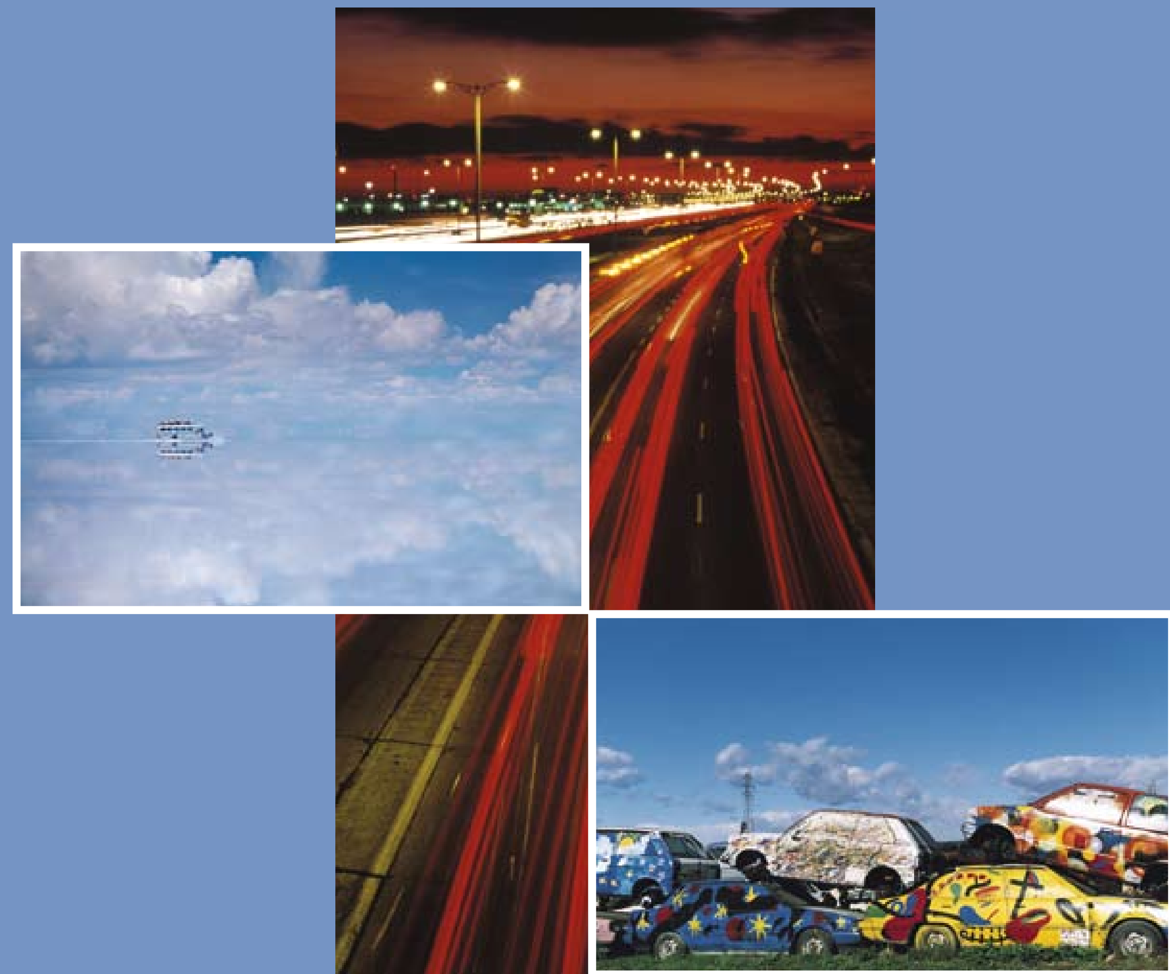
Hybrid Electric Vehicles

An overview of current technology and its application in developing and transitional countries



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List of Acronyms

CNG	compressed natural gas
CO	carbon monoxide
CO2	carbon dioxide
DOC	diesel oxidation catalyst
DPF	diesel particulate filter
FCV	fuel cell vehicle
Gt	gigatonne
HC	hydrocarbon
HEV	hybrid electric vehicle
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ITF	International Transport Forum
Km	kilometer
L	liter
LPG	liquefied petroleum gas
MECA	Manufacturers of Emission Control Technology
MPG	miles per gallon
NOx	oxides of nitrogen
PCFV	Partnership for Clean Fuels and Vehicles
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PPM	parts per million
SCR	selective catalytic reduction
SOx	sulphur oxides
TWC	three-way catalyst
UNEP	United Nations Environment Programme
UPS	United Postal Service
USD	United States dollars
U.S. EPA	United States Environmental Protection Agency
WBCSD	World Business Council on Sustainable Development

Executive Summary

A well functioning and efficient transport sector is a requirement for economic and social development, bringing people together and enabling the trade and exchange of goods and ideas. However, the transport sector is also responsible for a number of negative social and environmental effects, including a significant contribution to global greenhouse gas emissions and air pollution. A global shift to a greener, low carbon economy will require significant improvement in the ways in which energy is produced and used. The transport sector uses over a quarter of the world's energy and is responsible for a comparable share of global CO_2 emissions from fossil fuel combustion. This will require both systemic and more specific technological solutions, such as: smart growth urban planning for fewer motorized trips, increased modal share of non-motorized and public transport, shifting incentives to more efficient and less polluting modes and technologies, and taking advantage of best available and most fuel and energy efficient technologies.

The global light duty vehicle fleet is expected to triple by 2050, with most (around 90%) of the growth to take place in developing and transitional countries. Therefore, special attention needs to be paid to controlling the fleet sizes and composition on a global level in the medium and long term. When exploring solutions to lower road transport emissions and improve fuel efficiency, policy makers, industry, and consumers often look to technology that has proven to be cost effective. Hybrid electric vehicles, along with other cleaner vehicle technologies, are increasingly on the list of options.

This report is an introductory review of hybrid electric vehicle (HEV) technology and its use in expanding markets in non-OECD countries. An HEV uses both an electric motor with both a battery and a combustion engine with a fuel tank for propulsion; hence, a hybrid between an electric and a conventional vehicle. While not fully electric vehicles, HEVs are realistically a bridging technology in developing and transitional countries and markets; their increasing share in the global fleet is a move toward greater eventual fleet electrification (via the use of plug-in hybrids – or PHEVs - and pure electric vehicles - EVs) as HEVs require no infrastructure changes – e.g. electrical grid modification or special fueling stations. This is why HEVs are of particular interest now, even as countries struggle with fuel quality (e.g. sulphur levels), the adoption of very clean diesel technology, and the sustainable use and production of liquid biofuels.

Hybrid passenger cars have been on the market since 1997, with hybrid buses and delivery trucks emerging in the last 3-4 years. Widespread use in industrialized markets is now leading to use in developing countries through second hand markets.

HEV technology, albeit more expensive than conventional vehicles, is poised for entry into new markets. This will present a number of opportunities and advantages, given that the right policies and complementary standards (including fuel quality standards) are in place and policy makers, industry groups, consumers, and vehicle maintenance providers are sufficiently informed and have realistic expectations of HEV technology. It is also important to consider that HEVs are not the only clean vehicle option available today. Cleaner diesel vehicles, compressed natural gas (CNG) vehicles, and vehicles that run on liquid biofuel blends are also viable alternatives for reducing air pollution and greenhouse gas emissions. In addition, HEVs are not necessarily fuel specific; this technology is versatile and can be applied to CNG, diesel, and flexi fuel vehicles.

This report looks specifically at what needs to be considered from a developing and transitional country perspective for the introduction and promotion of HEVs. The UNEP *Hybrid Electric Vehicles* report is designed to guide decision makers and institutions in assessing the feasibility of hybrid technology in transport and fuel efficiency measures and to assist knowledge and technology transfer for lower emissions.

