concentration of NO_2 in the exhaust gas, an extra oxidation catalyst is placed before the filter to convert NO into NO_2. This is a continuous process. This type of filter is very sensitive to the sulphur level of the fuel that is used.

The reduction potential of both active and passing filters is assumed to be 90%. Some car manufacturers already offer filters with efficiency above 90% for the entire spectrum of particulate sizes. At the end of 2003, Peugeot had equipped more than 600 000 new vehicles with such filters.

Unlike with petrol engines, lambda excursions do not play a role. Analyses of the emission causes and possible technical improvements of diesel engines indicate a significant potential for emission reduction, albeit smaller than for petrol engines. Cold start emissions can be improved by optimising the catalyst, though not to the same extent as for petrol engines. "Warm" NO_x emissions can be reduced by using a de-NOx catalyst and improved exhaust gas recirculation (EGR). The reduction of "warm" particulate emissions requires a particulate filter, while off-cycle emissions can be reduced by means of optimised engine calibration. All in all, reductions of the real-world emissions of CO, VOC, NO_x and PM by 75% or more compared to Euro 3 seem possible by a combination of incremental improvement of existing technologies and the application of additional aftertreatment technologies.

The actual level of emissions of future vehicles will be strongly influenced by the evolution of emission legislation.

Fuel consumption and CO_2 emission

A modern direct injection diesel engine has a fuel consumption advantage of 25% over modern petrol engines. Because of the difference in density between petrol and diesel, the advantage in MJ/km is about 15%. The corresponding CO_2 emissions are about 14% lower when compared to a petrol engine.

Given its relatively good performance at present, the possibilities for further improvement in diesel engine efficiency are limited. Diesel engines do not suffer from throttle losses; howeve,r turbo-diesels (nearly all modern diesels) have a worse cylinder filling at low engine revolutions because of the slow response of the turbocharger. Regarding turbo-pressure regulation, major improvements are still possible. Slightly decreased efficiency is also to be expected through the application of exhaust aftertreatment systems such as particulate filters and de-NO_x catalysts.

Downsizing and start-stop systems are also options for diesel-engines, but because of the different behaviour of diesel-engines under partial load, the gains to be achieved are rather limited compared to what can be expected with Otto-cycle engines.

Alternative fuels

Diesel engines are also suitable for use of durable low-CO_2 or CO_2-neutral fuels, such as vegetable biofuels or synthetic fuels.

Biodiesel can be made from any vegetable oil, using a process known as trans-esterification, which involves the addition of methanol in the presence of a catalyst to produce biodiesel and a by-product, glycerol. Rape-seed based biodiesel has smaller benefits in terms of CO2 but does offer the agricultural sector a diversified market for its products. A UK study (Mortimer *et al.*, 2002) on biodiesel carbon balance suggested that a 55% reduction in CO_2 was a representative figure for UK production, with higher figures achievable with the best cultivation conditions. One promising option for bio-diesel production is the application of the Fisher-Tropsch processes[3] to diesel production, potentially enabling the production of a renewable diesel fuel.

Improvements of non-stoichiometric (lean burn) petrol engines

First, it should be noted that non-stoichiometric (lean) spark ignition (Otto) engines are not necessarily direct injection engines. The opportunities of direct injection are used to create lean conditions in a part of the engine map. In fact, this possibility to create and control lean conditions led to the development of the DI engine in the first place. It can be assumed that in the future, all Otto engines will be equipped with direct injection. The question remains whether these engines will be stoichiometric or non-stoichiometric. This will strongly depend on the direction of future legislation and the choice between NO_x reductions and CO_2 reductions.

It is well known that the Otto engine does not reach its optimal efficiency at a stoichiometric mixture setting (λ=1). Lean mixtures can result in up to 15% higher efficiencies. However, in order to respond to accelerations and high power demands, the mixture needs to be enriched. The latter limits the efficiency gains to the low-partial load areas. In the ideal case, the throttle valve could be deleted completely, leaving a quality regulated power output.

[3] Production of diesel through natural gas.

Lean mixtures tend to ignite less effectively than rich mixtures. A solution for this problem is stratified charge, creating a rich area in the combustion chamber near the spark plug. Because of the non-homogeneous mixture, the particulate emissions rise signify-cantly using this approach.

The promise of this concept has been greater than the actual results thus far, because considerations regarding power and emissions enabled lean conditions in only a small area of the engine map. Much effort is being put into the further development of this concept, which would increase the benefits. Therefore the prospects for this concept are rather good. The improvements in the fuel consumption could eventually be up to 20%.

For emission reduction, a three-way catalyst is added, which under lean conditions, functions as an oxidation catalyst. NO_x emissions are however not reduced under such conditions, which causes the end-of-pipe emissions to rise dramatically. NO_x storage catalysts (see also diesel engines) are currently under development and may be a solution for this problem but they are extremely sensitive to the sulphur content of the fuel. The conversion efficiency of a NO_x storage catalyst is lower than a three-way catalyst. As a result, it is assumed that the NO_x emission of lean burn cars will be about 20% higher as compared to a stoichiometric engine. In practice, this signifies that manufacturers will calibrate the NO_x emission close to the legislative limits in order to reduce fuel consumption as much as possible.

Air resistance improvements

The force of air resistance of an object moving through air (aerodynamic drag) is determined by the following equation:

$$F_D = \frac{1}{2} C_D \cdot A . \cdot \rho . v^2$$

in which:

C_D is the non-dimensional drag coefficient of an object.
A is the projected frontal area of an object.
ρ is the density of the surrounding air.
v is the speed of an object.

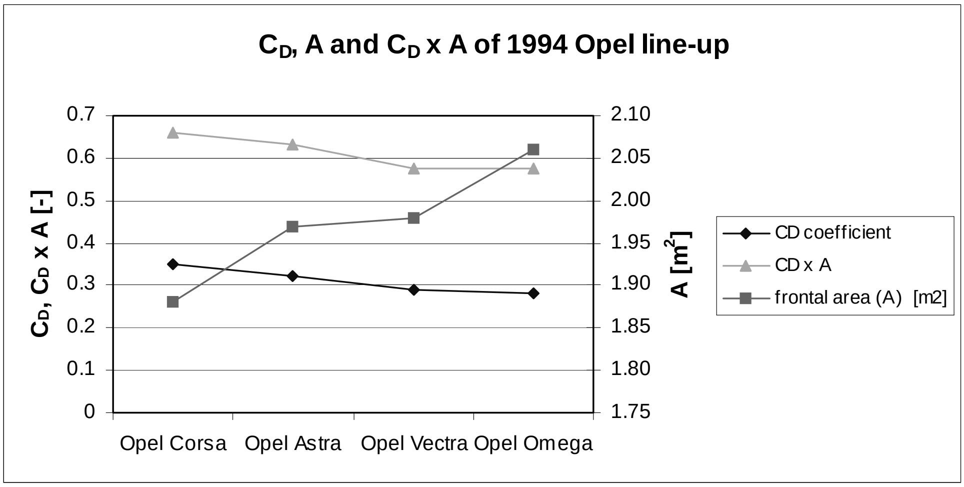
The drag of a vehicle is therefore determined by its frontal area and by its shape, the aerodynamic quality of which is described by the drag coefficient C_D. Generally, the vehicle size and hence frontal area, is determined by the design requirements, and efforts to reduce drag are concentrated on reducing the drag coefficient.

Practical considerations, such as the capability to carry 5 persons and a sufficient luggage space usually lead to the C_D coefficients of production cars averaging around 0.30. The lowest C_D coefficients are around 0.25 as is the case with the Honda Insight.

An average C_D coefficient of 0.25 is possible when innovative systems such as rear view cameras instead of mirrors and aerodynamic optimised underbodies are applied. It must also be kept in mind, however, that since air resistance increases with the square of speed, the effects on fuel consumption of aerodynamics are more prominent at high speeds (above 120 km/h) that are becoming increasingly uncommon in today's traffic.

The frontal area is also a matter of practical design considerations relating to customer demand. As an example, some aerodynamic parameters of the 1994 Opel line-up are displayed in Figure B.7. This figure shows that though the bigger-sized cars have larger frontal areas, the product of the frontal area and the drag coefficient is decreasing. This is caused by the better aerodynamic efficiency of the larger cars compensating for the larger frontal area.

Figure B.7. Drag coefficient (CD), frontal area and CD x A of the 1994 Opel product line-up



Source: Opel.

Improvements in the rolling resistance of traditional vehicles

Rolling resistance is the result of energy losses that occur through deformation of the tread of a tyre when driving over a certain surface. The amount of rolling resistance is determined by the damping characteristics of the materials used. This converts mechanical energy into heat.

A reduction of the rolling resistance will reduce the driving resistance and thus fuel consumption. In "traditional" tyres, rolling resistance was reduced by lowering the hysteresis, and as a result, the damping characteristics of the tread. However, this reduces the braking force of the tyre, especially on wet surfaces, which is an unwanted side effect. In modern tyres, this problem is therefore overcome through the introduction of other components in the tyre.

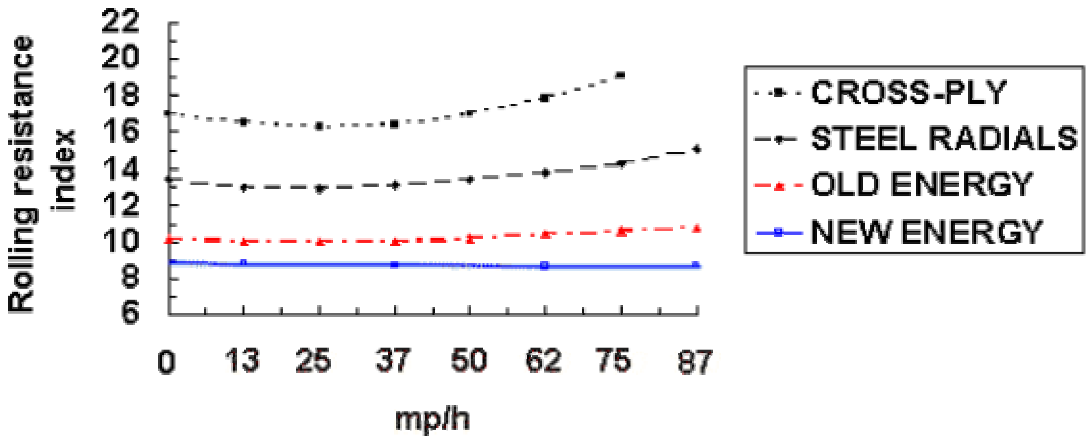
The rolling resistance value is determined by the following parameters:

- Road surface.
- Tyre.
  - Tyre temperature.
  - Geometry of the tyre.
  - Height/width quotient.
  - Material characteristics.

- Driving circumstances.
  - Tyre pressure.
  - Wheel geometry.
  - Gravitational force.
  - Speed.

Figure B.8 indicates the rolling resistance as a function of speed for four types of tyres.

Figure B.8. Rolling resistance as a function of speed



Source: Pirelli.

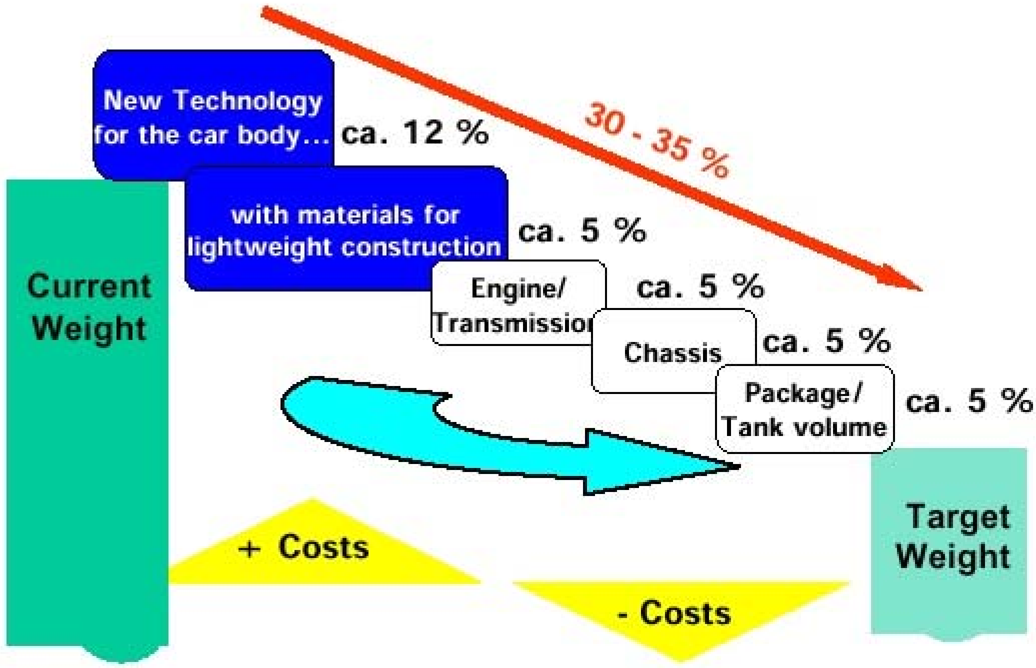
The rolling resistance increases from speeds above 50 mph for old cross ply and steel radial tyres, but the rolling resistance for modern "energy" tyres remains constant.

Tyre pressure is an important parameter influencing the rolling resistance. When the pressure drops below the prescribed pressure, the rolling resistance increases. To overcome this problem, it is becoming more common to equip cars with a system that continuously checks the tyre pressure, and warns the driver when the pressure is too low.

Raising the tyre pressure above the value prescribed by the manufacturer lowers the rolling resistance caused by less energy losses occurring through deformation of the tyre. Overly elevated pressures, however, have adverse effects on vehicle handling and braking power of the vehicle. It is therefore advised not to raise the pressure by more than 10% above the prescribed value.

The weight of vehicles results in a gravitational force on the wheels. If the weight of the vehicles is reduced, the rolling resistance and the resulting fuel consumption are also reduced. Some gains in the vehicle weight can still be made. These effects are presented in Figure B.9 and can result in a weight savings of up to 35%.

Figure B.9. Technical parameters influencing fuel consumption



Source: Volkswagen.

The first two actions reduce the vehicle weight by approximately 17% but also add cost to the vehicle, because other more expensive materials must be used. The last three actions not only reduce the vehicle weight, but also reduce the cost of the vehicle, because they require less material.

Advanced driveline concepts

The existing technology has some shortcomings: low-efficiency, emission of greenhouse gases, health risks related to the emission of toxic material, consumption of non-replaceable fuels. The question arises whether there exists a better alternative. For some years, research has been going on to develop new techniques. The techniques under consideration are: full electric vehicles, hybrid vehicles and fuel cell vehicles. This section presents a description of each of these technologies.

Hybrid vehicles

What is a hybrid vehicle?

A hybrid vehicle is equipped with a conventional internal combustion engine and an additional power source. Possible additional power sources include electric motors, hydraulic motors, mechanical flywheels and ultra capacitors. Most of the hybrid vehicles developed in recent years are hybrid electric vehicles (HEVs) equipped with an electric motor for higher efficiency and better controllability. HEVs have three primary advantages:

- Regeneration of deceleration energy.
- Engine stop concurrent to vehicle stop.
- Optimisation of engine drive conditions.

Energy Breakdown of a Hybrid Vehicle

The breakdown of the energy consumption of a typical hybrid vehicle is given in Table B.4. In a hybrid electric vehicle, an electrical machine and battery are used to improve the drivetrain losses.

Table B.4. Energy breakdown of a typical hybrid car

Type of road		Urban		Highway	
Energy content of fuel			**100%**		**100%**
Drivetrain losses	Thermodynamic losses	51%		56%	
	Engine losses	11%		3%	
	Transmission losses	6%		6%	
	Total		**68%**		**65%**
Used for components	Auxiliaries	3%		1%	
	Accessories	1%		1%	
	Air conditioning (when in use)	15%		11%	
	Total (with air conditioning)		**19%**		**11%**
	Total (no air conditioning)		**4%**		**2%**
Used for propulsion	Air resistance	2%		12%	
	Roll resistance	5%		8%	
	Kinetic losses/braking, no inclination	6%		2%	
	Total (with air conditioning)		**13%**		**22%**
	Total (no air conditioning)		**28%**		**33%**

Regeneration of deceleration energy

In conventional vehicles, deceleration energy is exclusively dissipated as the heat generated by frictional braking and engine braking. In HEVs, deceleration energy is harnessed to activate a drive motor serving as a generator so as to be stored in a battery or another energy storage system until reutilisation during acceleration.

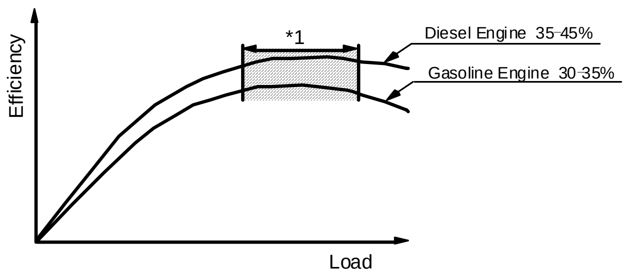
Engine stop concurrent to vehicle stop

When coming to a stop, HEV engines stop as well. This is made by possible by the fact that HEVs are equipped with a far more powerful electric motor than the starter of a conventional vehicle. HEVs are therefore capable of restarting their engines in an instant at the request of the driver.

Optimisation of engine drive conditions

As shown in Figure B.10, engines are characterised by low efficiency at low loads. For this reason HEVs are designed to run in the high efficiency region as much as possible by minimising low load driving. In addition, the motor is activated to assist the engine in its peak engine load period so as to reduce NO_x and PM emissions.

Figure B.10. Load-efficiency characteristics of internal combustion engines and the engine operation target for HEVs



*1: Engine Operation Target for HEVs

Due to their advantages, HEVs achieve greater fuel economy (up to twice the fuel economy of conventional heavy passenger vehicles on urban cycles) and lower exhaust emissions. When drivers take control over the driving conditions, the efficiency generally is lower than when the automatic hybrid management system (calibrated by the manufacturer) is used.

On the other hand, a disadvantage of HEVs is their tendency to require a heavyweight and complex structure, mainly because they must incorporate a battery, an electric motor and an inverter in addition to a conventional engine. Another disadvantage is that, although designed to generate the maximum output power equivalent or superior to that of conventional vehicles, HEVs cannot yield the maximum output over a sustained period. The above disadvantages lead to a lowered running performance on uphill roads. On continuous and steep uphill roads, the fuel economy advantage of HEVs over conventional vehicles dwindles because of a drop in deceleration energy regeneration.

However, HEVs currently in the market have nearly resolved these problems by increasing the output/energy density of energy storage systems, improving the motor's specific power output, optimising the output capacity (mounted weight) according to vehicle applications, and by improving the system design.

HEV types

HEVs are classified into types according to the charging mode and the system architecture.