The cleaner vehicle options considered in this report can meet future stricter regulations on emissions such as hydrocarbons, nitrogen oxides, sulphur oxides, and particulate matter using available, 'off the shelf' emission control technologies. The main difference between the technologies considered is in fuel consumption and the resulting emissions of carbon dioxide (CO2).

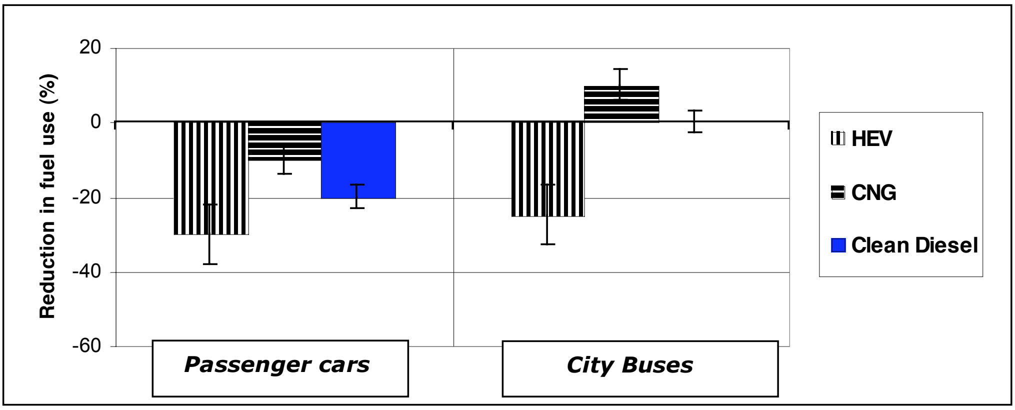

Figure 1 A comparison of the fuel reduction potential with the different comparable options. The bars indicate the variety among models and the uncertainty. Passenger cars are compared to petrol vehicles and city buses are compared to diesel buses. Reductions in fuel use will vary depending on operating conditions.

Figure 1 provides a broad comparison of the reduction in fuel consumption from the three main technologies considered and compared in this report. On average, hybrid passenger vehicles offer 30% better fuel economy, and switching from petrol to diesel vehicles gives a 20% reduction in fuel use, whereas CNG vehicles offer a 10% reduction (based on energy content in the fuel). However, the reduction in CO_2 emissions from use of CNG is roughly 20% on a life cycle basis (compared to hybrids and diesel) due to the lower carbon content in natural gas. For example, in city bus applications, HEV buses reduce fuel use by 25%; CNG use increases and diesel efficiency remains the same. In HEVs, savings are compounded by the fact that these vehicles do not require special fueling infrastructure.

In addition to the technology and fuel used, reduction in fuel consumption is dependent on driving conditions (traffic management, infrastructure, etc.). The more stop-and-go traffic (e.g. city driving conditions), the greater the potential for fuel savings when using a hybrid as compared to an ordinary vehicle. This is especially relevant for city buses and delivery trucks; a careful analysis of drive cycles should inform HEV programs for heavy-duty vehicles.

The four key policy-relevant and consumer choice advantages of HEVs over conventional and comparably clean and efficient technology (clean diesel, CNG) can be summarized as follows:

- **Emissions** – Available HEV technology will decrease emissions of conventional air pollutants substantially as compared to a standard vehicle on the roads today. While similar emission reductions can be achieved with, e.g. CNG and clean diesel vehicles with advanced emission control technologies, the HEV combines both non-CO2 and CO2 reductions.

- **Energy** - HEVs decrease fuel consumption substantially compared to conventional vehicles used today and also compared to CNG and the new generation of cleaner diesel vehicles. Calculations have shown that over the average HEV useful life time savings can amount to 6,000 L of fuel.

- **Life Cycle Cost** – While HEVs are more expensive initially, the fuel savings are recouped based on mileage and driving conditions. Analysis has shown that the HEV life cycle cost, including the cost of purchase, fuel and maintenance costs, is, in most cases, less than owning a conventional vehicle. However, these calculations are strongly dependent on fuel prices and taxes.

- **Strategic Stepping Stone Technology** - HEVs, plug-in hybrids (PHEVs), full electric vehicles (EVs), and fuel cell vehicles (FCVs) share basic technologies such as electric motors, batteries, and power electronics. Therefore, HEVs and plug-in hybrids function as stepping stone technologies to the large-scale electrification of fleets that is required for a long-term reduction of CO2 emissions from road transport, and a low carbon transport sector.

When used to improve fuel economy and reduce carbon emissions, rather than to increase vehicle power and size, hybrid technology compares favorably with existing; vehicle technology.

While already an established market in North America, Europe, and parts of Asia, HEVs are also present in limited, but growing, numbers in developing and transitional countries. However, as these countries join global efforts to curb pollution and greenhouse gas emissions, HEVs are expected to be introduced on an increasing scale in the next 5 to 10 years through enabling policies and international second hand vehicle flows.

While these technologies are still maturing, hybridization of fleets can start making a significant dent in transport energy usage today, and can help countries meet fuel efficiency targets by 2050. Together with systemic improvements in traffic management, the increased use of non-motorized transport modes in more compact city centers, and higher rates of mass transit use, HEVs are poised to contribute to long term improvements in emission reductions.

1 Introduction

1.1 The Global Vehicle Emissions Challenge

With the expected tripling of the global light-duty[1] vehicle fleet and a doubling of its CO2 emissions, the importance of addressing fuel efficiency in road transport is rising on global and national environment, energy, and climate change agendas (IEA 2008 and WBCSD 2004B). Road transport is responsible for 17-18% of global CO2 emissions from fossil fuel combustion[2] and in most countries transport CO2 emissions are growing at a faster rate than total CO2 emissions (OECD/ITF 2008a). Projections for road transport growth and car ownership for the next few decades show that road transport will continue to dominate, despite the rapid growth in shipping and aviation.

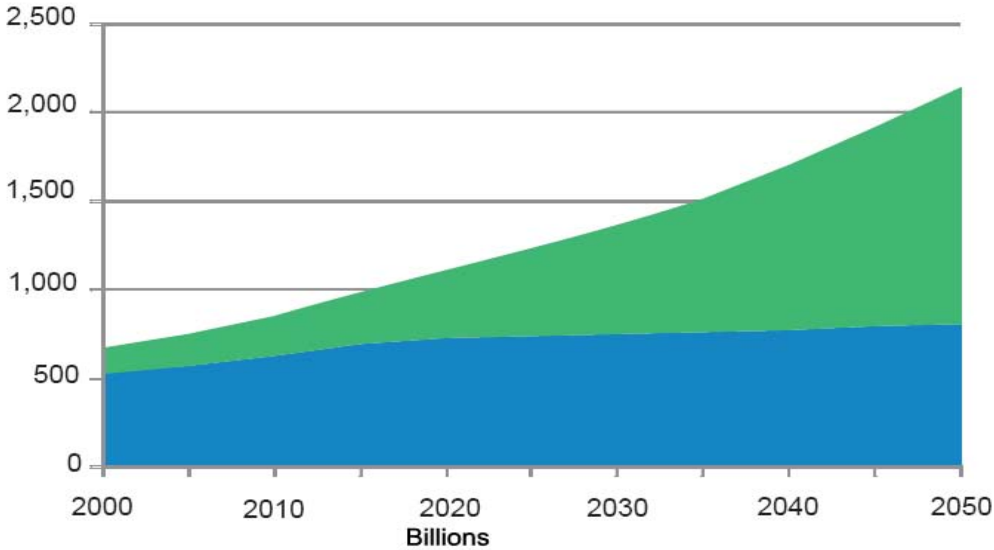

Figure 2 Global Growth in Light Duty Vehicles A tripling of the non-OECD fleet is foreseen by 2050 [WBCSD 2004b(WBCSD 2004b)].