Classification by charging mode

HEVs can be classified into two categories: those with and without external charging on the power network.

HEVs with a charging system on the power network are mainly electric vehicles equipped with a small additional ICE engine which is used as an auxiliary electric generator in order to extend the driving range, while most of the energy comes from the electric storage of the batteries. These HEVs (often called electric vehicles with "range extender") are mainly being developed in Europe to extend, on an exceptional basis, the EV's cruising distance, but they have not yet won over many consumers due to frequent charging and weighty battery requirements.

HEV without a power network charging system are equipped with a major ICE engine to produce the electricity used for propulsion. The external non-charging type has been developed and introduced to the market, primarily in Japan over the past years. As the vehicle makers in Europe and the United States are also planning to commercialise this type in the coming years, external non-charging HEVs are expected to become the future mainstay.

Classification by system composition

HEVs are also classified according to system composition, usually into three types: series, parallel and series/parallel.

1. Series HEVs

As illustrated in Figure B.11a, series type HEVs utilise engine power converted into electricity through a generator. Series HEVs have the advantage that their engine is not mechanically linked with a wheel axle, providing the ability to optimise their engine operation region. Their primary disadvantage is large energy loss due to a long energy transmission series from the engine, generator and battery to the motor. The fuel economy of series HEVs exceeds conventional vehicles in the low speed/low load region where the engine efficiency drops. Nevertheless the HEV fuel economy falls below that of conventional vehicles in the high load region due to an increase in energy transmission loss. As a result, series HEVs are suited to the low speed go-&-stop driving inside the city. Mitsubishi Motors and Nissan Diesel have introduced city buses of this type.

2. Parallel HEVs

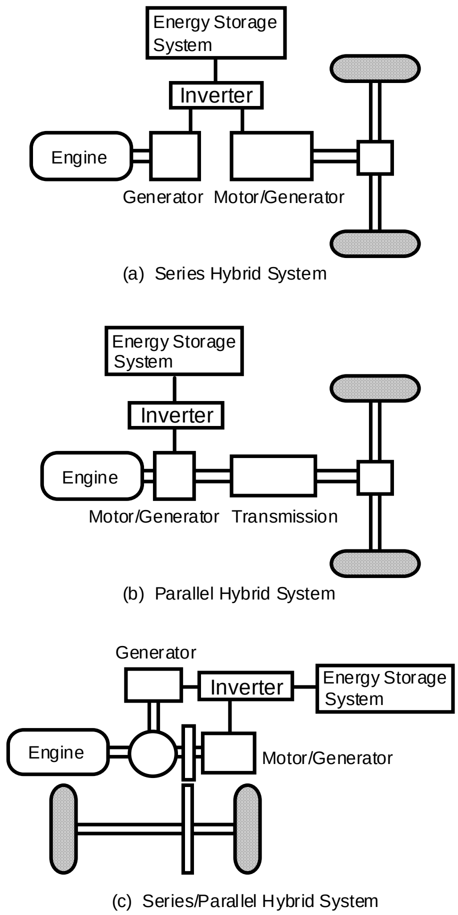
The system composition of a parallel type HEV is presented in Figure B.11b. By directly utilising the engine power during high load drive, parallel HEVs are characterised by their better fuel economy than conventional vehicles irrespective of vehicle speed. In the Honda Insight, the engine flywheel is replaced by a relatively low output motor so that this motor serves simultaneously as starter and alternator, leading to a highly simplified structure. (The Honda Insight, however, is also equipped with an emergency starter.) Parallel HEVs offer considerable potential for vehicle cost reduction, because they allow the use of conventional wheel-to-wheel power transmission systems and minimise the amount of battery mass. On the other hand they are disadvantaged by lower efficiency of deceleration energy recovery. This is because their engines are linked directly with a motor, thus sustaining an engine friction loss during regenerative brake operation.

Presently, a simpler version of a parallel HEV is being developed, using rated 36V batteries and a 42V power source system. This simple type of HEV – which is called a "mild HEV" – adopts conventional power trains and replaces the starter and alternator by a single motor/generator unit. Its biggest advantage lies in the reduction of specialised parts and battery mass.

3. Series/parallel HEVs

As graphically displayed in Figure B.11c, a series/parallel type HEV is a mixture of series and parallel HEVs. Series/parallel HEVs are powered by a motor in the low-speed / low-load region and by an engine in the high-speed / high load-region. Consequently, they offer favourable efficiency irrespective of running conditions (Iwai, 1999). As a disadvantage, many of these vehicles require a specialised transmission. For example, the Toyota Prius incorporates a planetary gear continuously variable transmission (CVT) and the Nissan Tino Hybrid, a belt type CVT. Optimal design and control of the transmission is considered to be the crucial key to success for series/parallel HEVs.

Figure B.11. Composition of three hybrid systems



Potential of hybrid vehicles to reduce local pollutants

In hybrid vehicles there is not always a direct relationship between engine speed and torque and wheel speed and torque (Smokers *et al.*, 2001). In the most extreme case of some series hybrids, they are actually completely decoupled. In this case, the internal combustion engine – which is the only source of emissions – is operated at a working domain picked in order to minimise fuel consumption and/or emissions. Therefore, the emissions are independent of real world driving conditions and always minimal and well-known.

In a “simple parallel hybrid” there is a mechanical link from the internal combustion engine (ICE) to the wheel so that the speeds of both devices are proportional to each other. The electric machine can be used to keep the ICE’s torque in a low emissions area. This area can vary with speed. Regulation of this type of hybrid can be tricky and the success of this technology in the domain of emissions is a function of the quality of the engineering of the vehicle. The hybridisation in itself is not a guarantee of low emissions.

The Honda Insight

The Honda Insight is a parallel HEV. It employs a lean-burn engine with a close-coupled, three-way catalyst and a NO_x adsorbing catalytic converter. The exhaust manifold is integrated into the cylinder head (allowing the TWC to be mounted very close to the engine for rapid light-off). The engine design includes increased swirl in the combustion chamber for more complete combustion. The Insight’s hybrid control strategy includes an idle stop feature to reduce fuel consumption and emissions during idle operation. The idle-stop is not allowed to engage until the engine has reached a sufficient temperature to avoid repeated cold starts. Honda also quotes precision fuel and spark control augmented by a new honeycombed catalyst and a new secondary air-injection system with an electric air pump.

The Honda Insight was certified using the FTP-75 and the Cold CO test procedures. Table B.5 summarises the Honda Insight emissions certification data available from the US EPA.

Table B.5. Honda Insight emission data

	Useful life level (km)	Test results (g/km)		Emissions standards (g/km)	
		test1	test2	CA-ULEV	NLEV
FTP-75 test results					
CO	80.5K	0.249	0.329	1.056	2.113
	161K	0.398	0.478	1.305	2.610
NO_x	80.5K	0.037	0.050	0.124	0.124
	161K	0.037	0.050	0.186	0.186
NMOG	80.5K	0.019	0.020	0.025	0.047
	161K	0.023	0.024	0.034	0.056
HCHO	80.5K	0.0002	0.0002	0.0050	0.0093
	161K	0.0002	0.0002	0.0068	0.0112
Total HC	80.5K	0.025			0.255
	161K				
Cold CO test results					
CO	80.5K	1.72		10	10

The closed loop fuel metering in combination with the catalytic converter have greatly decreased emission levels of conventional vehicles to levels far below the homologation requirements. There is no technical reason why emissions of conventional vehicles could not be low in all operating areas, but as long as there is no obligation for low emissions over the whole engine map for off cycle use, performance and drivability will be favoured rather than fuel economy and low emissions (as discussed previously).

A significant advantage of hybrid vehicles over petrol or diesel vehicles is their ability to not produce emissions of local pollutants. Therefore, HEVs can be driven in areas reserved for "zero emission" vehicles. In congested traffic, they perform extremely well, since the vehicle operates in these conditions in the electric mode. In these situations, the emissions of conventional vehicles are actually higher than average because of the low distance travelled or the small amount of energy produced. The emissions of HEVs would be lower than average even for parallel hybrids with limited electric traction power.

The Toyota Prius

The Toyota Prius is a series-parallel hybrid. It is a unique design that regulates energy flows by using an Internal combustion engine, a NiMh battery, a planetary gearbox and two electric machines.

For the engine, the Prius employs a high expansion Atkinson cycle engine with slanted squish area combustion chambers and multi-injector nozzles for increased atomisation of the charge fuel. Toyota quotes a "high-density ceramic catalyst substrate with super-thin walls that heats to catalysing temperatures faster". While the catalyst is still below temperature the hybrid control system prioritises engine control to maintain low-level emissions. Also, while the catalyst is below temperature, a HC absorber is employed to capture HC's and release them after the catalyst lights off. Evaporative emissions are reduced through the use of a fuel tank that expands and contracts to reduce the volume available for evaporation depending on the fuel level. Other key emissions related features of the hybrid control system include balancing the use of the electric motor and engine to maintain engine operation within an efficient band, shutting off the engine during idle or deceleration, and electric-only operation under low speed and load conditions. The Prius also controls the use of the electric motor and petrol engine to smooth out transient operation of the engine.

The Toyota Prius was certified in the United States using the FTP-75, Cold CO, US06 and SC03 test procedures. Table B.6 summarises the Toyota Prius emissions certification data available from the US EPA.

The Prius was initially built and certified for the Japanese market with a smaller engine than the one for the US and European markets. Emission data on this version are available from different laboratories (Table B.7). In Europe the Prius was certified to EURO 4.

Table B.6. Toyota Prius US emission data

	Useful life level (km)	Test results (g/km)		Emissions standards (g/km)	
		test1	test2	ULEV	CA-SULEV
FTP-75 test results					
CO	80.5K	0.087		1.056	
	161K	0.130		1.305	
	193K	0.267			0.621
NO_x	80.5K	0.006		0.124	
	161K	0.006		0.186	
	193K	0.006			0.012
NMOG	80.5K	0.001		0.025	
	161K	0.001		0.034	
	193K	0.002			0.006
HCHO	80.5K	0.000		0.005	
	161K	0.000		0.007	
	193K	0.000			0.002
Cold CO test results					
CO	50K	1.056		6.214	
		1.118			6.214
US06 test results					
CO	-	0.056		4.971	4.971
NMHC+ NO_x	-	0.007		0.087	0.087
SC03 test results					
CO	-	0.081	0.323	1.678	1.678
NMHC+ NO_x		0.000	0.015	0.124	0.124

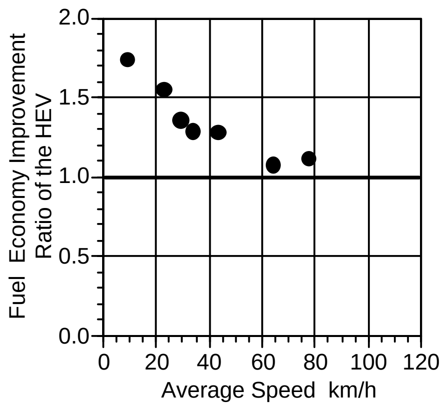
Table B.7. Japanese and European Toyota Prius fuel consumption and emission data

Source	Cycle	Fuel C. l/100	Emissions g/km			Remarks
			CO	*HCt*	*NO_x*	
Euro 4 limits	NEDC		1.00	0.10	0.08	
Japanese Prius						
IFP	10-15	4.4	0.01	0.01	0.05	1360 kg
INRETS	10-15	4.3	0.09	0.02	0.05	1360 kg
Toyota	10-15	3.6	0.36	0.03	0.04	
TNO	10-15	4.57	0.05	0.01	0.03	
INRETS	MVEG	5.6	0.60	0.120	0.09	
IFP	MVEG	5.7	0.60	0.09	0.06	
TNO	FTP 4 bag		0.20	0.03	0.05	
EPA	FTP 4 bag	4.85	0.25	0.04	0.03	
European Prius						
Toyota	NEDC	5.1	0.63	0.05	0.05	

Potential of hybrid vehicles to reduce fuel consumption

Figure B.12 shows the fuel economy of a series/parallel HEV in comparison to a conventional vehicle of the same model. The HEV's fuel economy improvement ratio increases as the average vehicle speed declines, and falls as the average speed rises. This can be explained by the fact that as the average speed rises, the percentage of idling time declines while that of constant-speed running increases, which results in a reduced effect of engine stop and deceleration energy regeneration. As the average speed rises, the running load increases to create a region similar to the engine drive region of conventional vehicles. It is therefore more advantageous to introduce HEVs into city areas where the average vehicle speed is low.

Figure B.12. Fuel economy improvement ratio of the series/parallel HEV compared to the same body conventional vehicle



When one compares fuel consumption of the hybrid Honda Insight with fuel consumption of vehicles in the same class, the fuel consumption of the Insight is 50% better (see Table B.8).

Table B.8. Comparison of fuel consumption

	City [l/100km]	Highway [l/100km]
Honda Insight	3.9	3.4
Chevy Metro	6.1	5.2
Suzuki Swift	6.6	5.7
Honda Civic HX	6.8	5.5
Toyota Echo	7.0	5.8

Source: American Council for an Energy-Efficient Economy, The Detroit News.

Life cycle analysis

While the above comparison relates to energy consumption during HEV use, the energy consumption during HEV production needs to be examined on a life cycle basis in order to undertake a comprehensive evaluation of the energy consumption by HEVs in production and use. The HEV's energy consumption in production is considered likely to exceed a conventional vehicle's energy consumption in production due to the greater number of parts required by HEVs. As an example, according to an inter-industry relations table and analysis, a 2 tonne class CNG hybrid electric cargo truck's energy consumption in production is estimated to be no more than 1.2 to 1.8 times that of its conventional counterpart (Tanaka and Nakamura, 2000). Assuming a lifetime driving distance of 200 000 km, the results obtained suggest an HEV's energy saving during use is likely to be more than offset by its energy spending excess in production. In other words, there is likely to be no net energy saving on s life-cycle basis.

Brake energy regeneration

Brake energy regeneration also results in fuel savings. Energy is stored in an energy storage system. Technologies for storage of energy are high-power batteries, ultra capacitors and flywheels. Batteries used to store braking energy must have a high power-to-energy-ratio. Furthermore, these batteries must withstand charging and discharging many times during operation. The development of batteries is mainly focused on applications for full electric drivetrains. The specific power amounts to up to 3000 W/kg. The same specifications apply to ultra capacitors: high specific power and high charge/discharge energy efficiency. The properties of the ultra capacitors make them suitable for applications in hybrid electric vehicles. The specific power is around 1000 W/kg. The discharge of ultra capacitors when not in use is rather high: around 10% per day, whereas for batteries it is (much) less than 1%.

The specific power of flywheels is a maximum of 500W/kg and their specifications make them suitable for applications in hybrid electric vehicles. Their power discharge when not in use is in the same order as for ultra capacitors – 10% discharge per day. A drawback of flywheels is that their weight. For all three technologies, there is the problem of added weight, space and cost. What is needed is lightweight and compact equipment provided at low cost.

Technical measures to overcome current HEV barriers

The greatest barrier to widespread use of HEVs is their relatively high cost, which is caused mainly by the high costs of the batteries and the motor's permanent magnets. The HEVs sold in Japan – excluding "mild HEVs" – are for sale for around USD 4 000 to USD 8 000 more than their conventional vehicle counterparts. The price gaps are not closed by the savings in fuel purchases for the HEV's over their service life. To narrow the price gaps, the government in Japan has implemented various promotional measures, including a tax reduction and the extension of a subsidy to HEV purchasers equal to one-half of the price differential between the HEV and its conventional vehicle counterpart.

Vehicle manufacturers are striving to cut HEV production costs by expanding the merit of mass production and developing simpler hybrid systems. In the case of mild HEVs, manufacturers have successfully narrowed the price gap to about USD 1 250. Although the fuel savings by mild HEVs are moderate – around a 15% reduction - experience has shown their fuel economy is an effective attribute that promotes HEV purchases. The IEA's World Energy Outlook Reference Scenario assumes the average IEA crude oil import price (a proxy for international oil prices) to remain at about the same level over the period 2002 – 2010 as for 1986 – 2001. However, the Reference Scenario anticipates petroleum prices could then rise continuously in the medium term to 2020 and 2030. In such circumstances, it can be expected that HEVs will become relatively more attractive for the public. (IEA, 2002).

Full electric vehicles

Energy breakdown of a full electric vehicle

Table B.9 presents the energy consumption of a full electric vehicle.

Table B.9. Energy breakdown of a full electric vehicle

		Urban		Highway	
Energy content of the battery			**100%**		**100%**
Drivetrain losses	Battery losses	18%		13%	
	Electric machine losses	6%		4%	
	Transmission losses	27%		23%	
	Total		**51%**		**40%**
Used for components	Auxiliaries	4%		2%	
	Accessories	2%		2%	
	Air conditioning (when in use)	21%		18%	
	Total (with air conditioning)		**27%**		**22%**
Used for propulsion	Air resistance	4%		21%	
	Roll resistance	8%		13%	
	Kinetic losses/braking, no inclination	10%		4%	
	Total		**22%**		**38%**

In the past decade, several full electric vehicles were developed and made commercially available. One of their major problems has been their limited range due to the limited energy density of the batteries that are commercially available today (65 Wh/kg for Ni-MH batteries for example). Only a limited amount of battery capacity can be installed in the vehicle because of the added battery weight, thus resulting in the limited range. A breakthrough for battery electric vehicles (BEVs) is not expected. In the short and medium-term there would not seem to be any prospect of a new generation of affordable batteries becoming available with a high energy density. Another problem faced by battery electric vehicles is the lack of infrastructure available for re-charging the batteries.

Modern electric vehicles have the ability to recuperate braking energy. During braking, the electric motor acts as a generator and converts brake energy in electric energy which can be stored in the on-board battery. With this ability, their limited range is extended a little.

Electric vehicles offer the greatest potential advantages in densely populated areas, because they produce no emissions of local pollutants and emit no motor noise. In these areas, niche applications are available – such as taxi cabs or delivery vans which operate close to their ‘base stations’ – in which case the limited driving range of a BEV is less of a problem and re-charging infrastructure can be developed more easily. The most promising new form of electric vehicle that is being developed is an electric vehicle equipped with a range extender, which is termed a “hybrid” vehicle.

Fuel cell vehicles

This section complements the summary description given in the main report. The reader should refer to it for discussion on fuel choice, fuel storage and reformer type.

What is a fuel cell vehicle?

In a fuel cell vehicle, the power train consists of three major modules: a fuel cell stack; a fuel reforming and conditioning system and an electric motor. The stack consists of a sequence of fuel cells. The reforming and conditioning system is dependent on the fuel used. The fuel cell is an electro-chemical device directly converting fuel (*e.g.* hydrogen) to electricity.

The highly efficient conversion in fuel cells from chemical energy to electrical energy results in few pollutant emissions. In fuel cell vehicle applications, a fuel cell system based on hydrogen fuel is often chosen in which case the hydrogen needs to be stored on-board or produced from other fuels such as petrol, natural gas or methanol by means of a reformer.