Significant fuel economy improvements in road transport are required to stabilize and eventually decrease greenhouse gas emissions from the transport sector; past improvements in efficiency will not be adequate to compensate for the steady increase in traffic volume. The United Nations Intergovernmental Panel on Climate Change (IPCC) states that an ambitious 50-80% reduction in global CO2 emissions is required by 2050 (as compared to 2000 levels) in order to limit temperature rise to 2-2.4 degrees Celsius and stabilize atmospheric CO2 concentration at 450 parts per million (ppm), thus avoiding severe climate change. Doubling the fuel efficiency of road vehicles (in particular light duty cars, vans and trucks) is one of the most cost-effective and accessible measures towards achieving global stabilization of CO2 emissions. However, the targets for both global CO2 emission reduction and fuel efficiency improvement require that all countries adopt cleaner technology on a large scale.

1. Cars, minivans, SUV's
2. Transport greenhouse gas emissions account for around 27% of total emissions on a well-to-wheel basis when including emissions from feedstock, fuel production and delivery to end user. [IEA 2008]

Currently available, off-the-shelf technology[3] allows improvements in the average fuel economy of new light-duty vehicles of up to 30% by 2020 in OECD countries[4], and large-scale hybridization of major vehicle markets can double efficiency in these countries by 2030. Global technology transfer through vehicle renewal and import/export markets can distribute and magnify the efficiency gains worldwide by 2050. Even if vehicle kilometres travelled double by this time, fuel efficiency improvements on a global scale together with complementary systemic transport measures can effectively stabilize emissions from cars. Emission savings can add up to over 1 gigatonne (Gt) of CO2 annually from 2025 onwards, and fuel cost savings are expected to equal 6 billion barrels of oil per year by 2050. In the IPCC scenario outlined above, halving CO2 emissions by 2050 would mean that global emissions would fall to 14 Gt per year (IEA 2008).

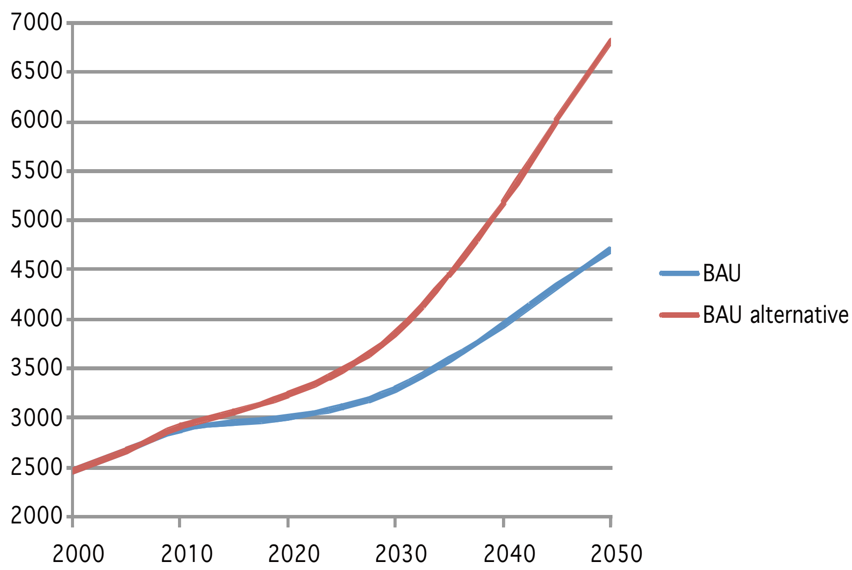

Figure 3 World CO2 emissions from cars (Mt of CO2 equivalent). A doubling in emissions is foreseen by 2050, with the possibility of even higher emissions if non-OECD countries follow the same pattern of automotive demand as in OECD countries. The figure presents IEA business as usual (BAU) case and an alternative that assumes demand for driving in non-OECD countries will grow strongly with growing incomes, as it did in the past in the USA and other OECD countries. Source: ITF calculations using the IEA MoMa Model Version 2008 [OECD/ITF 2008b].

3 The technology required to improve efficiency of vehicle by 30% by 2020 will include incremental change to conventional internal combustion engines and drive systems, along with weight reduction and improved aerodynamics. Examples of specific technologies include: idle-off stop-start systems, low rolling resistance tires, low friction lubricating oils, and smaller engines with turbo-chargers.

4 A full list of OECD countries is available from www.oecd.org/countrieslist/0,3351,en_33873108_33844430_1_1_1_1_1,00.html; In this document 'OECD' and 'non-OCED' is used to designate industrialized versus industrializing/rapidly industrializing countries.

In addition, improvements in air quality will add to the economic savings due to lower air quality-related morbidity and mortality. An even stronger shift to fully electric vehicles can lead to a decrease in global vehicular CO2 and non-CO2 emissions (e.g. atmospheric black carbon).

With shifting consumption patterns in developing and transitional countries, growth in vehicle ownership in non-OECD countries is expected to make up close to three-fifths of the global vehicle fleet by 2050; at the moment the non-OECD fleet is a quarter of the global fleet.[5] While rapid early improvement in fuel economy in OECD countries through 2030 is essential to slowing emission growth, only a global effort to double vehicle fuel efficiency will stabilize emissions from road transport.[6] According to leading transport and energy outlooks developed by the International Energy Agency and the OECD International Transport Forum, stabilizing emissions from light-duty vehicles requires fuel economy of around 4L/100km (or approximately 90 g CO2/km) by 2050 worldwide. Currently, new vehicles average around 8L/100km. Conventional technology can take us up to a 30% increase in efficiency, but the remaining 20% will require widespread global hybridization and the use of flanking transport measures.[7] Therefore, the adoption of enabling policies and incentive structures and the uptake of appropriate cost-effective technology in developing and transitional countries is crucial.

In addition to CO2 emissions, the role of road transport in local and trans-boundary air pollution is also an important and closely related issue that deserves equal attention. On average, road transport may be responsible for an estimated 70-90% of air pollution in urban areas - especially in developing countries where fuel quality, vehicle technology, and inspection and maintenance regimes are inadequate. While the transport sector is an engine of economic growth, the sum of associated social and environmental costs - including air pollution, congestion, road injuries and fatalities - is of increasing concern to both local and national governments.

The United Nations Environment Programme (UNEP), the International Energy Agency (IEA), the International Transport Forum (ITF), and the FIA Foundation for the Automobile and Society are working together to develop and implement the Global Fuel Economy Initiative (GFEI) to double road vehicle fuel efficiency by 2050, thereby reducing emissions from vehicles by 50%. UNEP, together with partner institutions, provides knowledge products and support for national policy development to countries addressing road transport emissions and investigating appropriate cleaner technology options. The UNEP-based Partnership for Clean Fuels and Vehicles (PCFV) has demonstrated that vehicular emission reductions and improved air quality can be achieved through international and national cleaner fuel and vehicle initiatives. UNEP's assistance to countries to reduce CO2 emissions from the transport sector is based on a partnership and globally harmonized approach.

The Hybrid Electric Vehicles (HEV) report is designed to guide decision makers and institutions in assessing the feasibility of hybrid technology in transport and fuel efficiency

5 In 2008 there are an estimated 0.8 billion light duty vehicles of which 0.21 billion are in non-OECD countries (or 26%) and 0.59 billion are in OECD countries (74%). In 2050 there will be and estimated 2 billion light duty vehicles, of which 1.2 billion are in non-OECD countries (60%) and 0.8 billion are in OECD countries (40%) (WBCSD, 2004b).

6 Global fuel economy scenarios are discussed in detail in (OECD/ITF 2008b)

7 Such as travel demand management, strong shifts to low-carbon fuels and greater share of non-motorized and public transport modes.

measures and to assist knowledge and technology transfer. The HEV report was developed following requests for more information on HEV technology and its application in new markets – i.e. developing countries, as first and second generation HEVs are now starting to make their way into these markets through second hand markets. In order to provide a balanced assessment of the application of HEV technology in these markets, a comparison to conventional petrol, natural gas and diesel technology is included in this report, as these are the currently available alternatives in these markets and are comparable from an efficiency and emissions standpoint. The report seeks to provide an overview of how HEVs perform in comparison, including an assessment of applications and operating conditions to optimize emissions performance. The UNEP Clean Fleet Management Toolkit [http://www.unep.org/tnt-unep/toolkit/] provides a similar comparison geared to vehicle fleet managers; however the toolkit can be used by individuals as well.

This report follows on a series by UNEP and the Partnership for Clean Fuels and Vehicles highlighting and seeking to clarify cleaner fuel and vehicle technologies fpr developing and transitional countries[8] – including low sulphur fuels and vehicle emission control technologies.

1.2 Vehicle Fuel Efficiency and the Role of Hybrid Technology

Given its importance in current and future emission scenarios and its near-complete dependence on fossil fuels, innovations in road transport - and particularly vehicle technology - are receiving a lot of attention from decision makers and consumers searching for more efficient mobility. This is true in both developed and developing countries.

Hybrid electric vehicle (HEV) technology and its various applications, the subject of this paper, have made significant market gains in recent years and form an important part of the fuel economy equation. Initially only introduced in North American, European and Japanese markets in the mid-1990's, HEVs are now starting to gain markets in developing and transitional countries, including China and Brazil. The export and import of second-hand vehicles also ensures that new markets are gaining exposure to hybrids. Hybrid electric vehicle technology is already mature enough for large scale deployment worldwide today; however, cost, limited production capacity, and various market barriers hinder their wide scale use.

UNEP has developed this overview of the basics of hybrid technology to guide users on the spectrum of hybrids currently available, the rapid pace of innovation in vehicle manufacturing, and the emergence of plug-in hybrids and fully electric vehicles. The subsequent chapters cover HEV technology applications, potential savings in terms of fuel and lower emissions, and its feasibility in developing and transitional country settings where policy environments for vehicles and fuel efficiency, fuel quality and maintenance facilities for advanced vehicle technology vary considerably.

Fuels and vehicles work together as a system; the vehicle-fuel system determines the quality and amount of both conventional and greenhouse gas emissions and the extent to which emission control technologies will be able to reduce these emissions. The type of fuel

8 see http://www.unep.org/pcfv/publications/publications.asp

used, the quality of the fuel, vehicle maintenance, and driving conditions all play a role. This paper also explains the required complementary conditions for the use of advanced vehicle technology – from enabling policies and incentives to aid introduction and create consumer demand, to ensuring that fuel quality is sufficient to maintain proper vehicle function.

In addition, hybrid technology is compared to other cleaner vehicle technology options. New generation diesel vehicles with advanced engine technology and emission controls can offer comparable efficiency when used with low and ultra-low sulphur fuels (500 ppm or less, 15 ppm or less respectively). Low carbon fuels and fuel switching is also an option; introducing compressed natural gas (CNG) vehicles or low-level blending with bio-ethanol or biodiesel from sustainable sources are other options to consider and compare. Biofuel blends are already in use worldwide, but given that in-depth information is already available in a number of other publications, an analysis is not provided in this paper.

1.3 Document Overview

This paper is aimed at government and industry decision makers and institutions in developing and transitional countries that are investigating, developing and/or revising policies to enable greater vehicle fuel efficiency for improved air quality, lower CO2 and non-CO_2 emissions, lower fuel import costs, and improve energy security. The subsequent chapters are designed to clearly describe both the potential and restrictions of HEV technology in an accessible way, including policy implications for new markets in developing and transitional economies.

Chapter 2 will compare available current vehicle technologies, including HEV, CNG and clean diesel, emerging plug-in and hydrogen fuel cell vehicles, and the rise of small low-cost cars. It will also explain the important role of appropriate fuel quality in the operation of advanced vehicles, and the uptake of new technology in developing and transitional countries.

Chapter 3 will outline the technical considerations and basics of HEV technology, the various types of hybrids available on the market and how they compare in terms of efficiency and technology, and the existing barriers to their widespread uptake in certain markets.

Chapter 4 looks at the cost implications of hybrid purchase and ownership, expected fuel costs and savings, and will compare light and heavy duty hybrid vehicles with their conventional counterparts.

Chapter 5 will summarize the package of underlying policies, incentives and consumer awareness required to promote this technology in developing and emerging markets.

2 Cleaner Vehicles: Improving Efficiency, Reducing Emissions

To reduce the environmental effects of the transport sector, different options are available, including advanced vehicle technologies, alternative fuels and improved conventional fuel quality.

2.1 Comparison of Current Technologies– HEV, CNG, Clean Diesel

In this paper three cleaner vehicle options will be compared - HEV, CNG and clean diesel vehicles – for emission reductions, fuel efficiency and overall CO_2 reductions, and life cycle costs. The cleaner vehicle options considered in this report can meet future stricter regulations on emissions such as hydrocarbons, nitrogen oxides, sulphur oxides, and particulate matter using available, 'off the shelf' emission control technologies. The main difference between the technologies considered is in fuel consumption and the resulting emissions of CO_2.

Although petrol is widely used for passenger vehicles, the diesel engine is inherently more efficient than a conventional petrol engine. For the average passenger car fuel savings are around 20%. Advanced cleaner diesel vehicles now include emission control technologies to lower tailpipe emissions, including harmful particulate matter (PM).

Changing to Liquefied Petroleum Gas (LPG) or CNG are additional options that are still fossil-based. The advantages are that they are inherently low sulphur and the combustion process is cleaner, resulting in lower harmful particulate matter and hydrocarbon emissions. CNG vehicles also typically have lower emissions of NOx compared to standard petrol vehicles. CNG or LPG fueled petrol engines can also use a 3-way catalyst to reduce emissions even further.

Hybrid Electric Vehicles

HEVs are powered with a combination of a combustion engine and an electric motor. This design, which is described in more detail in the next section, makes the HEV more energy efficient, potentially achieving almost twice the fuel-mileage compared to conventional vehicles and reducing tailpipe emissions substantially. Another driver for the high interest in hybrid technology is that HEVs can act as a stepping-stone for future zero-emitting fuel cell and electric vehicles, which will be described in section 2.3. Fuel cell vehicles and HEVs share several critical components such as the electric motor, power controls, and high power density batteries. By driving the cost reduction and increased performance of these components, the continued development of HEVs will also help the development of the low and zero emission vehicles of the future.

Research on HEVs started in the 1970s following the first oil crisis, but decreased in the 1980s with falling oil prices. In 1997 with increasing concern for air quality and energy security the first HEV was launched on the Japanese market in the form of the Toyota Prius. The Prius was followed by the Honda Insight and later by several other Japanese hybrid models. Since then, US auto manufacturers have also begun to introduce HEVs. Now, a number of countries are competing to lead HEV and electric vehicle development, including Brazil and China.

The global production numbers for HEVs have been relatively small when compared to the overall fleet. In 2007, a total of 541,000 hybrids were produced, accounting for 0.8% of the global light vehicle assembly. This is a major increase from the 0.25% hybrid share in 2004 (150,000). According to the 2007 PricewaterhouseCoopers outlook, HEV production numbers are expected to increase to 1.7 million vehicles by 2014 (see figure 4). Of the 2007 global hybrid production, 52% (280.000) were Toyota Priuses, of which 181.221 were sold in the U.S (EDTA 2008). Figure 5 shows the U.S. hybrid sales by model through October 2008.