Despite their potential; efficiency, there are a number of problems facing the introduction of fuel cell vehicles on a large scale in the marketplace. One is the choice of fuel: hydrogen or petrol or methanol. When hydrogen is chosen, a complete new distribution network must be developed which is a costly business. When methanol or petrol is chosen, the vehicle must be equipped with a reformer – and if it is, the vehicles have no great advantage over new generations of ICEs in the field of emissions and fuel consumption.

Energy breakdown of a fuel cell electric vehicle

The breakdown of the energy consumption of a fuel cell reformer electric vehicle is provided in Table B.. The fuel is processed through a reformer into hydrogen. In the stack, hydrogen is used to generate electric energy, which is converted by an electric motor into mechanical energy. If the vehicle operates on pure hydrogen, no reformer is needed onboard the vehicle and the resulting breakdown will be different from that set out in the table.

Table B.10. Energy breakdown of a fuel cell electric vehicle

Type of road		**Urban**	**Highway**
Energy content of the fuel		**100%**	**100%**
Drivetrain losses	Reformer losses	31%	27%
	Fuel cell losses	28	29%
	Transmission losses	12	11%
	Total	**71%**	**67%**
Used for components	Auxiliaries	3%	1%
	Accessories	1	1%
	Air conditioning (when in use)	12%	10%
	Total (with air conditioning)	**16%**	**12%**
Used for propulsion	Air resistance	3%	11%
	Roll resistance	5%	8%

	Kinetic losses/braking, no inclination	5%	2%
	Total	**13**%	**21**%

Fuel cell types

In a fuel cell, the chemical energy of the fuel is converted directly into electrical energy. It is theoretically possible to achieve electrical conversion efficiencies up to 80%. One of the main differences from a battery-powered electric motor is that with a battery, the "fuel" and oxidant are stored internally as a solid or fluid. They can be regenerated when charged. In a fuel cell system, the fuel and the oxidant are stored externally and can be added continuously in a gaseous or fluid form. For this reason, the range of the vehicle is determined by the capacity of the fuel tank, just as with conventional vehicles.

Six types of fuel cells are currently under development for use in vehicle. Each has its characteristic electrode materials, electrolytes, membranes and operation temperature. Table B.11 gives an overview of current fuel cell types. The name of the specific fuel cells is mostly derived from the electrolyte type used (Mourad *et al.*, 2001).

Table B.11. Overview of fuel cell types

Type	Electrolyte	Temperature °C	Specific power W/kg	CO_2 Tolerance	CO Tolerance	Reformer needed	Development stage
PAFC	H_3PO_4	150 – 200	50 - 100	Good	Average	Yes	Commercial
AFC	KOH	50 - 80	50 - 100	Bad	Bad	Yes	Demonstrator
PEFC	Membrane*	60 – 90	50 - 1000	Good	Bad	Yes	Demonstrator
SOFC	ZrO_2/Y_2O_3	800 – 1000	50 - 300	Good	Good	Yes*	Demonstrator
MCFC	Li_2CO_2/K_2O_3	600 – 650	50 – 100	Good	Good	Yes*	Demonstrator
DMFC	Membrane*	60 – 90	50 - 300	-	-	No	Testing

* Fluorpolymer which is selective for passing proton.
** Reformer for SOFC and MCFC is relatively simple and sometimes not necessary.
PAFC = phosphoric acid fuel cell.
AFC = alkaline fuel cell.
PEFC = polymer electrolyte fuel cell.
SOFC = solid oxide fuel cell.
MCFC = molten carbonate fuel cell.
DMFC = direct methanol fuel cell.

The characteristic cell voltage of a fuel cell is 0.5-0.8 V with a current density of 0.1-1 A/cm^2 (power density of 0.05-0.8 W/cm^2). The performance is commonly expressed in terms of its specific power. This falls most often in the range of 50-1000 W/kg. The cells are positioned in so called stacks. This results in a series alignment with resulting Voltages of 10 to 100 V per stack. When fuel cells are mentioned, one is often referring to fuel cell stacks. For low temperature fuel cells, hydrogen is up to now the only suitable fuel. Other fuels (*e.g.* methanol, methane, LPG, diesel, petrol) need to be converted to hydrogen first by means of a reformer. The gas so formed (*e.g.* hydrogen, carbon dioxide, carbon monoxide) must meet strict demands for use in the fuel cell. Higher temperature fuel cells do not necessarily need a reformer (*e.g.* in the case of natural gas) or need only partly reforming (from diesel to natural gas). For cars and trucks, a Polymer Electrolyte Membrane (PEM) is most often chosen.

The advantages and disadvantages of a fuel cell can be summarised as follows:

- Advantages:
  - High potential efficiency.
  - Low emissions.
  - Opportunity to use hydrogen produced from sustainable sources.
  - Possibly less maintenance as a result of the absence of moving parts.
  - In the event of the use of fuel cells in combination with reformers: the opportunity to make use of the existing fuel infrastructure.

- Disadvantages:
  - Hydrogen is extremely inflammable, and difficult to store.
  - The complete absence of a hydrogen infrastructure for supplies to ordinary vehicles.
  - The use of a reformer to enable other fuels lowers the energy efficiency, particularly on a well-to-wheel basis.
  - High costs.
  - Slow response of the reformer to varying loads.
  - The power train can be of a substantial size.
  - System integration.

Potential of fuel cell vehicles to reduce local pollutants

The emissions from a fuel cell electric vehicle on pure hydrogen are limited to only water. In the case of a fuel cell vehicle with a reformer, the fuel cells produce pollutant emissions. There are only a few test results currently available from fuel cell electric vehicles with a reformer. The available figures show a large diversity of results. However, even if the highest values are used, pollutant emissions of fuel cell vehicles with reformer could still be quite low. The indirect local HC-emissions of fuel cell vehicles resulting from refuelling and evaporation from the tank could be higher per kilometre than direct emissions. Some studies predict for FCEVs on methanol and petrol a value of 15 mg/km and others 5 mg/km.

Potential of fuel cell vehicles to reduce energy consumption

The direct CO_2 emissions of fuel cell vehicles with reformer in the mid-term are a little bit less than those of diesel vehicles. It is however important to consider CO_2 emissions on a well-to-wheel basis. On this basis, the CO_2 emissions for the production of petrol are about 14g CO_2/MJ. For Diesel the equivalent figure is approximately 11g CO_2/MJ. The efficiency for the production of methanol from natural gas is around 19g CO_2/MJ. On this basis, the well-to-wheel CO_2 emissions of fuel cell vehicles using methanol (from natural gas) are therefore around the same or at best only slightly lower than those of advanced conventional diesel vehicles.

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Annex C

OVERVIEW OF THE USE OF LOW-EMISSION VEHICLES BASED ON MEMBER COUNTRIES' QUESTIONNAIRE RESPONSES

Introduction

Member countries' experiences with a variety of technologies were analysed on the basis of the responses from 18 countries to the working group's survey, which was conducted in June-October 2001. A number of case studies were collected which focus on cases where evaluations had been undertaken of emissions levels resulting from actual use of the vehicles.

The following countries responded to the questionnaire: Australia, Belgium, the Czech Republic, Denmark, Finland, France, Hungary, Iceland, Italy, Japan, Mexico, the Netherlands, New Zealand, Poland, Sweden, Switzerland, the United Kingdom, and the United States.

Experience with conventional and alternative fuels

Petrol and diesel

Many countries have developed and applied measures to traditional petrol and diesel vehicles to achieve low-emission vehicles:

- Development of "clean fuels" such as oxygenated and/or reformulated petrol, very low-content sulphur diesel fuel (less than 50 ppm, or even 10 ppm), or biofuel (mixed with diesel or 100% biofuel). The advantage of such approaches is that they can be applied easily and quickly where appropriate – either in specific cases or generally across vehicle fleets.
- Improvement of the diesel mixture.
- Installation of aftertreatment systems such as particulate filter and de-NO_x technologies on diesel vehicles. Several new car models are now equipped with very efficient particulate filters. Laboratory testing has found that, with the latest technology, the PM emissions are so low that they are at the lower limit of official measurement techniques. This is for instance the case for the new diesel cars from Peugeot where more than 98% of the PM emissions are filtered out, even after 80 000 km in use. The filtration is efficient for all the sizes of PM. (Ademe, France, June 2002, see case study below).

Case studies on improvement of diesel and petrol vehicles

Evaluation of the emissions from a Peugeot 607 diesel-equipped with particulate filters

Source: ADEME June 2002

Type of vehicles: diesel with particulate filters

Usage: taxis

Fleet: 5 vehicles

Description of the study

The study was conducted by the ADEME (French Agency for Energy and Environment Management) in co-operation with a taxi operator in Paris.

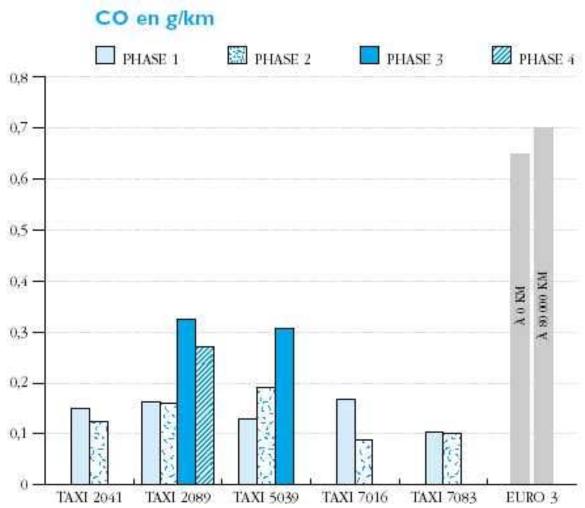
A fleet of five taxis equipped with filter traps was monitored for 14 months, with the objective of evaluating the effectiveness of the new filter trap system developed by Peugeot. The measurements aimed at defining the size and the number of particulates that were emitted. Measurements were made under the official European Motor Vehicle Emission Group (MVEG) cycle.

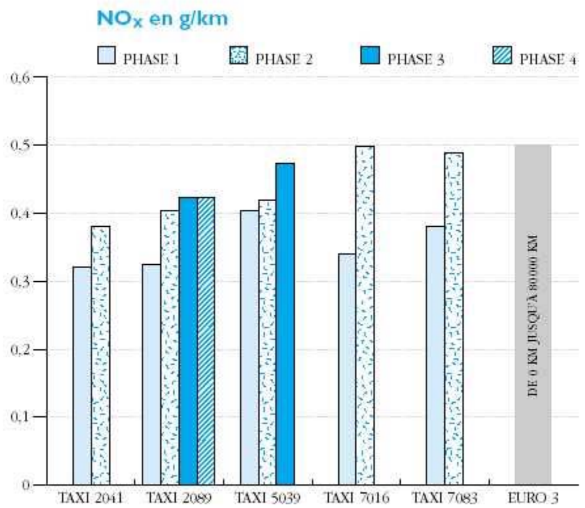
Evaluation in real use

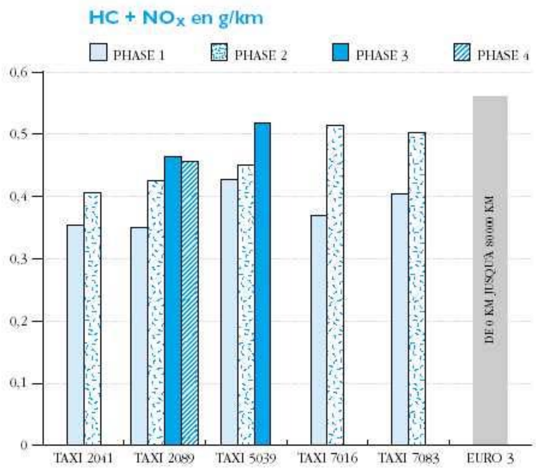
The average fuel consumption in real use, as recorded by the taxi operator, was around 9 litres per 100 kilometres.

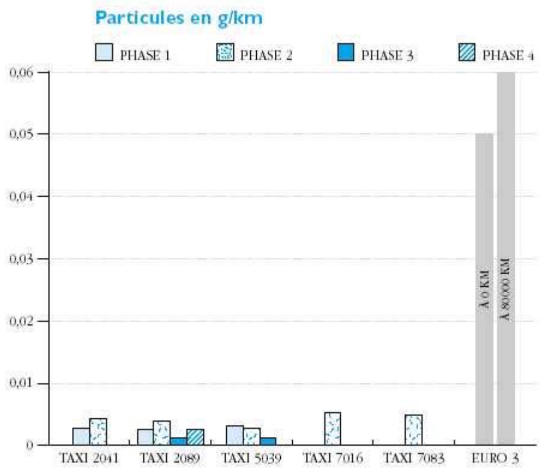
CO and HC emissions were very low – well under the Euro 3 standard. They were mainly produced during the first phase of the MVEG cycle (*i.e.* during cold start). 100% of the CO emissions and 50% of the HC emissions were produced during the first three minutes of the cycle (the total length of the MVEG cycle is 20 min.)

NO_x emissions were below but close to the levels required by the Euro 3 standard.









Regarding particulate emissions, levels were very low, more than 10 times lower than the levels required under Euro 3. They were so low that their measurement required specific methods to remove stray emissions.

Particulate emissions were measured for three classes of particulates (20, 70 and 120 nanometres). Emission levels were almost negligible for the three classes - except at the end of the MVEG cycles where peaks were observed.

Preliminary conclusions from the study can be summed up as follows:

- No problem was reported with the working of the filter traps, even after 80 000 km.
- Levels of particulates were constant during the test, and well below the Euro 3 limit (0.05 g/km).
- Particulate levels were around 10 000 times lower than those observed with a diesel engine without a particulate filter and of the same magnitude as those of a petrol engine. After treatment by the filter, PM content was between 1000 and 4000 particulates per cm^3 (normal diesel emissions without filter trap are between 1 million and 10 million of particulates per cm^3).
- Given the concentration of sulphate in the emissions, reduction in the sulphur content of the diesel fuel should lead to even lower levels of particulate emissions.

Evaluation of diesel emulsion technology (Florence/Italy)

Type of low-emission vehicles: Use of GECAM diesel emulsion for conventional buses in the collective Transport Company (ATAF)

Usage: Urban buses

Number of vehicles in the fleet: 96 conventional buses. (There are more than 4 000 similar vehicles throughout the country).

Description of the study

GECAM is an emulsion for diesel engines, developed in order to reduce the polluting emissions of the fleets of urban services and public transport vehicles. The emulsion of water (10.3%) in diesel fuel (88%) plus a specific additive compound (1.7%) makes the

GECAM a homogenous mixture, immediately usable in diesel vehicles in place of the normal diesel fuel - without the need for any modification to the engines.

Evaluation of GECAM in real use

The emulsion is widely used in Italy with more than 4000 vehicles (mainly buses) travelling a distance of than 90 million kilometres in 2001. There is an additional cost of approximately 0.12 USD /kg for fuel, but there are important emissions advantages in terms of NO_x and PM reduction, without any other harmful compounds in the exhaust emissions due to the presence of the additive.

The emulsion is stable and no separation among the components has been observed, even when fuel stations have been closed for many days during the summer-time. While there is now considerable experience in the use of the emulsion, the effects of the fuel use need further monitoring to detect possible drawbacks under particular operational conditions.

Specific tests have shown the following results:

Change in emissions compared to 100% diesel (g/km):

- CO: -10%
- NO_x: -15%
- PM: -30%
- Smoke: -50%

No significant reduction was observed in CO_2 emissions; however in fuel consumption increased by less than 10% given there is approximately 10% water in the emulsion.

No particular difference in vehicle operation was found compared to conventional diesel buses.

Some minor problems can arise if the emulsion is left for more than three months in a tank, as some sedimentation can occur. Therefore, the tanks are to be provided with a recirculation system that avoids such problems.

The adoption of GECAM by an increasing number of operators reflects the success of the technology as well as the economic incentive provided by the Italian Government for use of the emulsion, in terms of a significant reduction of the fuel excise. The Council of the European Union has authorised Italy to continue to apply differentiated excises for emulsions of water and diesel fuel until 2005, but there is uncertainty as to whether such incentives will be continued beyond 2005.

Liquefied petroleum gas (LPG)

The first use of LPG on spark ignition engines appeared in many countries in the 1950s. At that time, fleets using LPG were limited in number and in use (local use). Then, during the 1970s and 1980s, LPG use became more widespread because of its lower price compared to petrol (especially in Europe). From the 1990s, LPG came to be considered as a “clean” fuel and, in some countries, grants have been offered to encourage the purchase of LPG cars or buses and to build refuelling stations. In 2001, more than three million LPG vehicles were in-use around the world.

Among the responding countries, in 2001 the largest fleets were found in Italy (1.3 million), Australia (550 000), Poland (450 000, only retrofitted vehicles), the Netherlands (330 000), the United States (269 000), Japan (289 000, mainly taxis; at March 2003), the Czech Republic (250 000 –large part as retrofit), France (150 000), Mexico (149 000), Belgium (68 000), Hungary (80 000) and the United Kingdom (50 000).

From a technical point of view, it should be noted that:

- A large proportion of LPG passenger-cars are bi-fuel (petrol and LPG) and the share of driving with LPG or with petrol is not known.
- The percentage of retrofit varies by country and is sometimes very high and very low (from 100% in Poland to 5% in France).

In many countries, sales are declining, and the number of LPG vehicles has stabilised or reduced. As an example, Table C.1 illustrates the evolution in the number of LPG vehicles in use in the United States.

Table C.1. Evolution of the LPG fleet in use in the United States

1993	269 000
1994	264 000
1995	259 000
1996	263 000
1997	263 000
1998	266 000
1999	267 000
2000	268 000
2001	269 000

Source: For 2001: estimation from *Green Car Journal*, Vol. 10, no. 12, December 2001.

In the Netherlands, the share of LPG vehicles reached 11.4% of the total fleet in 1990 and is now decreasing (Table C.2). Like other countries, LPG in the Netherlands is obtained from two sources: (*i)* from refining operations, and (*ii)* from natural gas fields. During a long period, the quantities of LPG available were very large due to the Rotterdam refineries and the Groningue natural gas fields. Today, the production of natural gas is declining drastically and LPG is no longer produced in such large quantities. It is for this reason that the price of LPG has risen and the price of diesel relative to LPG has fallen.

Table C.2. Evolution in the vehicle fleet composition in the Netherlands
(in thousands and in percentage of the total fleet)

	Total	Petrol	Diesel	LPG
1977	3 518	3,335 (94. 9%)	76 (2.1%)	106 (3.0%)
1980	4 123	3,664 (88.9%)	155 (3.7%)	304 (7.4%)
1985	4 551	3,708 (81.6%)	325 (7.0%)	518 (11.4%)
1990	5 118	3,965 (77.4%)	571 (11.2%)	582 (max.) (11.4%)
1995	5 581	4,596 (82.4%)	608 (10.9%)	376 (6.7%)
2000	6 343	5,215 (82.2%)	797 (12.6%)	331 (5.2%)

In France, the sales of LPG passenger cars have been falling. In 2001 the sales (8 000) were three times lower than in 1998 (26 000). In 2002, all the car-makers offered LPG models, but sales remained limited.

There are various explanations for these trends:

- The higher price of LPG vehicles compared to petrol or diesel vehicles (5%-20% more for passenger cars and 15% more for heavy trucks or buses), mainly due to the price of high pressure tanks required.
- Limited numbers of refuelling stations.
- Lower overall operating costs (based on lower price of LPG relative to conventional fuels) but typically only after for a mileage of more than 14 000 km per year (and more in the United States because of the lower price of petrol). Currently, the cost advantage of LPG has been lost by comparison with the new diesel vehicles with direct injection which have a higher energy efficiency and a lower fuel consumption.
- Loss of engine power due to the lower caloric value of LPG.
- Resale value of a LPG vehicle is relatively low.
- Loss of storage space due to the LPG tank.
- Higher maintenance costs for LPG vehicles especially heavy trucks, where maintenance requires additional safety measures and the total running costs are higher than for a diesel truck.

In addition, it is increasingly more difficult and very expensive to produce new LPG engines with the same low levels of local pollutant emissions (CO, HC, NO_x,) as petrol or diesel and with low levels of CO_2 and other greenhouse gas emissions. For example, it would is too expensive to build LPG engines for buses which meet the Euro 3 regulations. Consequently, the engine-maker DAF has decided to stop producing LPG buses (the market is too limited to obtain a positive financial result). CO_2 emissions are higher with LPG buses than with similar diesel buses.

Some countries have had successful experiences with LPG vehicles. A very instructive example to look at is in Vienna, Austria, where LPG buses have been in use since the 1960s. In the beginning, local authorities decided to use LPG buses because LPG was available at a very low price compared to diesel fuel. As a result, more than 550 buses used LPG in the 1970s. During the 1980s, LPG fuel was again promoted because of its low levels of local pollutant emissions. The manufacturer MAN, the LPG engine producer for these buses, decided to equip the buses with a three-way catalytic system and then in the 1990s, with a lean-burn system to reduce the fuel consumption. Now, all the buses in Vienna are LPG-powered for the following reasons:

- Very low pollutant emissions (CO, HC, NO_x).
- Less noisy than diesel (minus 3 to 5 dB(A)).
- Very low price of fuel when compared to diesel (but only limited to the urban area of Vienna).
- Engine-makers decided to produce specific LPG engines for Vienna buses and to achieve Euro 3 and Euro 4 standards by having lower powered engines.

In the *United States*, propane motor fuel tanks may be installed in cars, vans, pick-up trucks and buses. Many cars are dual-fuelled and may also be equipped with petrol tanks which allow the operator to switch fuels based on availability and price. In terms of emissions levels, when compared to petrol, LPG is better for CO (-20%), VOC (-60%) NO_x (-9%), PM_{10} (-30%) and CO_2 (-3% during vehicle operation only and -11% including feedstock extraction, fuel refining, storage and distribution). When compared to diesel, LPG is better for CO (-56%), NO_x (-75%), PM10 (-92%), but is worse for VOC (+88%) and for CO_2 (+5% during vehicle operation only, and + 2% including all the operations from well to wheel) (Baer et al., 1997 and Raj *et al*, 1997).

Conclusion

Today, LPG is more often used as a means of diversifying energy sources, rather than with the aim of achieving "low emission vehicles". New "conventional vehicles" perform as well as LPG vehicles in terms of local pollutants, while CO_2 emissions of LPG vehicles (model year 2002) are around 20% higher than diesel vehicles (model year 2002).

LPG vehicle case studies

Evaluation of LPG passenger cars in the Czech Republic

Type of low-emission vehicles: Conversion of petrol vehicles to LPG

Usage: Passenger cars and delivery vehicles in usual traffic conditions

Description of the study

In the Czech Republic, conversion of spark ignition engines to LPG vehicles has been legally permitted since 1990. Many users have taken advantage of this possibility to benefit from the lower price of LPG fuel, compared to petrol, on vehicles with high yearly mileage. These users therefore have a rather quick return of the money invested in the conversion of the vehicle. In most cases, the possibility to operate with the original fuel (petrol) was retained (bi-fuelled vehicles).

The approval of the converted vehicles is subject to Czech legislation and consists of following steps:

- Components of the LPG system subjected to high gas pressure must be certified (homologated) according to ECE Regulation 67.
- Emission limits valid for the converted vehicle must be met.
- The conditions set for installation of LPG equipment in the vehicle, especially from the point of view traffic safety, must be met.

Approximately 250 000 vehicles have been converted to LPG and are now in operation in the Czech Republic.

Evaluation in real use

Pollutant emissions

A comparison of emissions levels of LPG vehicles and petrol vehicles is illustrated in Table C.3. Measurements were made on four variants of the Skoda Forman model, on the modified ECE 15 test, simulating urban driving conditions. The entire cycle includes four identical segments, the driven distance is 4.052 km, the average speed is 19km/h and the maximum speed is 50 km/h.

Table C.3. Comparison of emissions of the LPG and Petrol Skoda Forman

Emissions	Skoda Forman Petrol		Skoda Forman LPG	
	without catalyst [g/test]	with catalyst [g/test]	without catalyst [g/test]	with catalyst [g/test]
CO	25.9	1.8	19.9	2.0
HC	6.8	0.2	6.2	0.4
NO_x	8.3	0.9	4.9	4.2

Source: Motor Vehicle Research Institute Ltd., Prague.

It should be noted that the LPG vehicles are converted from petrol vehicles, which explains in part their relatively bad performance, since conversion does not provide an optimised system.

Fuel consumption

In comparison with the original petrol passenger car, the fuel consumption is approximately 1.5 – 2.0 l/100 km higher. However, from a cost perspective this is compensated by the lower price of the fuel.

Safety issues

Some safety problems with LPG vehicles were observed when the first conversions were made, since these were often performed unprofessionally and without proper approval. The application of standards via legislation has practically eliminated the safety problems. LPG vehicles are today subject to some restrictions including:

- A prohibition on entering enclosed garage rooms or repair shop rooms.
- More frequent official checks of the vehicles in use.

Fuelling issues

The most unfavourable result of the conversion for the passenger car user is the loss of space in the boot (where the LPG tank is usually placed).

Regarding fuelling infrastructure, there is in Czech Republic an adequate infrastructure of LPG filling stations (more than 450).

Operation and maintenance

In terms of operation, LPG vehicles converted from petrol vehicles does not differ from the base petrol vehicle. Regarding maintenance, LPG vehicles require more frequent checks (sealing of the LPG system). In addition parking restrictions may be a problem for some of the users.

Summary of the study

For assuring reliability of the vehicles in use, the conversion must be undertaken in specialised garages. The declared improvement of emissions parameters is attainable only with appropriate setting of the gas apparatus and with a long term stability of this setting. Measures against tampering with the gas equipment settings proved to be useful.

The use of LPG in comparison to petrol shows merit with vehicles with higher yearly mileage (25 000-30 000 km), where the cost of conversion is recovered.

To date, very few new vehicles are supplied to the market fitted with LPG equipment.

Evaluation of LPG urban buses in France

Source: ADEME

Usage: Urban buses in operation.

Number of vehicles in the fleet: 20 vehicles operated on six sites between 1998 and 2001 (Bayonne, Laval, Tours, Saint-Germain-en-Laye, RATP).

Description of the study

In the framework of a major evaluation programme undertaken by ADEME between 1998 and 2001, the “Clean buses programme”, a fleet of 20 LPG urban buses was evaluated for emissions performance in real use.

Evaluation in real use

Table C.4 presents the emissions levels (g/km) obtained with two types of diesel vehicles and 3 types of LPG vehicles.

Table C.4. Comparison of pollutant levels from diesel and LPG urban buses (France)

Polluant g/km	Véhicule Diesel Type A	Véhicule Diesel Type B	Véhicule GPL 1 Type A		Véhicule GPL 2 Type A		Véhicule GPL 3 Type B	
			Neuf	Vieilli	Neuf	Vieilli	Neuf	Vieilli
CO	3,85	1,77	2,03	58,16	1,50	3,32	11,02	7,56
HC	1,14	1,17	0,085	5,14	0,06	0,27	0,11	0,12
NOx	30,12	19,71	13,66	28,15	14,97	13,16	12,70	10,69
Particules	0,422	0,282	0,057	0,039	0,038	0,042	0,019	0,037
Consommation (litre / 100 km)	61	56	118,3	120,9	116,5	122,6	119,2	117,7
CO_2	1620	1483	1902	1841	1873	1968	1903	1884
Puissance max	110 KW	136 KW	103 KW		100 KW		N.C.	

Polluant = pollutant. GPL = LPG. Particules = particles. Consommation = consumption. Puissance = power.

The following conclusions for the LPG vehicles (in comparison to the diesel vehicles) were drawn from the evaluation:

- Particulate emissions were much lower, even with older vehicles.
- The engine adjustments were not reliable enough (see vehicle LPG 1); progress must be made to maintain low emissions over time, mainly with CO emissions.
- In operating condition, the increase in fuel consumption was very high compared to diesel buses (between 1.8 and 2.1 times as much). This implies around 20% higher CO_2 emissions).

The reference frame for these evaluations was the Euro 2 regulations. Since October 2001 the Euro 3 regulations have been the mandatory standards for new vehicles, but Euro 3 LPG engines are still not available in France. Engine makers (Irisbus and DAF) decided to stop the production of LPG engines for urban buses. MAN produces Euro 3 LPG urban buses, but these are not yet approved for use in France. Conventional diesel engines are much more cost-competitive for this market.

Compressed natural gas

Like LPG, the first use of CNG as a fuel for vehicles occurred 50-60 years ago, but it was during the 1990s that CNG sales began to take off. .

In 2001, the total world fleet of vehicles using CNG for emissions reasons (*i.e.* because they were considered as "clean") was almost 500 000 vehicles. If one also takes into account the vehicles using CNG for cost reasons (retrofit systems), the total number of CNG vehicles is more than 1 million vehicles.

Among the responding countries, the largest fleets are found in Italy (290 000 vehicles, including 289 000 private cars and 500 buses), in the United States (110 000 vehicles, including 5 200 buses, 15 000 trucks and 59 000 light duty vehicles), in New Zealand (13 700 vehicles), in Japan (16 500 vehicles including 8 130 trucks and 770 buses), in France (5 000 vehicles including 1 500 buses), in Australia (2 200 vehicles including 600 buses), and in Mexico (2 100 vehicles). There are a number of countries which have less than 1 000 CNG vehicles (*e.g.* 300 in Switzerland).

In some countries such as Algeria, Argentina, and Iran many vehicles (primarily cars, but also many heavy trucks) are using CNG with retrofit systems. In these countries, the objective is not so much to reduce pollution, but to use national production of natural gas that is available at a very low cost. The size of these fleets is not known, but the total number of vehicles is quite substantial, certainly many hundred of thousands (630 000 in Argentina alone).

A large proportion of CNG vehicles (passenger cars, buses, heavy trucks) are used in specific fleets only because of the refuelling constraints (*i.e.* high-pressure systems). Some private cars in Canada and in the United States are refuelled at home using small compressors.

In Japan, measures have been taken to promote the use of CNG for small and medium-sized trucks (gross vehicle weight < 8 tonnes), especially in cities, with the objectives of reducing NO_x and PM emissions.

The use of CNG on-board vehicles needs specific pressured tanks and specific safety systems. The extra-cost is therefore significant and, even with large production and economies of scale, the cost of CNG vehicles remains higher than similar petrol or diesel vehicles.

For passenger cars, costs are significantly higher: between 15% higher (in France Italy and Australia) and 100% higher (in Japan). In the United States, a dedicated Natural Gas Vehicle (NGV) car costs USD 3 500-7 000 more than a petrol vehicle. In mass - production, an evaluation undertaken by the US DOE estimates that an NGV will cost USD 900 more than an equivalent petrol vehicle. For heavy trucks, the additional cost is more than 10 -15% and for buses, it is near 20%.

In the United States, CNG vehicles are the most prolific alternative fuel vehicles currently produced by US auto manufacturers. They produced four CNG-powered automobile models during the 2002 model year which are all available as bi-fuel CNG/ petrol and three which are available as dedicated CNG vehicles. US auto manufacturers also offered seven CNG light-duty trucks in the 2002 model year including three as bi-fuel and four as dedicated CNG vehicles. In terms of emissions, many heavy-duty vehicles powered with CNG now meet the 2004 emissions standards, while some dedicated CNG light-duty vehicles currently meet the California Super-Ultra Low

Emitting Vehicle (SULEV) standards, equivalent to Bin 2 of EPA's 2004 Tier 2 light-duty vehicle emissions standards. But even with these advantages, sales remain limited because of the low price of petrol.

Today, many countries have a lot of experience with the use of CNG, and it is possible to clearly identify the advantages and disadvantages of CNG-powered vehicles, which are summarised below.

Advantages

- In principle, CNG is safer than LPG (LPG is heavier than air).
- Less emission of NO_x and particulates than diesel.
- Less noisy than diesel engines.
- Low price of fuel.

Disadvantages

- Loss of engine power.
- Extra weight due to the pressured tank and more space required because of the shape of the tank (cylinder).
- Regarding CO_2 emissions: in urban use, CNG vehicles perform better than petrol vehicles, but no better or worse than diesel vehicles principally because of the poor efficiency of the spark engine at low loads compared to diesel. This is an important disadvantage for buses and very important for delivery vans and refuse trucks.
- Many constraints with refuelling: including tight safety regulations (especially in Europe), high cost of the system, noise produced by compressors and the energy required to compress the natural gas from 3 bars to 250 bars.
- No clear price advantage for CNG (in much of Europe at least).
- No market for second-hand vehicles.

In addition, "conventional" engines are in constant progress and the new generation of petrol and diesel vehicles now on the market is as "clean" as CNG vehicles.

Conclusion

As for LPG, CNG can provide an alternative fuel for road vehicles and there is considerable experience in many countries, primarily those with a large market. Except in Italy (where a large number of public refuelling stations are available), the use of CNG in most countries is generally limited to specific fleets — because of the constraints on refuelling. It might be possible to extend the use of CNG with large public distribution systems. Some extensions are now in progress in Europe (*e.g.* France and Switzerland) and in other OECD countries (*e.g*. Australia and the United States).

To reduce the constraints associated with refuelling involving compressed gas, a possible solution would be to modify the natural gas being used by a chemical transformation from a gas to a liquid. Some experiments along these lines are being undertaken by car manufacturers and oil companies.

CNG vehicle case studies

Evaluation of a Taxi Cab CNG Fleet Case in Kensington, United States

Reference: Barwood CNG Cab Fleet Study: Final Results. May 1999, US Department of Energy, National Renewable Energy Laboratory. Report No. NREL/TP-540-26035

Type of low-emission vehicles: Comparison of CNG and Petrol Ford Crown Victoria sedans, 4.6L V8 engine

Usage: Passenger vehicles (taxi cabs). The fleet provided a unique opportunity to evaluate alternative fuel vehicles in a high mileage application

Number of vehicles in study: 10 dedicated CNG sedans and 10 petrol sedans

Description of the study

In 1996, Barwood, Inc., a taxi cab company based in Kensington, Maryland, committed to incorporating a limited number of dedicated CNG vehicles without additional capital expenditures. Operations, maintenance, and cost data for the dedicated CNG and selected petrol vehicles were collected throughout 12 months of vehicle operation. In addition, a series of emissions tests was conducted on the study vehicles at selected mileage intervals. Finally, the performance and cost of operating the CNG and petrol vehicles were evaluated and compared.

The CNG vehicles were used in essentially the same manner as the petrol vehicles. At the end of the study, the CNG vehicles had accumulated from 80 000 to 155 000 miles, averaging nearly 108 000 miles per vehicle. The petrol vehicles accumulated from 112 000 to 143 000 miles, averaging more than 127 000 miles per vehicle. The petrol vehicles were in service about three months longer, on average, than the CNG vehicles. Differences in monthly mileage accumulation rates – vehicle to vehicle – generally resulted from the work patterns of the individual drivers.

Evaluation in real use

Fuel economy and cost

For three months during the study, all available fuelling records were compiled to enable evaluation of fuel economy and fuel costs. Barwood supplied the CNG vehicle fuelling records. Fuel usage data on the petrol vehicles were collected directly by the drivers of the study vehicles. The fuel economy of the CNG and petrol versions of the vehicles were basically identical – rounding to 17.3 miles per gallon (petrol gallon equivalent for CNG) of fuel for each vehicle type. Some real differences between CNG and petrol appear in the area of cost. On a cents per mile basis, fuel costs for the CNG vehicles were almost 30% *lower* than those of the petrol vehicles: 4.35 cents per mile compared to 6.39 cents per mile for petrol. During the portion of the study period evaluated, fuel averaged about USD 0.75 per petrol gallon equivalent for CNG and USD 1.10 per gallon for petrol. This can prove to be a big advantage to a fleet.

Maintenance comparison and cost

All maintenance and repair records and cost data were collected for the study vehicles, including scheduled and unscheduled maintenance and repairs. These records included a description of the service or repair, service date, odometer at time of the work, and a list of the costs associated with the required servicing. The number of miles and days between service was nearly the same for the two vehicle types. Each vehicle type logged 4 300 to 4 400 miles, with just over 31 days between service visits. On a per-mile basis, the rate of unscheduled repairs was slightly higher for the petrol vehicles than for the CNG vehicles. No differences in the types or frequency of fuel system or engine-related repairs were noted. Over similar mileage ranges, the petrol vehicles had slightly higher occurrences of brake and tire-related repairs. The cause of this difference is not entirely clear, but the drivers of the CNG cabs reported that their vehicles do not accelerate as quickly as the petrol vehicles. The drivers said that the difference in responsiveness forced them to modify how they drive the CNG vehicles. Overall, similar performance and reliability were experienced for the two vehicle types and the total maintenance costs were slightly lower for the CNG vehicles, at 3.39 cents per mile compared to 3.95 cents per mile for the petrol vehicles.

Total operating costs

The CNG vehicles cost about 25% less to operate than the petrol vehicles on a per-mile basis. Based on these operating costs, a fleet could expect to save about USD 1 300 a year operating a CNG vehicle in an application where vehicles accumulate 50 000 miles or more annually. In more typical light-duty vehicle service, where vehicles accumulate about 15 000 miles annually, a fleet could expect to save about USD 390 with a CNG vehicle.