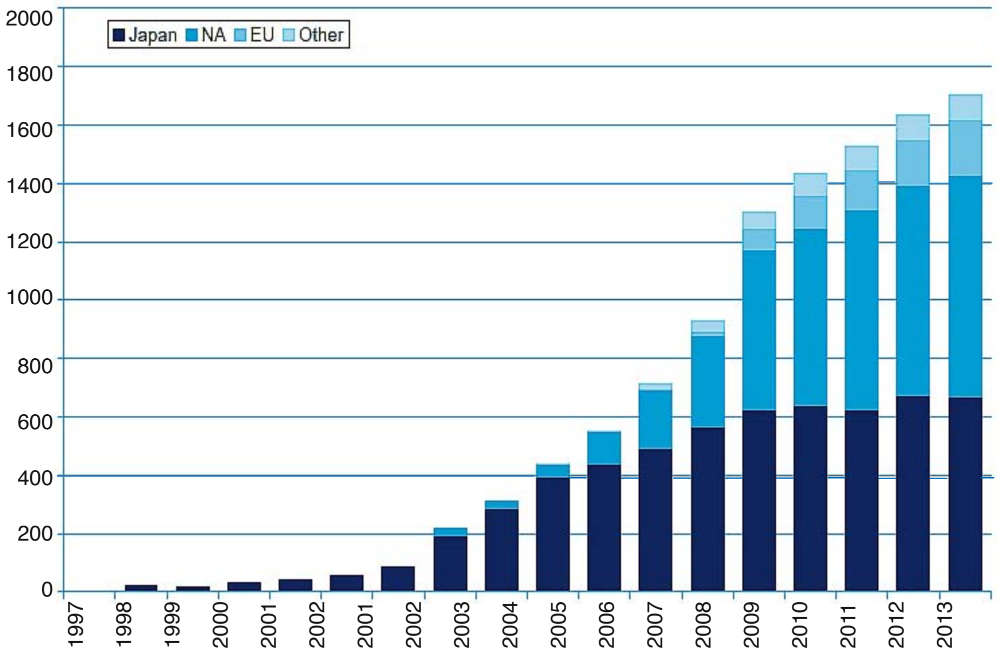

Figure 4: Global Hybrid Vehicle Assembly by Region 1997 - 2014 (thousands). An October 2007 Prognosis of the future global hybrid vehicle production [PwC 2007].

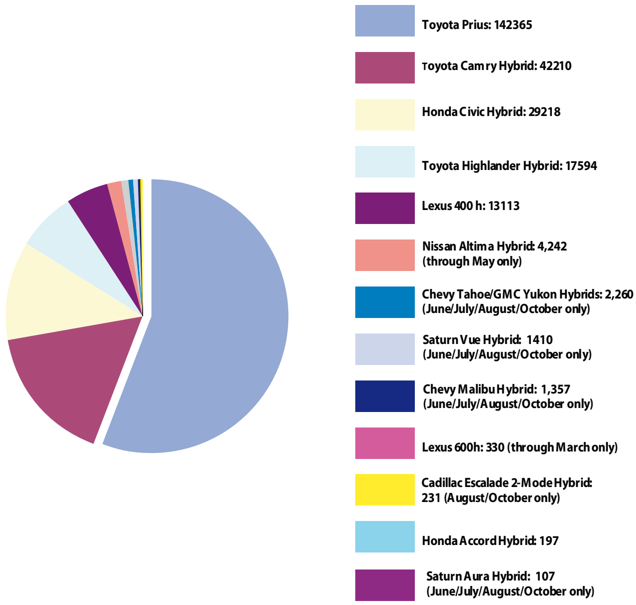

Figure 5. US hybrid passenger vehicle sales by model through October 2008 [EDTA 2008].

Clean diesel vehicles

Clean diesel vehicles are equipped with advanced after treatment technologies, such as filters, and fueled with clean diesel, i.e. ultra low sulphur diesel (15 ppm or less). Diesel engines are inherently more efficient than petrol engines, but have historically had problems with high emission, especially nitrogen oxides (NOx) and PM. However, diesel emission control technologies have made great progress over the past decade, resulting in low emitting diesel vehicles with high efficiency. Today, diesel vehicles fueled with ultra low sulphur diesel and equipped with emission control technologies such as catalyzed particulate filters, selective catalytic converters, and NOx adsorbers are an energy efficient and cleaner vehicle option. Particulate filters are already installed in many diesel vehicles sold in the EU and the U.S. today and with the coming stricter emission regulations SCRs or NOx adsorbers will be mandatory.

In Western Europe, diesel passenger cars have increased from 23% of new vehicle sales in 1994 to 53% in 2007 [ACEA 2008]. The fast development of diesel technology in Europe can be explained by the long-standing tradition of relatively small diesel cars produced for the European market and the relatively high taxes on fuel. This has led European auto manufacturers and consumers to favor diesel cars. Since EU emission standards for vehicles have traditionally been less strict diesels were able to compete with petrol vehicles. But aside from being a European preference, dieselization of the global fleet is increasing with volatile fuel prices.

Small diesel vehicles sold in Europe can be very fuel-efficient. For example, the Volkswagen Lupo "3-liter car" can range for 100 kilometers on three liters of diesel (about 78 miles per gallon), combining a diesel engine with lightweight construction. A host of other "super-mini" diesel vehicles manufactured by European auto manufacturers attain around 50 miles per gallon, or just under 5 liters per hundred kilometers. Diesel vehicles must, however, be equipped with advanced emission control technologies in order to attain the same low level of tail-pipe emissions as HEVs.

Clean diesel vehicle technologies are also available for buses and trucks. However, the slower turn over rate for heavy trucks means that retrofitting older diesel vehicles with emission abatement technology (e.g. oxidation catalysts and diesel particulate filters) is often considered before replacement with a cleaner vehicle.

Compressed Natural Gas vehicles (CNG)

Natural gas vehicles have adjusted engines that run on natural gas (95% methane) stored in a fuel tank in the car under high pressure (around 200 to 240 bars). Petrol engines need some adjustments to run on CNG. Diesel engines can also be adjusted to run on CNG; however, in this case the CNG needs an "igniter", usually in the form of a small amount of diesel. CNG as an automotive fuel has been developed since the 1970s in the aftermath of the oil crisis in countries that have ample supplies of natural gas. Argentina, New Zealand, United States, Brazil, Eastern European countries, and China all have major fleets of CNG vehicles. CNG buses have also replaced diesel buses in places like India and the U.S. in an effort to reduce air pollution.

Comparison of fuel reduction potential

A comparison of the fuel reduction potential between HEV, CNG, and clean diesel vehicle technology is given in figure 6 for passenger and city busy applications.

Figure 6 indicates that the benefits to be expected from HEV technology depend on the type of vehicle and its function. For passenger vehicles the potential reduction of energy use is substantial. Fuel use reduction as a result of hybrid drive train technology is currently between 25-35%. However, the hybrid drive train is a new technology and future improvement are

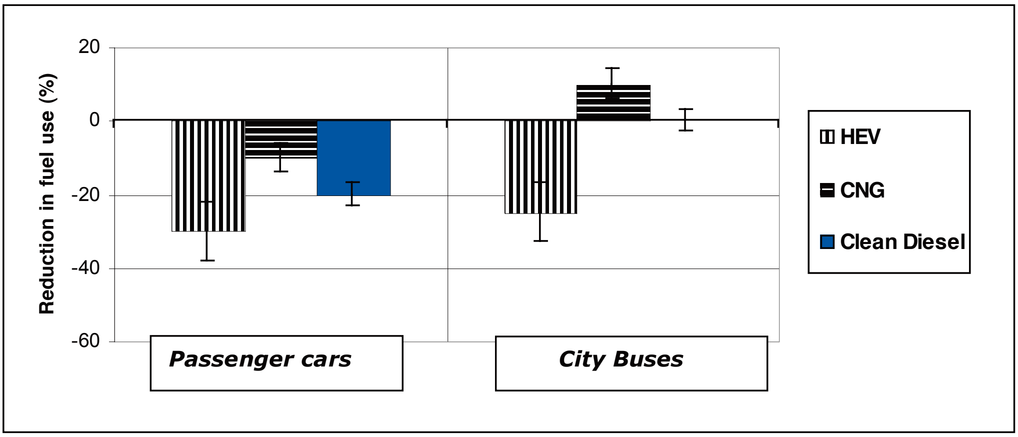

Figure 6 A rough comparison of the fuel reduction potential with the different options. The bars indicate the variety among models and the uncertainty. Passenger cars are compared to petrol vehicles and city buses are compared to diesel buses [IEA 1999, Åhman 2001 and reported results from the case studies cited in this report].

estimated to improve HEV performance up to 50% compared to a conventional vehicle of the same size and power. Note that most HEVs on the market today also utilize lightweight construction materials and low air resistance designs that enable consumption as low as 4.45 L/100 km [9] under normal driving conditions as compared to 8.5 L/100 km for a similar sized car with conventional technology.