Emissions results

Three rounds of emissions testing were performed on seven CNG and seven petrol vehicles. The testing followed the EPA's Federal Test Procedure (FTP-75), which uses the urban dynamometer driving schedule for exhaust emissions, and includes two one-hour evaporative emission tests. The tests were scheduled at odometer levels of 60 000 miles, 90 000 miles, and 120 000 miles. Both CNG and petrol vehicles were tested on fuels specially blended for this testing. The CNG was blended to represent an industry-average fuel composition. The petrol used was California Phase II reformulated gasoline (RFG), which was selected to represent the "best case" petrol fuel.

The CNG exhaust emissions were significantly lower than their petrol counterparts, even when a very clean RFG was used as the baseline fuel. The average regulated emissions from both the CNG and petrol vehicles fell within the applicable EPA standards, but the CNG vehicles had significantly lower levels of non-methane hydrocarbons (NMHC) and carbon monoxide (CO), and similar levels of oxides of nitrogen (NO_x) (see tables below). CO_2 emissions were not measured. This study is believed to be one of the first to provide an independent confirmation that these benefits can be maintained in real-world service throughout the useful life (100 000 miles) of the vehicle and beyond. The results suggest that emissions from CNG vehicles may, in fact, deteriorate less quickly than from similar petrol vehicles.

Mileage (miles)	CNG	Petrol	Difference
Non-methane hydrocarbons (average emissions, grammes/mile)			
60 000	0.049	0.125	-61.1%
90 000	0.055	0.172	-67.8%
120 000	0.045	0.177	-74.7%
Carbon monoxide (average emissions, grammes/mile)			
60 000	0.928	2.764	-66.4%
90 000	1.257	3.703	-66.1%
120 000	2.043	4.622	-55.8%
Nitrogen oxides (average emissions, grammes/mile)			
60 000	0.243	0.263	-7.5%
90 000	0.295	0.269	+9.7%
120 000	0.309	0.338	-8.6%

Evaporative emissions testing measured the hydrocarbons emanating from the vehicle with the engine off. Low levels of hydrocarbons (less than 0.4 grams per test) were measured from the CNG vehicles. Evaporative hydrocarbons from the petrol vehicles were significantly lower. The result is a bit surprising because it is generally accepted that CNG vehicles have zero evaporative emissions. However, the test measurement includes small quantities of gaseous fuel that may escape from the fuel and air intake system after the engine is shut off. Similar low level hydrocarbons have been measured from other dedicated CNG vehicles.

When this study ended, Barwood had been operating the CNG vehicles for more than 18 months, and the company expected to operate the vehicles for about five years.

Evaluation of CNG urban buses in France

Source: ADEME

Type of low-emission vehicle: Euro 2 CNG Buses

Usage: Urban public transport

Number of vehicles in the fleet: 60 Euro 2 CNG vehicles (Irisbus, Heuliezbus , Mercedes) operating in six sites, between 1998 and 2001 (Nice, Les Ullis, RATP, Poitiers, Valence, Montbelliard)

Description of the study

The ADEME (*French Agency for Environment and Energy Managemen*t) “Clean buses programmes” evaluation programme included an in-depth evaluation of CNG buses. The evaluation concluded that in comparison with diesel, CNG buses:

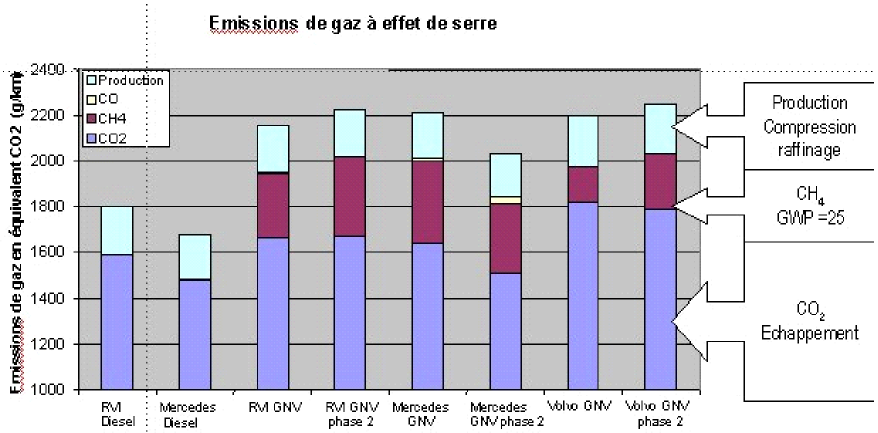
- Emit 50% less NO_x and very low levels of particulates. Comparable results were obtained for CO and HC. Some pollutants increased as buses get older. (See Table C.5)
- Emit higher levels of CO_2 (g/km) emissions: As illustrated in Figure C.1, higher emissions of greenhouses gases (CH_4 and CO_2) with CNG busses were observed on a full fuel cycle basis.
- Are generally well received by various groups of users (drivers, passengers) as they produce less noise and vibration and emit a less disagreeable odour.

Table C.5. Comparison of pollutants levels between diesel and CNG urban buses in France

Polluant G/km	Véhicule type A	Véhicule type B	Véhicule type A GNV		Véhicule type B GNV		Véhicule type C GNV	
	diesel	diesel	neuf	vieilli	neuf	vieilli	neuf	vieilli
CO	3,85	1,77	5,37	4,79	11,63	33,37	0,54	1,95
HC	1,14	1,17	8,34	10,3	4,96	9,86	5,21	7,7
Non méthaniques	-	-	14,6%	5.5%	1,2%	1.6%	2,2%	0.8%
NOx	30,12	19,71	14,73	15,72	8,25	8.17	13,42	16.29
Particules (masse)	0,422	0,282	0,036	0,027	0,026	0,045	0,025	0,047
Conso. Cycle ADEME /100km	61	56	78 nm3	83 nm3	81 nm3	77nm3	91 nm3	89nm3
Puissance max	110 KW	136 KW	103 KW	90 KW	103 KW	Non mesu-rée	127 KW	124 KW

Neuf = new. Vieilli – older. Polluant = pollutant. GNV = CNG. Particules (masse) = particles (mass). Conso. = consumption. Puissance = power.

Figure C.1. Greenhouse gas emissions from diesel and CNG buses in France



Producation, compression, raffinage = Production, compression, refining. Echappement = exhaust. GNV = CNG.
Source: ADEME.

Euro 2 CNG technology suffers from variability in gas composition and a lack of reliable tuning. CNG bus fuel consumption increases in heavy traffic conditions, and is more sensitive to traffic conditions than diesel buses. It is expected that the Euro 3 technology will bring many improvements.

The reference frame for these evaluations was the Euro 2 regulations. Since October 2001 the Euro 3 regulations have been mandatory. New CNG engines meeting Euro 3 standards are now available. The adoption of injection technology should bring significant gains in terms of CH_4 and CO_2 emissions. The engines that meet Euro 3 standards have yet to be evaluated in operation.

Biomass fuels

There is much experience world-wide with biomass fuel, even though biofuels have not been widely used in any country – except in Brazil during the 1970s and 1980s.

Biomass fuels come from crops such as corn and can be used in petrol or diesel engines without major modification.

Reasons for producing biomass fuels vary from country to country and from time to time. Biomass fuels may be promoted in order to maintain the price of corn or wheat (as has been the case in Europe and in some states of the United States), because of the lack of national fossil oil or the high production of ethanol from sugar cane (as in Brazil from 1973), or to produce very low-emission fuel (as in the United States or France). During the 80s and 90s, biofuels were developed with the objective of reducing CO, HC, NO_x, and PM emissions and more recently for their potential to reduce CO_2 emissions. Today, biomass fuels are generally developed primarily for their positive impact on CO_2.

Technologies and types of fuels are different:

- Methanol (in mixture with petrol at 85 or 95 %).
- Ethanol (in mixture with petrol at 10 % or 85%).
- ETBE[1] or MTBE (in mixture with petrol at 4-12%).
- Di-esters (in mixture with diesel fuel 5-30 %).

In principle, all these fuels come from crops (or wood). However, because the quality and availability of crops can depend on the weather, and a portion of these fuels are also sourced from fossil oil or natural gas (depending upon the season and crops).

In Europe, there are few national programmes promoting specific fuel such as di-ester 100% or ethanol 85%. The preference is to use normal petrol supplies with the addition of 4% of ETBE or diesel fuel with the addition of 2-5% of di-ester.

In North America, specific refuelling stations are available which are devoted to such fuels (*i.e.* methanol 85% or ethanol 85%).

The results are not impressive, even after years of research and development and many funds and grants to produce the crops and the fuel and to buy the vehicles for such fuels.

In France, in 2000, the production of di-ester was 250 000 tonnes (0.6% of the total fuel consumption for road transport – 42 Mt) and the production of ETBE was 170 000 tonnes (0.4 % of total fuel consumption) - with a portion of ETBE is coming from natural gas.

In the United States, a report on "Alternative Motor Fuels and Vehicles – Impact on the Transportation Sector" published on 10th July 2001 by the US General Accounting Office –GAO-01-957T drew the following conclusions:

"In 1992, Congress passed the Energy Policy Act which, among other things, sought to replace at least 10% of the projected petroleum fuels consumed by LDV in 2000 and 30% in 2010 with alternatives fuels as ethanol, methanol, LPG, CNG, LNG, electricity,……EIA estimates that alternatives fuels accounted for the equivalent of 0.2% of total vehicles fuels consumption in 2000…."

In the United States, the number of alternative fuel vehicles is around 1 million or around 0.4% of the total vehicle fleet.

The reasons for such a moderate uptake of biofuels are numerous and sometimes complicated. One reason is the cost of the fuels made from biomass. In the United States, pure biodiesel costs are significantly higher than petroleum diesel costs, ranging from USD 1.95 to USD 3 per gallon (before taxes), which is equivalent to 250-400% of the cost of petroleum diesel. The comparative prices of fuel production in Europe are set out in Table C.6.

[1] ETBE: ethyl tertiary butyl ether. MTBE: methyl tertiary butyl ether.

Table C.6. Comparative prices of production in cents – Euro /litre – Europe (excluding tax)

Ethanol (wood)	Ethanol (corn)	Methanol (biomass)	Methanol (coal)	Methanol (natural gas)	Petrol (oil)	Diesel (oil)
48-69	32-54	42-77	40-68	17-40	15-16	14-17

A second reason is the additional cost of vehicles which are able to use two different fuels. Such duo-fuel vehicles are developed essentially in the United States. At the end of 2001, the specific fleets were estimated to be 50 000 E85 vehicles and 17 000 M85 vehicles (*Green Car Journal*, Vol. 10, no. 12, December 2001. p. 138).

A third reason is that the legislation in the United States allows manufacturers to obtain a CAFE credit by selling a “flexible” fuel engine (E85/petrol) while, at the same time, it is almost impossible to find an E85 ethanol station in the country (a total of 139 E85 stations in the country compared to 175 000 petrol stations).

Although methanol has been used as an alternative fuel, the methanol-fuel programmes in Japan and the United States have now stopped. There are many problems with methanol, such as toxicity, corrosiveness and poor performance in terms of fuel economy when compared to diesel vehicles. In Japan, car manufacturers have stopped the production of methanol-fuelled vehicles and in the United States, for model year 2002, there were no light-or heavy-duty methanol-fuelled vehicle models in production.

In terms of local pollutants (measured in g/km or in g/mile), the biomass fuels are similar to conventional petrol, diesel, LPG or CNG fuels. However, on a well-to-wheel basis, biofuels can allow savings of up to 60 % (and these savings can still be improved) in CO_2 emissions compared to vehicles fuelled with petrol or diesel.

Case study on biofuel

Evaluation of biofuel vehicles in Czech Republic

Type of low-emission vehicles: Commercial vehicles and buses using biofuel

Usage: Transport of persons and goods in usual traffic conditions

Description of the study

The biofuel (bio-diesel fuel) distributed in the Czech Republic is a fuel mixture consisting of rapeseed oil methylester and a hydrocarbon fuel derived from crude oil (or directly crude oil). Czech standards set following variants of fuel mixture with rapeseed oil methylester:

- Up to 5% of rapeseed oil methylester – this fuel composition is not distributed.
- At least 30% of rapeseed oil methylester – this fuel composition is distributed via the network of filling stations.

The main reasons for using fuel with this composition are:

- Biologic degradability.
- Tax allowances.

The fuel has to meet the requirements of the appropriate Czech standard (CSN) and must warrant that, from the point of view of noxious emissions it shows not worse results than standard diesel fuel.

Biofuel is used for compression ignition engines without any modifications of engine settings. In comparison to similar diesel vehicles, the biofuel vehicles have:

- A slight reduction in power parameters (about 3-5 %).
- A slightly higher fuel consumption (about 3-5 %).

The fuel quality has improved gradually and currently no adverse effects from long-term use of biofuels on reliability of engines and their parts, or on the oil change periods, has been experienced. Some problems may arise with variable quality of fuel from different manufacturers.

Evaluation in real use

As far as emission parameters are concerned, tests have shown lower levels of smoke, particulate matter and CO emissions. NO_x emissions are slightly worse or comparable with diesel fuel. Fuel consumption is slightly higher. Compared to diesel fuel driven vehicles, emissions of CO_2 in g/km from bio diesel are higher.

No negative influences on operational safety have been manifested in comparison with diesel fuel.

There are no practical changes compared with use of diesel fuel. The network of filling stations is adequate. In case of local unavailability the vehicle can be filled up with diesel fuel.

Practically, operation of the vehicle does not differ from the base fuel-driven vehicle. No changes of the extent and requirements on routine maintenance are needed. If the vehicle is not used for a long period (*e.g.* special seasonal agricultural vehicles), and because of a possible polymerisation of biodiesel, it is advised to consume the biodiesel and fill the tank with diesel before this period.

Biofuels meeting the quality requirements of the standard do not show negative influence on service life and reliability of vehicles. Emission parameters in comparison with other fuels are presented in the comparative Table C.7. The network of fuelling stations is adequate. The sale of the fuel depends on tax allowances, because the production costs are usually higher, than production costs of diesel fuel. At present time the consumption of biofuel represents about 5% of the total diesel fuel sales. Without decisive changes in agricultural production, there will not be any significant increase in biofuel production.

Table C.7. Comparison of basic properties of alternative fuels

	S.I. engine w/ catalyser	C.I. engine (diesel)	CNG	LPG with catalyser	Biodiesel	Rapeseed oil	Hydrogen	Electric vehicle **
Applicability	0	0	0	0	0	0	0	-
Readiness	0	0	0	-	-	--	---	--
Economy	0	+	-	0	-	0	---	---
Infrastructure	0	0	-	-	0*	--	---	-
Limited emissions								
CO	0	+	+++	+++	+	+	+++	+
HC	0	+	++	+++	+	+	+++	+
NO_x	0	-	+++	++	-	-	++	+
PM	0	-	+++	+++	-	---	+++	++
CO_2	0	+	++	++	++	++	+++	-

0 comparable
\+ slightly better
++ better
+++ significantly better
\- perceptibly worse
-- worse
--- significantly worse
* filling station net missing
** depends on the source of electric energy

Electric vehicles

Excluding trams and trolley-buses (which have permanent tracks), the number of electric road vehicles in the world in 2001 was less than 45 000. Some countries also have a large fleet of electric bikes and mopeds.

In OECD countries, the largest fleets of electric vehicles are found in the following countries:

- United Kingdom: 15 000 EVs including 10 000 milk delivery vans.
- United States: 10 000.
- France: 7 400.
- Japan: 3 800 (2 000 as smaller cars, 400 as passenger cars), of which 530 are currently in operation.
- Italy: 2 000 (Italy also has more than 25,000 electric bikes and mopeds).
- Mexico: 2 000 electric vehicles.

Most European countries have small electric vehicles fleets (*e.g.* 1 100 vehicles in Belgium, 800 vehicles in Switzerland, 320 vehicles in Sweden, etc.)

Important research and development programmes were launched in many countries at the beginning of the 1990s (for instance, in France, Italy, Sweden, Germany, Japan and the United States). These developments were mainly motivated by the California Zero Emission Vehicle mandate. In France, a mass-production factory was built by the vehicle manufacturer Peugeot with the potential to produce 50-100 electric vehicles per day; the current production is 2-3 vehicles per day.

Advantages and disadvantages of full electric vehicles are well known and are summarised below.

Advantages

- No local pollution from electric vehicle operation.
- Very low noise.
- Very low maintenance.
- Partial regenerative braking energy (very positive in urban use).

Disadvantages

There are three common problems:

- The operating range (90-200 km) and the relatively poor performance of electric vehicles when compared to conventional vehicles.
- The total cost (vehicle, batteries and electricity supply) which is the same or higher than for conventional vehicles when calculated on a cost per km basis.
- The energy balance – from well to wheel – which is not positive for electric vehicles when compared to conventional vehicles of the same performance. This is especially the case for the CO_2 balance on a well to wheel basis when the electricity comes from gas or coal, which is most often the case. (The CO_2 balance is, however, better when electricity comes from nuclear or hydro sources).

In addition, electric vehicles have the following disadvantages:

- The difficulty in using electric vehicles on “highways” because of their lower speed compared to other vehicles, even trucks.
- Long refuelling time.
- High price of the vehicle (between 50% and 100% more) when compared to a similar petrol vehicle.
- Lack of availability of recharging stations.

Conclusions

Sales of electric vehicles remain very limited, even with grants provided in some countries to encourage their purchase. Total sales, including buses and refuse trucks, are around 2-3 electric vehicles per day in France and in the United States.

Improved battery performance is required to increase the performance and the range of electric vehicles. Some research and development has been launched to replace lead batteries by nickel-metal-hydrid or by lithium-ion. However, there is no certainty about improvements in the foreseeable future being achieved through new batteries. An alternative approach is to use range extenders (see hybrids).

All the countries agree that electric vehicles have the most potential when used in urban areas: small cars, delivery vans, etc. A significant market is possible, but further assistance would be needed in order to develop the market. One example of regulatory change that could assist the electric vehicle market would be a requirement for drivers to stop the engine when the driver is exiting the vehicle, such as in the case of milk delivery trucks in the United Kingdom.

Electric vehicle case studies

Evaluation of the electric cars in a car-sharing service (La Rochelle, France)

Type of low-emission vehicles: electric cars (cadmium nickel battery).

Usage: Car-sharing in urban area, LISELEC service.

Number of vehicles in the fleet: 50 Liselec cars (25 Peugeot 106s and 25 Citroën Saxo).

Description of the study

The Liselec service offered by PSA Peugeot Citroën, Keolis and Alcatel CGA Transport is an urban mobility system for cities that want to broaden their range of public transit solutions. It provides members with shared access to electric vehicles, which are available 24h/24 at self-service stations.

Inaugurated in La Rochelle on 22 September 1999, the system has since generated an encouraging response in the marketplace. In one year, more than 250 clients have joined the programme and now make daily use of the 50 Liselec cars — 25 Peugeot 106s and 25 Citroën Saxos — that were deployed in La Rochelle.

The cars are parked at six recharging stations near high-use locations, such as the train station, the bus station and the university. In response to the steady rise in the number of program members, with four or five new sign-ups a week, La Rochelle has decided to expand the service by opening two new stations in Fall 2001.

Liselec users are generally young (50% are less than 35 years old) and 75% of them are men. The customer base is composed primarily of students (32%), tradesmen and shop-keepers (15%), employees (13%) and managers and self-employed professionals (12%).

As of mid-September 2000, the 50 cars had been driven a total of approximately 100 000 km. The average trip covered 8 km and the mean time of use was 38 minutes, while the median trip time came to 10 minutes. In all, the cars in the Liselec fleet were used to take some 15 000 trips.

A survey of 130 customers in February 2001 confirmed users' positive opinion of the service. Programme members especially appreciated the cars' driving comfort, the self-service system, the availability of cars at the recharging stations, and the competence of the sales agency staff.

At end of 2001, the number of clients (subscribers) had almost doubled to 471 and 2 200 trips/month were undertaken.

The authority has now built seven stations and the objective is to enlarge the service to include light duty trucks for freight transport.

Evaluation in real use

Operating costs

- Operating budget: about EUR 30 500/month, (50% staff, 14% management expenses and 36% cars and station maintenance. 43% of this last part is for battery rental). Maintenance and taking back the cars to parking locations require the operator to drive the car on 45% of the customer's mileage.
- Customer subscription: EUR 5.50/month, EUR 0.09/minute, EUR 0.18/km (as of May 2002).

Average in 2001	For a customer trip (average 6 km)	Per km
Total operating cost	EUR 10.70	EUR 1.75
Fare collection	EUR 4.00	EUR 0.67

Electric vehicles in tourism resorts (Bad Hofgastein and Werfenweng): The Model Project, Austria

Source: Bundesministerium für Land und Forstwirtschaft, Umwelt and Wasserwirtschaft

Type of vehicles: Electric vehicles (cars, scooters and bikes)

Usage: Professional and tourist use

Number of vehicles in the fleet: 99 (51 e-scooters, 30 e-bikes, 3 light electric vehicles and 15 e-cars)

Description of the study

Bad Hofgastein is a well-known tourist resort in the valley of Gastein, Land Salzburg (Austria), with 6 800 inhabitants, 8 000 tourist beds and 1 million overnight stays.

Werfenweng is situated about 45 km south of the city of Salzburg 1 000 metres above sea level on a plateau above the Salzach valley. The settlement, with its 650 inhabitants, consists of scattered groups of houses. 1 800 beds are offered and about half of the 195 000 overnight stays per year are counted during the winter season.

A model project in the field of environment, tourism and mobility was launched by the Austrian Ministries for Agriculture, Forestry, Environment and Water Management, Innovation, Transport and Technology and Economy and Work, the Province of Salzburg and the two model communities Bad Hofgastein and Werfenweng, supported by the European Union.

Objectives

The objectives are to: create a high-quality" car-free tourism" product, implement innovative traffic concepts; keep vehicles with internal combustion engines off the city centres; give impetus to innovative transport technologies; and improve environmental quality.

51 e-scooters, 30 e-bikes, three light electric vehicles and 15 e-cars (in a total 99 electric vehicles) have been funded over a period of 2 years beginning in 2000 and one of the first solar loading stations for electric vehicles in Austria was set up.

Photo: Solar recharge stations for electric vehicles, Werfenweng, Austria.

Approach

Two different approaches have been chosen to introduce electric vehicles. In Werfenweng all electric vehicles are operated by the Werfenweng Aktiv KEG (local tourism association) for rental for guests and inhabitants. Special attention is focused on fun cars (Velo-Taxi, Fun Rider, Biga). For excursions in the region, two Renault Clios and three Peugeot e-scooters have been acquired.

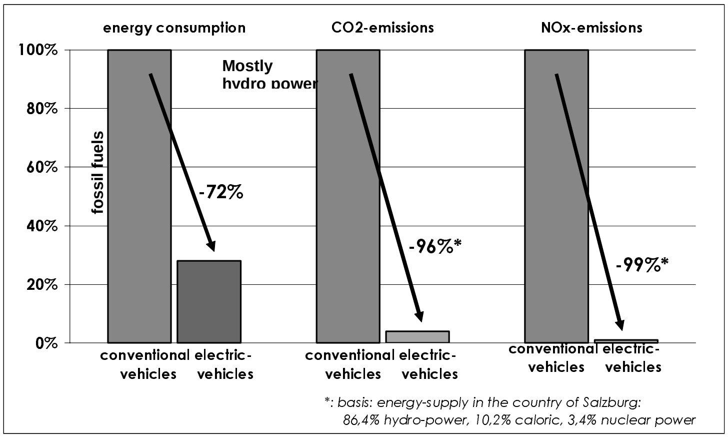
In Bad Hofgastein electric vehicles are used for professional purposes, as well as for deliveries, hotels and by the local craftsmen. For those purposes, five Peugeot 106 electric, eight Peugeot Partner electric, one Graf Carello (in total fourteen electric vehicles are for commercial use) and 28 Peugeot e-scooters (of which thirteen are for commercial use) have been purchased. For tourism a number of e-bikes and 16 Arrows by Wachauer (e-scooter) have been acquired by a group of hotels focusing their contribution to sustainable mobility.

Evaluation in real use

Recently an evaluation was undertaken of the use of fourteen electric cars acquired in 2001 for commercial use in Bad Hofgastein. This investigated the suitability of the electric vehicles for operation in Bad Hofgastein. It has been concluded that it is possible to make the change from vehicles with internal combustion engines to electric powered vehicles for selected purposes in hotels and in businesses, provided the additional costs compared to conventional vehicles are met by grants. Potential users could be gained through information campaigns, vehicle demonstrations and test runs which exposed them to the reliability and the capability of the electric vehicles.

Overall vehicle distance travelled is already 47 000 km. About 270 km per day, which accounts for 7% of the potential replaceable driven kilometres for business purposes in Bad Hofgastein, are now handled in an environmentally sustainable way. The electric vehicles have proven successful in commercial use. The battery range of about 100 km is sufficient for local deliveries. The vehicles are industrial products with locally secured maintenance.

Environmental effects of the operation of electric vehicles



Note: Read "thermic" instead of "caloric" in this figure.

The environmental effects of electric vehicle operation were evaluated using indicators such as energy use, emission of air pollutants (NO_x as a key pollutant and as a precursor of ground level ozone), emission of green house gases (CO_2) and noise.

Compared to vehicles with internal combustion engines (*e.g*. diesel) an electric vehicle has a lower energy use (around -72%). Beyond that, the energy use of fossil fuels can almost completely be replaced by renewable energy sources (hydro power).

The energy conversion to electric energy causes lower CO_2 emissions (by around 96%) and lower NO_x emissions (by around -99%) compared to the operation of a conventional vehicle. Through the operation of electric vehicles the energy use can be reduced by 86.8 GJ (24.1 MWh), the climate change related CO_2 emissions by 11.3 t and the NO_x emission by 53 kg during the term of the project.

Based on the daily number of "business" trips starting from Bad Hofgastein to destinations within the community or the Gastein valley, the energy consumption was reduced by -5.1%, CO_2 emissions by -6.7% and NO_x emissions by -6,5%. By shifting all replaceable business trips to electric vehicles, the CO_2 emissions could be reduced by -13%. This corresponds to the reduction target for Austria fixed in the Kyoto Protocol.

Due to the low noise level of the engine, a noise reduction in inner areas of villages and towns can be expected through the operation of electric powered vehicles, especially during start up, acceleration and on low speed levels (< 50 km/h).

Conclusion

The introduction of 99 electric vehicles in only two years limited to two communities has been successful. The interest in electric vehicles is still high in both communities; the response of the users is encouraging. The environmental effects evaluated so far are quite encouraging for the ongoing project as well.

New technologies

This section focuses on hybrid vehicles and fuel cell vehicles.

Hybrid vehicles

The primary reason for the research and development of hybrid vehicles at the end of the 1980s was the potential reduction of local pollutant emissions (CO, HC, NO_x) in urban areas by using in the same vehicles both electric motors and traditional engines. In urban areas, a hybrid vehicle could use its electric motor powered by batteries. Outside urban areas, it could use a traditional engine for motive power and to re-charge the batteries.

Many experimental hybrid vehicles were developed in the 1980s and the 1990s. One solution was the Audi Duo with an electric motor on the rear axle and an internal engine on the front axle: results were modest in terms of fuel economy. The objectives have changed and now the principal objective is to reduce emissions of local pollutants and greatly reduce CO_2 emissions.

Two families of hybrid vehicle architectures are possible: series or parallel. From a technical viewpoint, the most difficult task is the technical optimisation required to control all the connections between electric generation and power usage requirements. Applications now in use include:

- Passenger-cars (from Toyota and Honda): around 130,000 hybrid vehicles were in use at the end of 2002 (60,000 in Japan, others in the United States, Canada and Europe).
- Delivery vans: less than 1 000 around the world.
- Buses: around 200 in the United States and 200 in Europe.

Hybrid cars can charge electric batteries without connection to an electricity net. For delivery vans and buses, it is possible to charge batteries during the night.

Results are positive for the two models of cars (Prius from Toyota and Insight from Honda). The Toyota Prius is a five-passenger sedan weighing 1 220 kg, with a petrol engine of 53 kW and an electric motor of 33 kW. Results have shown a reduction of 5 to 10% of NO_x and 10-20% of CO_2 in urban use, 5-10% on road and zero in highway use. This is achieved by having the traditional engine functioning only when it is efficient to do so. In Europe, the Prius is classified as a 120g CO_2 /km, while the equivalent vehicles (weight, performances, indoor space, etc.) are 150-170g CO_2/km or more (in petrol application).

For buses, the energy and pollutant balance leads to different results. For instance, in New-York, between Orion VI hybrid and Nova diesel models, gains in CO_2 depend upon the cycle used:

- 40% on NY bus cycle.
- 32% on Manhattan cycle.
- 29% on NY composite cycle.
- 20% on CBD cycle (from NYCT, 2/2000).

Other tests have been less impressive compared to similar diesel buses (same engine technology, same number of passengers, same body, etc.) and in the same operational conditions (use in cities).

Comparative testing has been undertaken in France of two fleets: twelve hybrid buses and ten conventional and identical buses. The weight of batteries and the need to cool the electronic systems and batteries[2] leads to a similar level of fuel consumption for both fleets. For the hybrid buses, additional electricity is also required to charge the batteries.

The car-manufacturers have launched major programmes to develop hybrid vehicles. There are many possible architectures ranging from a "smooth" hybrid with small electric motor to "full" hybrid with powerful electric motor. New models appeared at the beginning of 2003, including an electric vehicle with range extender and smooth hybrid system (automatic stop and start engine).

Objectives are to reduce the CO_2 emissions by between 15 to 50%, especially in urban use, when compared to similar conventional vehicles. However, given the progress being made with conventional vehicles, it is becoming more and more difficult to achieve the hybrid vehicle fuel consumption when compared to new diesel engines with common rail technology that have very low fuel consumption. The work undertaken suggests that hybrid technology could be best used on mid-size and large-size vehicles, but not on small cars.

Hybrid vehicle case studies

Evaluation of the Audi Duo Hybrid in the Netherlands

Type of low-emission vehicles: Audi Duo Hybrid (diesel engine and electric motor)

Usage: Passenger car. During the course of the project the vehicles were driven by a wide range of users and user group.

Number of vehicles in the fleet: 10

Description of the study

The Audi Duo is a parallel hybrid vehicle. There are two drivelines: a diesel internal combustion engine and an electric motor. The electric motor can be used either as a motor to drive the wheels or as a generator. With a mode switch the driver can select which driveline is used to drive the vehicle. It has three operating modes: diesel only, electric only and hybrid (named duo). When the last mode is selected, the management system in the vehicle chooses the driveline depending on requested power and battery state-of-charge (SOC).

There are three ways to charge the battery of the Audi Duo:

- Connect the vehicle to the grid, via a normal plug the car can be connected to the grid. The battery charge unit converts the grid voltage (220 V AC) to the appropriate DC voltage for charging the battery.
- While driving with the internal combustion engine: The diesel engine is the primary power source for the vehicle. By using the electric motor as a generator, power is absorbed for charging the battery. The generator voltage is transformed via an inverter to the appropriate charge voltage.

[2] Battery lifetime is also a problem in France and New York.

- Regenerative braking: during braking the electric motor is used as generator, so a part of the brake energy is stored in the battery.

Charging the battery as described by the second and third methods described above is only possible when the state-of-charge of the battery is below 80%.

The Audi Duo project is a demonstration project with ten vehicles. The objective of this project was to get more insight into promising application fields and to expand the application possibilities of a parallel hybrid vehicle.

Driving patterns and driver behaviour are both important parameters that influence the energy use and emissions of the vehicle. By actively monitoring these parameters, it is possible to evaluate the types of use for which the Duo is a cleaner and/or more energy efficient vehicle than its conventional diesel equivalent.

During a six-month period, approximately 100 drivers, selected from all over the Netherlands and from various user categories, drove the Audi Duo for two weeks. To enable an environmental comparison, TNO Automotive developed an assessment methodology.

The environmental performance of the Audi Duo is mostly determined by the technology of the vehicle, and how the vehicle is used in real-life circumstances by different users. In order to assess the technology used in the vehicle, first the construction of the Audi Duo driveline was further analysed and the specifications of the different components summarised. To obtain information on how the vehicle is used in practice, three Audi Duo's were equipped with an on-board vehicle monitoring system that measures and registers relevant parameters to be taken into account for the environmental study. This data acquisition process includes:

- Driving parameters to record the use of the vehicle on the road (start and end time of driving sequences, distance driven, vehicle speed).
- Battery and charge parameters, (start and end time of the charge period, amount of electric energy charged (kWh), battery voltage, current and state-of-charge (SOC)).
- Vehicle parameters such as engine speeds, accelerator pedal position, selected gear, energy source used, selected mode (diesel/electric/hybrid) and fuel consumption.

Evaluation in real use

The environmental performance was evaluated by measurements on a chassis dynamometer. Therefore, driving cycles (speed-time patterns) were developed, based on the collected driving data. The generated driving cycles (14 in total) can be considered to be representative for specific types of vehicle use (e.g. urban, rural or motorway driving as well as % of time driven in diesel or electric mode). The cycles were driven with the Audi Duo as well as a diesel reference vehicle (Audi A4 Avant 1.9 TDI) on a chassis dynamometer. The environmental performance of the Audi is summarised qualitatively in Table C.8.

Table C.8. Environmental performances of the Audi Duo in each field of application

	Urban			Rural			Highway
	High % diesel	40% diesel	High % electric	High % diesel	60% diesel	High % electric	5-15% electric
CO	+	+	++	0	0	0	0
HC	0	+	++	-	0	++	-
NO_x	--	+	++	--	0	++	--
PM_{10}	-	+	++	-	0	++	--
SO_2	-	+	++	-	0	++	-
CO_2	0/+	0	-	0	0	-	0
Energy use	0/+	0	-	0	0	-	0

++ High environmental benefit.
\+ Environmental benefit.
0 Environmental neutral.
\- Environmental disadvantage.
-- High environmental disadvantage.

Conclusions can be drawn separately for pollution (CO, HC, NO_x, PM_{10}, and SO_2 emissions), and energy efficiency (energy use and CO_2, being responsible for global warming).

Pollution

- To obtain environmental benefits the Audi Duo should be driven in electric mode as much as possible in urban and rural areas.
- When the Audi Duo is driven both on diesel and electricity (for which case the vehicle has been developed), it is environmental friendlier in the urban areas. On rural roads however, the environmental performance compared to the reference vehicle is neutral.
- A high percentage of time driven in diesel mode should be avoided in urban and rural areas (except for the CO emission production). In these application fields the Audi Duo is more polluting than its conventional equivalent (especially for NO_x emissions).
- With the exception of CO emissions, the environmental performance on motorways is worse than the diesel equivalent vehicle.

Energy efficiency

- The Audi Duo is in almost no single field of application more fuel efficient on a well-to-wheel basis than its conventional counterpart.
- More driving in electric mode results into reduced fuel efficiency compared to the reference vehicle (because of the source of electricity used in the Netherlands).
- In urban traffic the Audi Duo is slightly more fuel efficient than its conventional counterpart when it is driven on both diesel and electric, provided the diesel engine is charging the battery ("charge sustaining" driving).

Apparently, the potential for the Audi Duo to reduce emissions (in urban and rural areas) is at its highest when driving as much as possible in the electric mode, but at the cost of energy efficiency.

The CO_2 emission calculation method used in this project takes into account emissions during the fuel and electricity production in the Netherlands). The CO_2 emission level of the Audi Duo is in most cases equal or higher (up to a maximum of 30% during electric rural driving) than the CO_2 emissions of the reference vehicle (average CO_2-emission level of the reference vehicle is 210 g/km).

Fuel consumption

Fuel and electric consumption of the Audi Duo are presented in Table C.9.

Table C.9. Fuel and electric consumption of the Audi Duo

Diesel		Electric	
Diesel engine	6.8 litre/100 km (diesel km)	Electric driveline	20.3 kWh/100 km (electric km)
External heater	0.2 litre/100 km	Electric auxiliaries (lights, power steering, etc.)	1.2 kWh/100 km

Operation and maintenance

Most users were positive about the performance of the Audi Duo in practice. Most users preferred to drive in electric mode since at that moment the vehicle is driving cleanly (no direct emissions), smoothly (more comfort) and without making any noise. The quietness of the vehicle was a very positive aspect for most users.

The user survey highlighted the following areas for improvement:

- Limited range in electric mode.
- Acceleration capacity of the vehicle in diesel and electric mode.
- Functioning of the “duo-mode” of the drive mode switch (diesel/electric/hybrid).
- Electric charging of the battery by the grid.

From the outside, the Audi Duo looks the same as a conventional Audi A4 Avant, but is very different in its operation. First, the driver has to operate on the mode switch to select the appropriate driving mode. In addition, the vehicle is equipped with a semi-automatic gearbox which means there is no clutch pedal available where the driver still has to change gear by hand (like with manual gearboxes). Most users quickly accustomed themselves with these particular characteristics of the vehicle.

Beside normal maintenance during which no particular problems occurred, only some of the Audi Duos had some difficulties with the battery capacity and functioning. Those problems were solved by the Dutch Audi importer.

Evaluation of the hybrid buses in Avignon, France

Source: ADEME

Type of low-emission vehicles: Diesel electric hybrid vehicles.

Usage: Urban buses.

Number of vehicles in the fleet: 4 vehicles Mercedes Cito diesel electric and 5 Neoplan hybrid (diesel electric with battery storage and an energy management unit).

Description of the study

In the framework of the “Clean buses programmes” undertaken by the ADEME (French Agency for Environment and Energy Management) between 1998 and 2001, all the current technologies for urban buses were evaluated in real use.