For city buses operating in stop-and-go traffic the reduction of energy use is also substantial. Although the first generation of HEV buses put into commercial operation in the late 1990s saved 10-20% fuel over their conventional diesel counterparts, today a reduction of 25-30% is considered reasonable for state-of-the-art hybrid buses. As the hybrid technology develops the potential fuel savings for city buses may be in the same range as for passenger cars (~50%). See also the case studies described in Annex C.

CNG vehicles can reduce overall energy use in purpose-built passenger cars due to a higher fuel octane rating allowing a higher fuel compression rate. However, on a "well-to-wheel" basis [10] this efficiency gain is partly offset by the energy needed for compression of the natural gas to the 200-240 bar required for onboard storage. The resulting overall reduction of energy use is therefore adjusted to an estimated 10%. CO2 emission reductions, however, are more pronounced (20 - 25%) due to the fact that natural gas carries less carbon per energy unit than petrol or diesel and therefore emits less CO2 per energy unit used.

A CNG engine operates according to the same principals as a petrol engine, but it is less energy efficient as compared to a diesel engine. A purpose built CNG bus replacing a diesel bus can use 10 to 15% more energy overall, [11] whereas a retrofitted CNG bus can use anything between 10-40% more energy. Therefore, the main benefits associated with CNG buses include reduction of pollutants such as particulate matter, NOx and HC, rather than increased energy efficiency.

Comparison of CO_2 and non-CO_2 emission reductions for various vehicles

Pure CNG vehicles emit less air pollutants than standard petrol and diesel vehicles due to natural gas being a cleaner burning fuel. CNG vehicles are usually also equipped with a catalyst, thus lowering emissions even further.

Clean diesel vehicles need advanced emission control technologies and ultra low sulphur diesel (15 ppm or less) for optimal emission reductions. However, with the use of advanced emission control technologies and ultra low sulphur diesel, clean diesel vehicles can meet stringent emission standards and are in some cases comparable to both CNG and HEV technology in terms of emission standards.

In a HEV, the combustion engine is less exposed to accelerations (transient loads) and burns fuel under more stable conditions, thus emitting less pollution and CO_2 than an engine in a conventional vehicle. However, all HEVs today require emission control technologies (e.g. catalysts) in order to meet emission standards.

9 In this report the metric system will be used, as it is used in most countries. The units of fuel economy can be either km/L or L/100km. To convert from MPG (Miles Per US Gallon) to km/L, multiply by 0.425, e.g. 20 MPG = 8.50 km/L. To convert from km/L to MPG, multiply by 2.35, e.g. 10 km/L = 23.5 MPG.

10 "Well to wheel" calculation includes all losses from the origin of resource (gas or oil field) to the point of end use (the wheel).

11 With the same reasoning as for passenger cars above the emission of CO2 can be reduced by 10% compared to a diesel bus.

Compared to older diesel and petrol vehicles, pollutant emission reductions from HEVs, CNG, and clean diesel vehicles can reach up to 90 % for particulate matter (PM) and NOx and 70% for HC and CO. Low and ultra-low sulphur fuels usage in clean diesel and CNG vehicles also results in substantial reductions of SOx emissions.

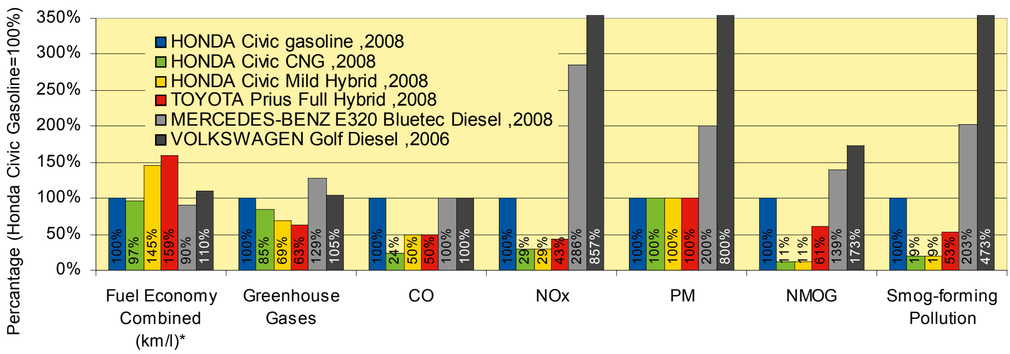

Figure 7 Relative fuel economies and emissions of passenger cars with different fuels [USEPA 2008].

Hybrid engine configurations have an inherent advantage over a conventional engine design due to less accelerations for the engine, just as petrol and CNG vehicles will always have an advantage over diesel vehicles in terms of PM and NOx emissions due to combustion characteristics. The size of this difference depends on the fuel used, the emission control technologies installed, and how the vehicles are driven. The technologies compared in this document are assumed to meet stringent emission reduction criteria such as Euro V and Tier II.[12] The major difference between the technology types compared is the reduction potential for reduced fuel consumption and thus the emission of CO2.

Figure 7 illustrates the fuel economies and emissions for six similar-sized passenger vehicles. They use three different fuel types, namely petrol fuel, CNG and diesel. Note the fuel economy of the two hybrid vehicles and the high emissions of air pollutants of the conventional 2006 diesel vehicle. The clean diesel has lower emissions, but still much higher than the petrol and CNG vehicles. The details of the comparison can be found in Annex B.

Hybrid school buses

School buses operate in proximity of children, and most of these bus fleets run on diesel fuel. As a result, children are often highly exposed to the diesel pollution, including PM. A child riding inside a school bus may be exposed to as much as 4 times the level of diesel exhaust as someone riding in a passenger car (Salomon 2001). Bus stop and in-vehicle exposure to harmful emissions can be diminished by using hybrid buses.

12 EURO V and Tier II are the EU respectively the US coming emission standards. EURO V is still being negotiated but will come into full effects in 2009. Tier II will come into full effect in 2009

2.2 The Role of Fuel Quality

Reducing emissions from motor vehicles is an important component of an overall strategy for reducing air pollution, especially in cities in developing and transitional countries where population and vehicle ownership are growing rapidly. One essential component of reducing vehicle emissions is to eliminate lead from petrol; in addition to being a toxic pollutant in its own right, the presence of lead in petrol also inhibits the functioning of catalytic converters and other emission control technologies. Low sulphur fuel (both diesel and petrol, 500 ppm or less) is essential for lower emissions of PM and SOx, in addition to being a requirement for emission filters and advanced emission controls.

Unleaded petrol

Most modern petrol fuelled vehicles, including HEVs, require unleaded petrol because of the irreversible damage lead causes to emission control technologies such as catalytic converters. One of the goals of the UNEP-based Partnership for Clean Fuels and Vehicles (PCVF, www.unep.org/pcfv) is to phase out leaded petrol globally. As of 1 July 2009, only a handful of countries (13) still use leaded petrol.