The hybrid buses were evaluated in comparison with reference diesels buses: the RVI Agora (standard 12 metre bus) and the Mercedes O405 (10 metre midibus).

Evaluation in real use

The evaluation led to the following results:

- Evaluation of the four Mercedes Citos: Reductions in pollutant emission were not significant, except for NO_x. The average fuel consumption was slightly higher than for diesel buses. All the vehicles operated like a normal diesel bus.
- Evaluation of the five hybrid Neoplans: The evaluation was conducted for three levels of battery charge, 80%, 55% and 30%.
- A good correlation was observed between the emissions and the load levels of the battery, except for CO and HC. However, in operating conditions, the total fuel consumption of hybrid buses (taking into account the recharge) was higher than for diesel busses. The Neoplan is a prototype with a complex technology and during the trial there were many technical problems. When the technology is more refined and developed, it is expected to provide more promising results.
- For both bus types, the staff and ridership survey show a very positive assessment (less noise and good comfort).

Table C.10. Pollutant emissions and fuel consumption of the RVI Agora (Diesel) and the Mercedes O405 (Hybrid)

			RESULTATS en g/km					Consommation l/100 km
			CO	HC	NO_x	CO_2	Part.	BC
RVI AGORA	N°1	Moyenne	3,52	1,19	30,17	1589	0,485	59,53
		Int. Conf.	0,321	0,194	0,708	11	0,079	
	N°2	Moyenne	4,18	1,10	30,07	1619	0,359	60,68
		Int. Conf.	0,092	0,157	1,06	9,5	0,043	
MERCEDES O405	N°1	Moyenne	1,63	0,95	18,26	1480	0,236	55,39
		Int. Conf.	0,10	0,09	1,24	27	0,029	
	N°2	Moyenne	1,92	1,39	21,17	1483	0,329	55,51
		Int. Conf.	0,14	0,23	1,12	39	0,036	

Moyenne = average. Résultats = result. Consommation = consumption.

Table C.11. Pollutant emissions of Neoplan hybrid bus based on the state of charge of the battery

		RESULTATS en g/km					Etat de charge Batterie		Conso. l/100 km	
		CO	HC	NO_x	Part.	CO_2	initial	variation	DV	BC
Etat de charge : 80 %	Moyenne	**0,61**	**0,20**	**9,90**	**0,33**	**1181**	**92,44**	**-3,78**	**45,14**	**44,64**
	Int. Conf.	0,12	0,04	0,29	0,03	14,99	0,43	1,15	0,56	0,57
Etat de charge : 55 %	Moyenne	**0,59**	**0,21**	**11,81**	**0,34**	**1372**	**85,40**	**0,50**	**52,13**	**51,81**
	Int. Conf.	0,10	0,03	1,07	0,04	139,71	2,16	3,68	5,16	5,20
Etat de charge : 30 %	Moyenne	**0,64**	**0,27**	**17,78**	**0,47**	**2093**	**72,47**	**19,13**	**79,08**	**79,09**
	Int. Conf.	0,06	0,02	0,50	0,07	79,09	2,50	2,60	3,05	2,99

Etat de charge = battery charge. Résultats = result. Conso. = consumption. Moyenne = average.

Evaluation of hybrid buses in Terni, Rome and Ferrara (Italy)

Type of low-emission vehicles: Series hybrid electric buses

Usage: Urban buses

Number of vehicles in the fleet: Four hybrids and two conventional buses in Terni. The project was also extended to two other Italian cities, Rome and Ferrara, for a total of 24 hybrid buses

Description of the study

In the city of Terni the THERMIE Project FLEETS, whose acronym stands for Fairly Low Energy and Environment Transport System, was carried out and was centred on the introduction of hybrid buses for public transport. The project was also extended to two other Italian cities, Rome and Ferrara, for a total of 24 hybrid buses. In Terni the use of biofuel was also tested on two conventional buses. The buses (four hybrids and two conventional) were equipped with a very complete data monitoring system, in order to record all the data useful for a performance and effectiveness evaluation of the series hybrid bus technology. In addition, some surveys were carried out with the city inhabitants to understand the acceptance level for the initiative from the population. The field test was important as technical problems were detected and this result was very valuable for the bus manufacturer in order to improve the vehicle reliability. On the other hand very promising results were obtained in terms of pollutant emission reduction.

Evaluation in real use

A specific test campaign was carried out on the hybrid and conventional diesel buses used in Terni. The results are shown in Table C.12 for the average values of specific emissions of hybrid and diesel buses in Terni. Basically, the hybrid bus fleet showed significantly positive effects in terms of polluting emission reduction but negligible effects for fuel consumption.

Table C.12. Pollutant emissions of the series hybrid bus compared to the Euro 2 bus

Specific emissions (g/km)	CO	VOC	NO_X
Euro 2 bus	5.05	0.82	24.92
Series hybrid bus	0.3	0.59	11.55

As shown in Table C.13 on fuel consumption, the effects of CO_2 reduction are deemed negligible. The poor effect in terms of efficiency of hybrid bus was due to the difficulty in achieving a good energy balance in the service, *i.e*. having the same level of charge for the batteries at the end of each trip. This required additional fuel consumption to recharge the battery.

Table C.13. Fuel consumption in equivalent litres of petrol per 100 km

Euro 2 bus	43.7 (diesel fuel)
Series hybrid bus	41.0 (diesel fuel)

No safety problems were reported. From the experience, it can be concluded that hybrid technology is promising, but still has some reliability problems. In addition, the current additional cost of hybrid vehicles inhibits their more widespread adoption. However, there is a likelihood of significant improvements in hybrid technology achievable with the introduction of new components and a more efficient control strategy, which would increase the appeal for such technology.

A survey of hybrid bus drivers was conducted in order to assess their reactions; almost all (96%) the drivers interviewed found the hybrid buses easy or very easy to drive.

The results of the experience were not completely successful, as many failures were detected during the testing period, therefore reducing the availability of the new buses. Most vehicle breakdowns were the result of battery failures, especially because the hybrids were reliant on general purpose batteries. The adoption of specially designed batteries (*i.e*. with characteristics able to satisfy the hybrid bus demands) could reduce or eliminate such problems.

Fuel cell vehicles

A fuel cell vehicle is an electric vehicle whose battery is replaced by a new concept power source that produces electricity on-board from hydrogen or petrol.

The interest in fuel cells is that their theoretical efficiency in producing electricity could be higher than the efficiency of generating electricity from internal combustion engines, especially at very low loads. First applications were for stationary electricity power plants, but applications involving mobile transport and road vehicles appear an interesting possibility.

Fuel cell experiments are in progress for cars, delivery vans and buses. Since 1997, many experimental vehicles have been tested (passenger cars and buses) in several countries. However, although the decision was made by some companies in 1997 to produce buses in numerous units, in 2000, technical and economic problems have appeared. These technical and economic problems include the need to:

- Greatly decrease the size and especially the price of the fuel cell stack.
- Produce and store hydrogen. (Hydrogen may be produced from natural gas or by electrolysis of water. In that case, the energy balance depends on the origin of the electricity (*e.g.* nuclear, coal or gas).
- Cool the stack. Because the energy efficiency is well below 100%, and probably only 60%, the cooling of the stack presents a difficult technical challenge. With a high power stack, the size of the heat exchanger is very large.

The real reasons for the use of fuel cells to produce electricity for the traction of mobile sources are not very clear. If hydrogen is provided from petrol with a chemical reformer on-board vehicle, the balance in CO_2 is not necessarily positive when compared to a conventional petrol engine.

Nevertheless, three manufacturers (Toyota, Daimler-Chrysler and BMW) have decided to produce fuel cell vehicles in 2003. Although only several units each, a mass production process will help evaluate the real price and the constraints in production and in use.

Toyota is producing the model FCHV (fuel cell hybrid vehicle): a hybrid vehicle with a fuel cell stack of 90 kW, an electric motor of 80 kW and a battery storage nickel-metal-hydrid. Several vehicles were in use in Tokyo in 2003, with nine refuelling stations by hydrogen. An extension to the United States is planned.

Daimler-Chrysler is producing 30 buses with fuel cells. These buses were on road in several cities in Europe in 2003.

Also in 2003, BMW was expected to engage in the first mass production of fuel cells on vehicles. However, the application was to be limited to an auxiliary power unit to produce electricity only for accessories in order to avoid the problems of size, price and cooling.

In fact, the last application is likely to be the best. A small fuel cell stack and a small pack of batteries could manage the electric power on-board vehicle for the auxiliaries and a conventional combustion engine could move the vehicle. The gain in CO_2 could be substantial, but it will take time before mass production of fuel cells for road vehicles can be achieved.

Overview of fuel cell research and development in some OECD countries

Australia

The Western Australian Government, with support from the Australian Government, is participating in the global Daimler-Chrysler trial of hydrogen fuel cell bus technology. Three buses were delivered in 2002 and the trial will be completed in 2004.

The objectives of the trial are to:

- Demonstrate the operational, environmental and social benefits of introducing fuel cell buses into the Western Australian and potentially the Australian bus fleet.
- Determine and facilitate the development of the infrastructure necessary to produce and distribute hydrogen as a fuel source.
- Provide a test bed for the establishment of the regulatory frameworks for the operation of a hydrogen powered transport fleet in Australia.
- Facilitate the introduction of fuel cell buses into the Western Australian and Australian public transport fleet.

There is no plan regarding the fuel supply for fuel cell vehicles in Australia. The fuel cell bus trial is expected to assist in evaluating supply questions.

Iceland

A company called Icelandic New Energy Ltd. was established with partnerships from foreign companies to assess the potential of hydrogen for fuelling vehicles and the required infrastructure on a nation wide basis. The first vehicles to be tested are three buses. The demonstration commenced at the beginning 2003 and the first hydrogen fuelling station of the world was opened in April 2003.

Many other projects are being planned involving vehicles, infrastructure and ships. The goal is to create a full scale hydrogen society before 2050.

Japan

Since 2001, Daimler-Chrysler, Mazda, Honda and Toyota have acquired the ministerial certification for fuel cell vehicles one after another. Currently, eight auto manufacturers (Toyota, Nissan, Honda, DaimlerChrysler, HM, Hino, Mitsubishi and Suzuki) have been demonstrating their own developed fuel cell vehicles on the public roads. It is expected that fuel cell vehicles will be available to common users in 2005.

United Kingdom

A rolling programme of fuel cell research is being funded by EPSRC. The programme concentrates on the materials required for fuel cell manufacturer. The next stage of the Forsight vehicle programme will include a call for proposals

A fuel cell delivery vehicle is currently being demonstrated in London. Additional demonstration projects started in 2002 including two fuel cell buses.

These projects are due to report around 2005.

United States

FreedomCAR and Fuel Initiative

On 28 January 2003, President Bush announced a USD 1.2 billion FreedomCAR and Fuel Initiative to reverse America's growing dependence on foreign oil by developing the technology needed for commercially viable hydrogen-powered fuel cells - a way to power cars, trucks, homes and businesses that produces no pollution and no greenhouse gases. The Initiative will invest USD 720 million in new funding over the next five years to develop the technologies and infrastructure needed to produce, store, and distribute hydrogen for use in fuel cell vehicles and electricity generation. Building on the FreedomCAR (Cooperative Automotive Research) Initiative, which was launched in January 2002, President Bush is proposing a total of USD 1.7 billion over the next five years to develop hydrogen-powered fuel cells, hydrogen infrastructure and advanced automotive technologies.

Together, the FreedomCAR and Fuel Initiative, through partnerships with the private sector, aim to develop new vehicle and fuel technologies and the infrastructure needed to make it practical and cost-effective for large numbers of Americans to choose to use fuel cell vehicles by 2020. These initiatives could dramatically improve America's energy security by significantly reducing the need for imported oil. At the same time, they are a key component of the President's clean air and climate change strategies.

More information can be found at *http://www.eere.energy.gov/hydrogenfuel/*

California Fuel Cell Partnership

In California, auto manufacturers, energy companies, fuel cell technology companies, and government agencies are collaborating to develop fuel cell vehicles. They have organized the partnership to advance a new vehicle technology that could move the world toward practical and affordable environmental solutions. For the first time ever, automobile companies and fuel suppliers have joined together to demonstrate fuel cell vehicles under real day-to-day driving conditions. The California Fuel Cell Partnership expects to place up to 60 fuel cell passenger cars and fuel cell buses on the road between 2000 and 2003. In addition to testing the fuel cell vehicles, the partnership is examining fuel infrastructure issues and beginning to prepare the California market for this new technology.

Specifically, the partnership aims to achieve four main goals:

- Demonstrate vehicle technology by operating and testing the vehicles under real-world conditions in California.
- Demonstrate the viability of alternative fuel infrastructure technology, including hydrogen and methanol stations.
- Explore the path to commercialization, from identifying potential problems to developing solutions.
- Increase public awareness and enhance opinion about fuel cell electric vehicles, preparing the market for commercialisation.

More information can be found at *http://www.drivingthefuture.org/*

Conclusions

In 2002, even after the significant range of actions taken in many member countries, the share of alternative low pollutant emission vehicles was less than 5-6 % of their vehicle fleets. Although most countries offer grants to buy these vehicles and/or very low taxes on specific fuels (*e.g.* LPG, CNG, bio fuels, etc.), sales of alternative fuel vehicles remain very low.

Some goods results have been obtained in specific fleets, such as buses or refuse trucks, but even in 2002, the proportion of new buses and collection trucks with LPG or CNG was not very high (near 30% in France, but lower in all the other countries). The reasons for these results include the following:

- Extra cost to buy the vehicle.
- Very small market.
- Difficulties to refuel.
- Resale of the car.

But the most significant reason is that conventional engines (petrol and diesel) have continued to improve and now produce very good results in terms of local pollutant emissions when compared to LPG, CNG and other alternative fuels. In addition, the performance of conventional engines has increased in terms of speed and energy efficiency, especially in the case of conventional diesel engines. As a result, the former advantages of alternative “low-emissions vehicles” have slowly disappeared.

In relation to CO_2 emissions, car-makers now produce many models that are below 120g CO_2 /km as measured on the European official cycle. At the end of 2001, more than 200 000 passenger-cars emitting 120g or less have been sold in Europe, the whole number of which was fitted with diesel engines.

Fuel cell experiments are in progress for cars, delivery vans and buses. Since 1997, many experimental vehicles have been tested (passenger cars and buses) in several countries. Some technical and economic problems have been encountered and there is now widespread co-operation and research on an international basis to find solutions that will enable fuel cells to become one of the preferred forms of motive power in the future.

Annex D

INFORMATION AND INCENTIVES IN OECD COUNTRIES

This annex summarises the answers to the survey undertaken by the OECD Working Group and related to incentives to promote the use of low-emission vehicles. In some cases, the working group also added information from non-responding countries.

It contains the following information:

Financial incentives

- Summary of differential taxes on “low-emission vehicles” (Table D.1).
- List of countries providing cash grants or rebates for purchase of new alternative fuelled vehicles (Table D.2).
- Country summaries of information and incentives for low-emission vehicles (Table D.3).

Clean fuel incentives

- Summary of taxation incentives for “Clean” Fuels (Table D.4).

Promoting low-emission vehicles through public information.

- Summary of environmental guides on vehicles (Table D.5).

The main trends are analysed in the core report.

Table D.1. Summary of differential taxes on "low-emission" vehicles

Country	Basis of differential vehicle taxes on low-emission vehicles (PT = "one off" purchase/income tax/subsidy; AT = annual tax/subsidy; ID = import duty)							
	Emission standards	Fuel consumption / CO_2	Alternative fuel vehicle			Alternative technology		
			LPG	NG	Other	Hybrid	Fuel cell	EV
Austria		PT						PT
Belgium	PT							
Canada		PT	PT	PT				
Czech Republic	PT							
Denmark		PT						
France			PT	PT	PT	AT		PT
Hungary	AT							
Iceland				ID			ID	ID
Italy							PT & AT	PT & AT
Japan	PT & AT (both conditions are necessary[1])			PT & AT	PT & AT	PT & AT[1]	PT & AT	PT & AT
Malaysia				AT				
Netherlands	PT, AT	AT?				PT & AT	AT	PT &AT
Sweden	AT					AT		AT
Switzerland								PT
United Kingdom		AT	PT & AT	PT & AT		PT & AT		PT & AT
United States			PT	PT	PT	PT	PT	PT

1. AT is given by emission standards and fuel consumption.

Table D.2. List of countries providing cash grants or rebates for purchase of new alternative fuelled vehicles

Country	Grants/rebates for purchase of new alternative fuelled vehicles		
	LPG	NG	Other
Australia	√	√	
Canada		√	
France	√ (taxis)	√	√
Italy	√	√	
Japan		√	√ (electric)
Netherlands		√	
United Kingdom	√	√	
United States	√	√	√ (methanol, hydrogen)

Note: In some countries the support is limited to particular classes of vehicles, *e.g.* heavy-duty vehicles, buses.

Table D.3. Country summaries of information and incentives for low-emission vehicles

Australia	
Information sources	• Data on fuel consumption available in printed form and at: *www.greenhouse.gov.au/transport/fuelguide/* • Fuel consumption labelling of vehicles
Incentives	
Belgium	
Information sources	• Data on emissions and fuel consumption available on Internet at *www.emis.vito.be/mobiliteit* • Fuel consumption labelling
Incentives	• Reduction in purchase tax for Euro 4 cars sold in 2002, 2003 and 2004
Canada	
Information sources	• Data on fuel consumption available at *http://autosmart.nrcan.gc.ca/pubs/fcg3_e.cfm* • Fuel consumption labelling
Incentives	• Purchase cost subsidies for natural gas vehicles
Czech Republic	
Information sources	• Data on emissions standards and fuel consumption is available from vehicle manufacturers' Web sites
Incentives	• 25% reduction in road tax for Euro 3 vehicles from 1 January 2002
Denmark	
Information sources	
Incentives	• Specific taxes linked to fuel consumption • Substantial rebate on vehicle taxes for very low fuel consumption vehicles (<4L/100km petrol; <3.5L/100km diesel)
Finland	
Information sources	• Data on emissions and fuel consumption available at *www.motiva.fi/autotietokanta*
Incentives	• Variations in vehicle taxes based on emissions standard and vehicle technology

Table D.3. Country summaries of information and incentives for low-emission vehicles *(continued)*

France	
Information sources	• Data on fuel consumption are available at *http://www.transports.equipement.gouv.fr/* • Data on purchase grants are available at *http://www.environnement.gouv.fr/actua/cominfos/dosdir/DIRPPR/ dosdppr.htm#transport*
Incentives	Purchase grants for: • LPG taxis: EUR 3050 until 31/12/2002 and then EUR 2000 until 31/12/2003 (no more than 3000 subsidies or vehicles) • NG buses, NG or biogas or electric or hybrid skips: EUR 7500 per bus on the first purchase year or during three years for at least 40 buses • Electric cars or vans: EUR 3050 per vehicle definitely replacing a vehicle first registered before 1993 (no more than 25000 subsidies or vehicles) • Electric two-wheeled vehicles: EUR 510 per vehicle (no more than 2500 subsidies or vehicles) • Particulate filters: EUR 1300 per bus first registered between 01/01/1991 and 31/12/2000 (no more than 1000 subsidies or filters)
Hungary	
Information sources	
Incentives	Differential road tax based on emissions standards as follows: • Euro 0 : Full tax • Euro 1: 75% • Euro 2: 50% • Euro 3/4: 25%
Iceland	
Information sources	
Incentives	• No import duty on zero-emission and CNG vehicles
Italy	
Information sources	• Data on fuel consumption at *http://mica-dgfe.casaccia.enea.it/* • Information on incentives available at *http://www.ceiuni.it/CIVES/Quadroin.htm*
Incentives	• Tax measures to reduce EV price by up to EUR 4300. • Exemption from annual circulation tax for first five years for EVs, including motorcycles and mopeds.