Low and ultra-low sulphur fuels and emission control technologies

Using diesel with lower levels of sulphur will reduce the emissions of sulfate, sulphur dioxide, and particulate matter (PM) substantially and will enable the introduction of advanced emission control technologies.

Sulphur occurs naturally in crude oil. The level of sulphur in diesel depends upon the source of the crude oil used and the extent to which the sulphur is removed during the refining process. While Western European, North American and a few Asian markets use ultra low sulphur fuels (50 ppm or less), sulphur levels as high as 5,000 to 10,000 ppm in diesel are still in use in developing and transitional countries. Diesel fuel with more than 500 ppm inhibits the use of any emission control technology available today, poisoning catalysts and particulate filters.

Desulphurized diesel can be classified in the following categories, along with the emission control technologies enabled at each level:

- ***Low sulphur diesel (<500 ppm)***: Diesel with sulphur levels below 500 ppm enables the use of diesel oxidation catalysts (DOCs). However, the lower sulphur content, the more effective the catalyst becomes.
- ***Ultra Low Sulphur Diesel (ULSD, <50 ppm)***: Diesel with sulphur levels below 50 ppm enables the use of diesel particulate filters (DPFs) that reduce particulate matter substantially, in addition to providing effective control of CO and HC emissions.
- ***Near sulphur free diesel (<15 ppm)***: Diesel fuel with even lower sulphur content below 15 ppm and even as low as <10 ppm enables effective control of NOx with, e.g.

NOx traps and NOx adsorbers in new vehicles. For diesel particular filters (DPFs) the efficiency and effective life of the filter increases substantially with reductions from 50 to 15 ppm.

Table 1. Sulphur impacts on emission control technologies. TWC = Three Way Catalyst; DOC = Diesel Oxidation Catalyst; SCR = Selective Catalytic Reduction (Blumberg, Walsh and Pera 2003)**.**

	For Diesel	For Petrol
If Sulphur > 500ppm		
	If the sulphur level of your diesel fuel is above 500 ppm, there are no diesel emissions control technologies that can be used with such high fuel sulphur levels. Your options include: • Start bringing fuel sulphur levels down to achieve immediate emissions benefits. • Develop vehicle emission standards, forcing the introduction of appropriate engine modifications, for all new vehicles, in line with the reduction in fuel sulphur levels. • Begin a program to replace the oldest vehicles in the fleet.	If the sulphur level of your petrol is above 500 ppm but below 1000 ppm, your options include: • Require catalytic converters in all new vehicles and simultaneously start bringing sulphur levels down. • Set age limits for imports of second-hand vehicles and require that they have catalytic converters.
If Sulphur < 500ppm		
	If the sulphur level of your diesel is 500 ppm or lower, some advanced emission control technologies can be introduced. Your options include: • Develop vehicle emission standards for all new vehicles, in line with the reduction in fuel sulphur levels, which will introduce additional engine modifications such as EGR. • Retrofit older, heavy-duty diesel vehicles with diesel oxidation catalysts to reduce HC, CO, and PM and explore the applicability of FTFs for further PM reductions.	If the sulphur level of your petrol is 500ppm or lower, introduction of advanced emission control technologies can take place. Your options include: • Develop vehicle emissions standards for all new vehicles. • Limit importation of second-hand vehicles to those that have catalytic converters.
If Sulphur < 50ppm		
	If the sulphur level of your diesel is 50 ppm or lower, more options become available. These options include: • Develop more strict emission standards for PM and NOx from new diesel vehicles to ensure the introduction of the most advanced control technologies. • Retrofit older, heavy-duty vehicles with particulate filters, matching the filter requirements, engine technology, and age of the vehicle.	If the sulphur level of your petrol is 50ppm or lower, introduction of more advanced emission control technologies can take place. Your options include: • Develop more stringent vehicle emissions standards for all new vehicles to ensure the greatest emissions control with the most advanced technologies. • Set import restrictions on second-hand vehicles to those that have catalytic converters and meet prescribed performance criteria.

Sulphur greatly reduces the efficiency of more advanced catalysts by blocking active catalyst sites; this effect is not completely reversible. Although conversion efficiency will improve with the use of low sulphur fuel (500 ppm or less), it does not always return to its original effectiveness after desulphurization. Optimal clean diesel vehicle function depends on the availability of near sulphur free diesel (<15 ppm) in order to attain specified emission levels and emission technology durability. Table 1 gives requirements and recommendations for the sulphur levels for some emission control technologies for gasoline and for diesel vehicles. As vehicle manufacturers might decline warranty demands when higher sulphur fuels are used, ensuring adequate fuel quality for correct vehicle function is important.

Fuel infrastructure

The infrastructure needed for cleaner and alternative fuels can be a major concern when it comes to new vehicle technologies. However, for diesels and HEVs, additional physical infrastructure is not needed as conventional fueling and distribution systems are used. In cases where a number of fuel grades are available on one market, adequate segregation in distribution and transport is essential for quality maintenance. Figure 8 shows the diesel sulphur levels worldwide.[13] The UNEP-based PCFV leads a global campaign to promote the use of fuel with 50 ppm or below with roadmaps and timelines developed regionally and nationally (UNEP 2007).

CNG vehicles need a separate natural gas infrastructure, including pipelines and filling stations. All major CNG fueling programs to date have been in countries with a strong supply

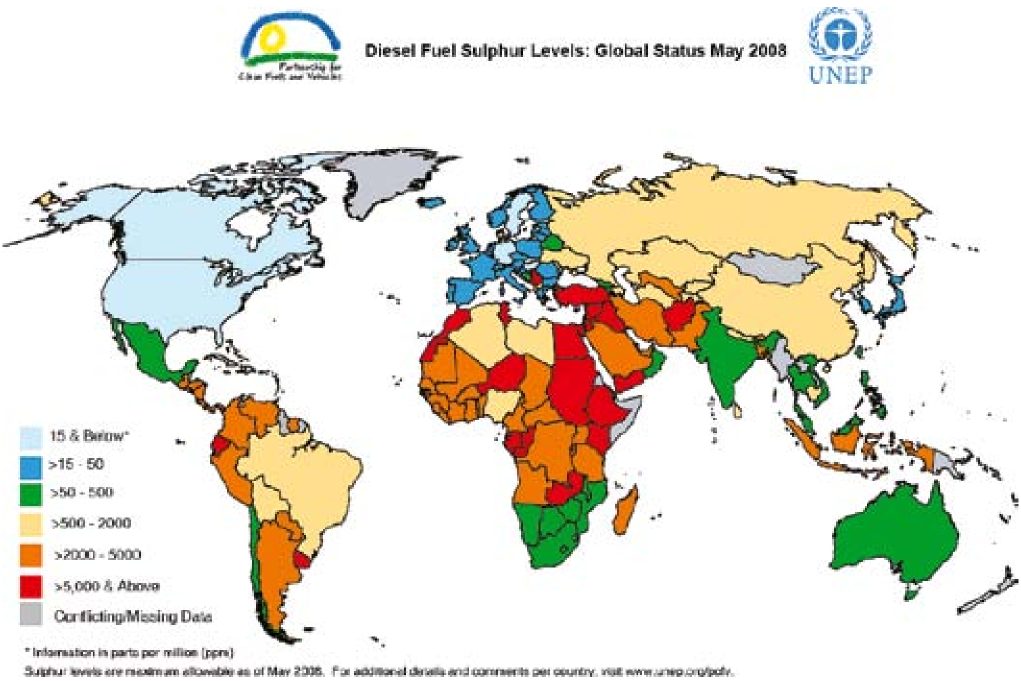

Figure 8 Diesel Fuel Sulphur Levels: Global Status

13 The PCFV website will give you the current sulphur levels world wide at www.unep.org/pcfv for both diesel and petrol fuels

of natural gas for other uses, including industrial use and energy production (e.g. Pakistan, Russia, New Zealand, Italy, Germany, and a number of Latin American countries). Multiple CNG uses improve the economic rationale for promoting CNG vehicles as the transport sector cannot alone motivate the high investment cost for building and maintaining a natural gas infrastructure. CNG vehicles need to be refilled more frequently compared to diesel and hybrid vehicles. This is often seen as a problem for fleet operators that do not drive their vehicles according to a fixed route, e.g. delivery companies. If fleets are operated from a central location, e.g. bus companies, CNG refilling stations can be set up for about 500 000 USD to 1 million USD per station.[14] Dual-fuel vehicles, operating on both CNG and petrol, are available and can reduce the need for CNG filling stations in a build-up phase.