Table D.3. Country summaries of information and incentives for low-emission vehicles *(continued)*

Japan	
Information sources	• Data on emissions and fuel consumption available at: *http://www.mlit.go.jp/jidosha/nenpi/nenpilist/nenpilist.html*
Incentives	• Reduction in annual vehicle tax on cars and other light vehicles during the first year after purchase based on emissions and fuel consumption as follows: 50% reduction for EVs, CNG, methanol; 50% for 1/4 emission stipulated in standards + 2010 fuel consumption target
	• Reduced purchase taxes on CNG , hybrid, methanol and electric vehicles
	• Various subsidies to local authorities to encourage adoption of “clean energy” vehicles into their fleets
	• Low interest loans to organisations to encourage purchase of NG, electric, methanol and hybrid vehicles
The Netherlands	
Information sources	• Fuel economy guide on the internet at *http://www.hetnieuwerijden.nl/*
	• Emissions information required in advertising
	• Energy labelling of vehicles
Incentives	• Reduction in purchase tax for Euro 4 cars sold in 2002, 03 and 04
	• Reductions in annual vehicle taxes on low emission and low fuel consumption vehicles.
	• No vehicle taxes on EVs and hybrids
Sweden	
Information sources	• Data on environmental classification of vehicles on Internet at *http://www.internat.environ.se/documents/legal/vehicle/vehicle.pdf*
Incentives	• Reduction in annual tax in first year for Euro 4 vehicles.
	• No vehicle taxes for first five years for EVs and hybrids
United Kingdom	
Information sources	• Data on emissions, fuel consumption and noise available at *www.vcacarfueldata.org.uk*
	• Data on “clean” fuelled vehicles available at *www.est-powershift.org.uk/ps_register.cfm*
Incentives	• Reduction in annual vehicle excise duty based principally on CO2 emissions, but also fuel and technology type as detailed in the table below.
	• Company car tax based on CO_2 emission levels
	• Fleet programme aimed at reducing CO_2 emissions (see *http://www.greenerfleet.org.uk/index.html*)

Table D.3. Country summaries of information and incentives for low-emission vehicles *(continued)*

United States	
Information sources	• Data on emissions and fuel consumption available on Internet at various sites, including: *http://www.epa.gov/autoemissions* *http:/www.fueleconomy.gov* (fuel consumption and greenhouse emissions only) *http://www.arb.ca.gov/msprog/ccbg/ccbg.htm* (noxious emissions only) *http://www.greenercars.com/indexplus.html*
Incentives	• Tax credits for purchase of EVs, fuel cell, hybrid and alternative fuel vehicles • "Gas Guzzler" tax of USD 1000 – USD 7000 on high fuel consumption cars • Fleet purchasing requirements for LEVs in high pollution areas (see *http://www.epa.gov/otaq/cff.htm*)

Table D.4. Summary of taxation incentives for "clean" fuels

Country	**Tax incentives for "clean" fuels ER = excise (or equivalent) reduction*; EF = excise free**								
	Low sulphur fuels				**Alternative fuels**				
	Petrol		**Diesel**		**LPG**	**NG**	**Ethanol**	**Methanol**	**Other**
	50ppm	**10ppm**	**50ppm**	**10ppm**					
Australia	-	-	ER**	-	EF	EF	EF	-	-
Belgium	ER	-	ER	-	EF	EF	-	-	-
Czech Republic	-	-	-	-	ER	EF	-	-	ER (biodiesel)
Denmark	-	-	ER	-	-	-	-	-	-
Finland	-	-	ER	-	EF	EF	-	-	-
Hong Kong, China	-	-	ER	-	-	-	-	-	-
Iceland	-	-	-	-	-	EF	-	-	-
Italy	-	-	-	-	ER	ER	-	-	ER (biodiesel)
Japan	-	-	-	-	-	-	EF	EF	-
Netherlands	ER		ER	-	-	EF	N/A	EF-	-
Norway	-	-	ER	-	-	EF	-	-	-
Sweden	ER	-	ER	ER	-	-	-	-	-
Switzerland	ER	ER**	ER	ER**	-	-	-	-	-
United Kingdom	ER	-	ER	-	ER	ER	-	-	ER (hydrogen)
United States	-	-	-	-	ER	ER	EF	ER	ER

* The excise reduction may be implemented by a direct reduction in the excise on the specified fuel, or an increase in excise on fuels with higher sulphur levels than the specified fuel (UK is an example of the second approach).

** Proposed.

Table D.5. Summary of environmental guides on vehicles

Country	Environmental guide details													
	Source	Scope/content						Information/presentation					Delivery medium	
		Greenhouse		Air pollution	Noise	Operat-ing costs	Other	Certification data	Standards compliance	Overall fleet ranking	Class ranking	Combined greenhouse and air pollution rank	Internet	Paper
		CO_2	Fuel cons.											
Australia	AGO		√								√*		√	√
Belgium	VITO	√	√	√					√		√**		▪	?
Canada	NRCAN		√			√							√	√
Finland	Motiva	√	√	√				√ (NOx+HC)					√	
France		√	√											
Japan	MLIT, MOE		√	√	√				√ (only low emission standards and fuel consumption)			√	√	
Netherlands	Novem		√								√**		√	
Sweden	EPA		√	√					√				√	
United Kingdom	VCA	√	√	√	√	√		√	√	√**			√	√
United States	EPA		√	√						√	√	√	√	
	DOE	√	√			√					√		√	
	ARB			√					√***				√	
	ACEEE	√	√	√		√	√		√	√	√	√	√	√

* top 5 best performers only in each group; ** on fuel consumption/CO_2 only; *** only vehicles meeting better than minimum standards are listed

Source Names: ACEEE – American Council for an Energy Efficient Economy; AGO - Australian Greenhouse Office; ARB – Air Resources Board (California); EPA – Environment Protection Authority/Agency; DOE – Department of Energy; MLIT — Ministry of Land, Infrastructure and Transport; MOE – Ministry of the Environment; Motiva – Energy Information Centre for Energy Efficiency and Renewable Energy Sources; NRCAN – Dept of Natural Resources, Canada; VCA – Vehicle Certification Agency; VITO - Flemish Institute for Technological Research.

Annex E

HYDROGEN PRODUCTION FROM FOSSIL SOURCES

This contribution was submitted by Iceland. It aims to describe the production process for hydrogen in view of a possible large scale application for fuel cell vehicles.

Natural gas

The most efficient process for large-scale production of hydrogen is steam reforming (SMR) of natural gas. Steam reforming refers to the endothermic, catalytic conversion of light hydrocarbons with water vapour. Industry scale processes of this kind are normally carried out at temperatures of 850°C and pressures in the order of 2.5 Mpa. The industrial scale production of hydrogen is carried out in steam reforming plants with usual capacities in the order of 100,000 Nm^3 H_2/h. The process is technically well proven.

With this process, efficiencies of 73% can be reached and 86% is possible when useful high-pressure steam is produced at the same time (steam credit).

Local production of hydrogen by steam reforming is less efficient because there is less scope for obtaining steam credits. However with catalytic partial oxidation of natural gas efficiencies of 80% or higher can be reached.

Oil

Partial oxidation (POX) of heavy fuel oils is also used as a hydrogen production method. Partial oxidation refers to the exothermic or autothermal conversion of heavy hydrocarbons (*e.g.* residual oil from the treatment of crude oil) with oxygen and steam. Similarly to SMR the industrial scale of this process is in the order of 100 000 Nm^3 H_2/h, and the process is technically well-proven. Two processes that are currently applied are the Texaco and the Shell gasification processes. The energy efficiency of these processes is about 50%.

Coal

The chemistry involved in partial oxidation of coal, commonly referred to as gasification, is similar to the partial oxidation of oil. Apart from the necessary initial preparation of the coal, the process elements of the plant as a whole are the same as for the gasification of oil. The coal is ground to a fine powder and then mixed with water to create a 50-70% solid content suspension suitable for pumping.

There are two types of coal gasification processes, the Toppers-Totzek process that can be carried out at atmospheric pressure and the Texaco process that is carried out at a pressure near 5.5 Mpa. The efficiencies for coal gasification are similar as for the POX of heavy fuel oils.

The efficiency of this process is comparable to that of heavy oil partial oxidation and the process is only carried out on a commercial basis in the coal rich countries of South Africa and China. The energy efficiencies for the various methods of hydrogen production from fossil sources are summarised in Table 2.

Emissions

Carbon dioxide emissions for hydrogen production (*excluding* compression/storage/ transport etc.) can be calculated from the energy efficiencies of the hydrogen production processes. To produce 1MJ of hydrogen would cost 2MJ of heavy fuel oil, 1.9MJ of coal, or 1.16MJ of natural gas (86% efficient process). Below the emissions for each feedstock are listed in g per MJ. These emissions are based on the emission factors of fuel combustion and exclude feedstock production, refining, transport and storage and compression.

Table E.1. Emissions of CO_2 for different energy sources

Energy source	gCO_2/MJ
Brown coal	111[1]
Hard coal (gasification)	92[2]
Residual oil	78[2]
Natural gas	57[2]

Table E.2. Energy efficiencies and CO2 emission for H2 production form fossil sources

Energy efficiency	CO_2 emissions g/MJ	
Oil		
50%	156	Non-catalytic Partial Oxidation of heavy fuel oil (Texaco- and Shell gasification process)[3]
Coal		
52%	177	Gasification [4]
Natural gas		
86%	66	Central hydrogen production, NG as feedstock, without steam or electricity export[5]
71%	80	Central hydrogen production, natural gas as feedstock, with steam or electricity export[3]
79%	72	Gaseous hydrogen production at refuelling stations, NG as feedstock[3]

[1] *www.umweltbundesamt.de*

[2] Greet emissions model, Argonne National Laboratories, *www.transportation.anl.gov/ttrdc/greet*

[3] NREL report: C.E.G. Padro and V. Putsche “Survey of the Economics of Hydrogen Technologies”, NRL/TP-570-27079.

[4] DOE Web site: *www.fe.doe.gov*

[5] J.J.J. Louis, “Well-to-Wheel Energy Use and Greenhouse Gas Emissions for Various Vehicle Technologies”, SAE paper 2001-01-1343.

Costs

Costs of hydrogen production from SMR and coal gasification have been investigated by Lipman and DeLucchi[6] and are listed in Table E.3. It is clear that the most cost effective way of producing Hydrogen is from large scale steam reforming of natural gas. (Assuming a natural gas price of USD 4-6/GJ and coal costs of USD 1.5/GJ).

Table E.3 Cost of hydrogen production

Costs of hydrogen production, post 2000 forecast [6]	USD/GJ
Hydrogen from steam reforming of natural gas	
Large plant (18 000 GJ/day)	6.4 - 8.6
Small plant (180 GJ/day)	13.8- 16.5
Hydrogen from coal gasification	
Large plant (18 000 GJ/day)	8.6
Medium plant (9180 GJ/day)	13

Hydrogen production by water electrolysis

The theory

Production of hydrogen from fossil sources creates greenhouse gases such as carbon dioxide. Also, the purity of the hydrogen gas coming from fossil sources is not very high so the gas needs purification before it can be used. Therefore, it can be stated that hydrogen production by water electrolysis, with electricity from renewable energy sources, has some clear advantages over hydrogen produced from fossil sources:

- No greenhouse gases or other pollutant gases are released.
- The purity of the hydrogen gas, produced by electrolysis, is very high (> 99,5%).
- The production is very simple, only water and electricity is required.

These advantages and Iceland's abundant renewable energy sources make water electrolysis in Iceland a very interesting choice for hydrogen production.

In electrolysis, water is spilt in to its elements, hydrogen and oxygen, by electricity causing the reaction.

$$H_2O + 283{,}58\ [KJ/mol]^7 \rightarrow H_2 + ½O_2$$

Two electrodes, anode and cathode, are placed in electrolyte and an electric potential is brought between it to propel the reaction. In theory the electrical energy needed is determined by the free enthalpy of water (283,58 [KJ/mol]). The theoretical voltage needed is roughly 1.2V but in practise the voltage is more like 2V, or so, due to resistance in the electrodes and the electrolyte.

In general, three processes have been developed for water electrolysis:

[6] T.E. Lipman and M.A. DeLucchi (1996), "Hydrogen-Fuelled Vehicles", *International Journal of Vehicle Design*, Vol. 17, p. 562.

[7] *D*.D. Wagman et al., eds (1982), "The NBS Tables of Thermodynamic Properties", *J. Phys. Chem. Ref. Data, 11, suppl. 2.*

1. Water electrolysis with alkaline aqueous electrolytes, employing a thin diaphragm to avoid remixing of the produced gases, oxygen and hydrogen, separates the anode and cathode.

2. Membrane or Solid Polymer Electrolyte water electrolysis, which employs a proton-conducting ion exchange membrane as electrolyte and as membrane that separates the electrolysis cell. The water to be dissociated dose not requires dissolved electrolytes to increase its conductivity and it is added solely on the anode side.

3. High-temperature steam electrolysis operates between 700 and 1 000°C and which employs oxygen ion-conducting ceramics as electrolyte. The water to be dissociated is entered on the cathode side as steam, which forms a steam-hydrogen mixture during electrolytic dissociation. The O_2 ions are transported through the ceramic material to the anode where they are discharged as oxygen.

The Norsk Hydro technology is of type one, so that will be the technology considered in this feasibility study.

The Norsk Hydro water electrolysis technology

Norsk Hydro Electrolysers AS provides one of the most efficient conventional alkaline electrolysis technologies commercially available. The first Norsk Hydro bipolar, filter press water electrolysers was built in 1927 for use in the Company's own ammonia plants. The two largest water electrolysis plants in the world were installed in Norway operating over 300 electrolysers and producing more than 60.00 Nm^3/h of hydrogen. Therefore this technology is based on a well-proven cell and cell package/electrolyser design.

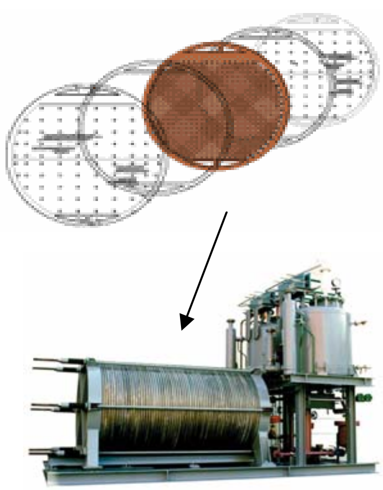


Figure E.1: Norsk Hydro electrolyser

The standard cell is made of two electrodes, two gaskets and a diaphragm frame. The construction can be seen from figure E.1. Electrodes, gaskets and diaphragm are sandwiched together thus forming two separate cell compartments separated by the diaphragm. Electrodes and frame are nickel-plated and catalytic coatings also activate the fore-electrodes. The diaphragm is manufactured of a polymer material. At the bottom of the cell there are openings, which form the electrolyte supply and distribution ducts. Hydrogen and oxygen gas respectively flow to openings at the top of the cell forming ducts for gas and electrolyte removal.

The electrolyser cell package is clamed together as a filter press assembled between rigid steel frames. Electrolyte from the cooler is fed to the supply duct. The produced gases together with some electrolyte flow through the removal ducts to the hydrogen and oxygen separators. The bus bars are connected to the electrolysers at the front and rear ends, the front end being earthed for safe operation.

The complete electrolyser consists of the cellblock (EL module) and the electrolyte system (ES module). Cell package size and the size of the electrolyte system, particularly the gas/lye separators, are determined by the gas generation capacity required. Forced circulation of the electrolyte is provided for optimum heat dissipation and uniform electrolyte concentration in all cells enabling the electrolyser to run at optimal conditions. Norsk Hydro Electrolysers provide two types of electrolyte system as standard, one is complete with gas coolers and water-seals where traces of KOH in the down-stream gas is removed by the use of a water-ring compressor and the other is supplied without the gas coolers and water-seals where down-stream gas is scrubbed by our standard scrubber (SC module).

LIST OF ABBREVIATIONS USED IN THE REPORT

ACEA	*Association des Constructeurs Européens d'Automobiles* (European Automobile Manufacturers Association)
APU	Auxiliary power unit
CAFE	Corporate average fuel economy (USA)
CARB	Californian Air Resources Board
CID	Displacement (cubic inch displacement)
CNG	Compressed natural gas
CO_2	Carbon dioxide
CRT	Continuous regenerating traps
CVT	Continuous variable transmission
deNOx	NO_x selective catalyser
EGR	Exhaust gas recirculation
EPA	Environmental Protection Agency
ESC	European steady state cycle
ETC	European transient cycle
EU	European Union
EUDC	Extra urban driving cycle
EV	Electric vehicle
EZEVs	Equivalent zero-emissions vehicles
FCEV	Fuel cell electric vehicle
GHG	Greenhouse gas
GRPE	Working Group of UN-ECE
HEV	Hybrid electric vehicle
HP	Horse power
hp	Horse power *(unit of power in the British engineering system equal to approximately 745.7 watts)*
HV	Hybrid vehicles
ICE	Internal combustion engine
IEA	International Energy Agency
ISA	Integrated starter alternator
IUC	In-use compliance
JAMA	Japan Automobile Manufacturers Association
KAMA	Korea Automobile Manufacturers Association
LEV	Low-emission vehicle
LPG	Liquefied petroleum gas
MON	Motor octane number
MPG	Mile per gallon
MPV	Multi-purpose vehicle
NG	Natural gas
OBD	On-board-diagnostics
PM	Particulate matter
PNGV	Program for a New Generation of Vehicles (United States)
ppm	Parts per million
SUV	Sports utility vehicle
UDC	Urban driving cycle
UN-ECE	United Nations Economic Commission for Europe
VOC	Volatile organic compounds
WHO	World Health Organization
ZEV	Zero-emission vehicle

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PRINTED IN FRANCE
(77 2004 02 1 P) ISBN 92-64-10495-X – No. 53415 2004