Renewable fuels

Renewable fuels, including liquid ethanol and biodiesel, are also in use in a number of markets. These can fully replace or be blended with petrol and diesel, depending on the vehicle technology used. Ethanol and biodiesel generally emit less PM, CO and HC and also have the advantage of a substantial reduction of CO2 emissions, depending on feedstock, cultivation, and processing methods used. Low carbon fuel standards being developed in the US and Europe propose emissions-performance requirements and renewable fuel percentage targets. These standards will provide incentives for lower-carbon fuels, including liquid biofuels. Where standards are technology-neutral they may even support the use of electric vehicles if emissions are calculated on a full life cycle analysis.

2.3 Emerging Technologies

The rapid growth and development of HEVs has also spurred the development of other emerging technologies that share critical components (e.g. electric motors, batteries) with HEVs, i.e. plug-in hybrid electric vehicles and fuel cell electric vehicles. Both plug-in hybrids and fuel cell vehicles require technologies for electric propulsion. However, as these emerging technologies are still expensive and require a reliable supply of electricity or hydrogen, these technologies are not expected to play an important role in developing countries soon. 'Ultra cheap' cars are more likely to enter these markets in the interim due to their fuel efficiency and low cost.

Plug-in hybrid electric vehicles

The plug-in HEV (PHEV) is a HEV with a larger battery pack, with battery ranges of 30-60 kms. This range should be enough for the majority (if not all) of vehicle kilometers traveled on a daily basis in urban centers and shorter commutes; more than 70% of all road trips are below 50 kms. Under average conditions, half of the vehicle kilometers driven by a PHEV could be driven on battery power alone with a range of 50 kms.

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14 The costs of a CNG filling station heavily depends on the location as illustrated by the New York City Transit example. The costs for the CNG filling facility was USD 7.4 million, as it had to meet all local New York building codes and requirements and included USD 2 million for construction costs to blast through solid rock to install the underground natural gas lines (Bartnitt and Chandler 2006)

In addition to recharging the battery by use of the combustion engine, the PHEV can also be recharged with electricity from a normal wall plug, reducing fuel consumption tremendously. Overall emission reductions and efficiency improvements will vary based on the way in which electricity is produced (fossil fuel or renewables) and transmitted (smart grid technologies will make a big difference in overall efficiency). Plugging in reduces air pollution at the vehicle tail pipe, but it may increase emissions at the power plant.

A number of major vehicle manufacturers have announced their plans to develop and market PHEVs in the near future. See section 3.2 on the multiple degrees of hybridization and what this means in terms of emissions and fuel savings.

Fuel cell vehicles

A fuel cell is a chemical engine that produces electricity from hydrogen, emitting only water vapor. The electricity produced is used for driving a vehicle with an electric motor. The hydrogen fuel can be produced in various ways, but currently the most viable method is steam reforming of fossil fuels using a nickel catalyst.[15] However, in the future, the plan is to produce hydrogen from solar power, biomass, or even coal with carbon capture and storage technology.

Fuel cell vehicles (FCVs) can be fueled with pure hydrogen gas stored onboard in high-pressure tanks. They can also be fueled with hydrogen-rich fuels including methanol, natural gas, or even gasoline; these fuels must first be converted into hydrogen gas by an onboard device called a "reformer." This will add cost, complexity and weight to the vehicle but will make the fuel distribution easier.

FCVs fueled with pure hydrogen emit no pollutants, only water and heat, while those using hydrogen-rich fuels and a reformer produce only small amounts of air pollutants. In addition, FCVs can be twice as efficient as similarly sized conventional vehicles and may also incorporate other advanced technologies to increase efficiency.

At the moment cost is the biggest impediment to widespread fuel cell use:

- An expensive fueling infrastructure must be set up for producing, transporting, and storing large quantities of hydrogen.
- The production of the hydrogen requires a lot of electricity, making hydrogen more expensive (and perhaps more unsustainable, depending on the electricity production) than the fuels it would replace.
- The vehicle fuel cell is expensive technology - a regular saloon car fitted with a fuel cell costs about 1 million USD.[16]

However, despite its current limitations this emerging technology has the potential to significantly reduce energy use and harmful emissions, as well as increase energy independence, depending on how the hydrogen is produced. Although they are not

15 In which the raw material, in most cases natural gas (methane) reacts with steam: CH_4 (methane) + H_2O (steam) CO (carbon monoxide) + $3H_2$ (hydrogen), followed by additional H_2 production from the CO: CO + H_2O CO_2 (carbon dioxide) + H_2 (UNEP 2006).

16 Technical costs and challenges (UNEP 2006)

expected to reach the mass market before 2010 FCVs may someday revolutionize on-road transportation.

Although most current hydrogen research and development is taking place in industrialized countries, developing economies have as much – if not more – to gain from a transition to a hydrogen economy. In addition to air quality concerns, developing economies are often more economically vulnerable to fluctuations in international energy prices. Countries lacking significant fossil fuel resources may be able to exploit biomass and other renewable energy potential to produce hydrogen (UNEP 2006).

The 'ultra-cheap' car phenomenon

Recently two major Indian auto manufacturers announced the production of ultra-cheap small vehicles, typically priced under 3,000 USD. In addition to low cost, these vehicles claim fuel efficiency of up to 20 km/L and a top speed of 120 km/hr. Future models are expected to adhere to strict European vehicle emissions limits (Euro V), and to increase fuel economy. These vehicles cater to a growing market of vehicle owners in Asia, and eventually in Africa. India's auto market is expected to double to 3.3 million cars by 2014, while China's will grow 140% over the same period, to 16.5 million cars (Business Week 2008).

2.4 Uptake and Fleet Turnover in Developing and Transitional Countries

Incomes, emission standards, and policy incentives affect the rate of vehicle renewal on a given market, and thus the uptake and introduction of cleaner vehicle technologies. Rates of change are crucial to the development of policies and programs designed to encourage emerging technologies.

Ageing vehicle fleets

Vehicles in developing countries are generally older compared to OECD countries. The average age of the vehicle fleet can be up to 15 - 20 years, with some vehicles (e.g. old heavy duty diesels) sometimes operating for more than 40 years; these vehicles can act as 'super-emitters' responsible for a high percentage of air pollution despite their low fleet numbers.[17] The main reasons for the persistence of old technology include the high cost of new vehicles, the relatively low maintenance and support cost for older technology, and a lack of government fleet renewal incentives (including inspection and maintenance regimes).

The high average fleet age is illustrated in figure 9 showing the age distribution of vehicles in Tanzania, up to January 2007. At that time the average age of Tanzania's 330,000 vehicles was 15 years, with 10% over 25 years old. Similar average ages have been reported in Uganda

17 Bond, Tami C. Black Carbon: Emission Sources & Prioritization, International Workshop on Black Carbon, London, UK, January 5, 2009 - January 6, 2009, http://www.theicct.org/documents/Bond_2009.pdf

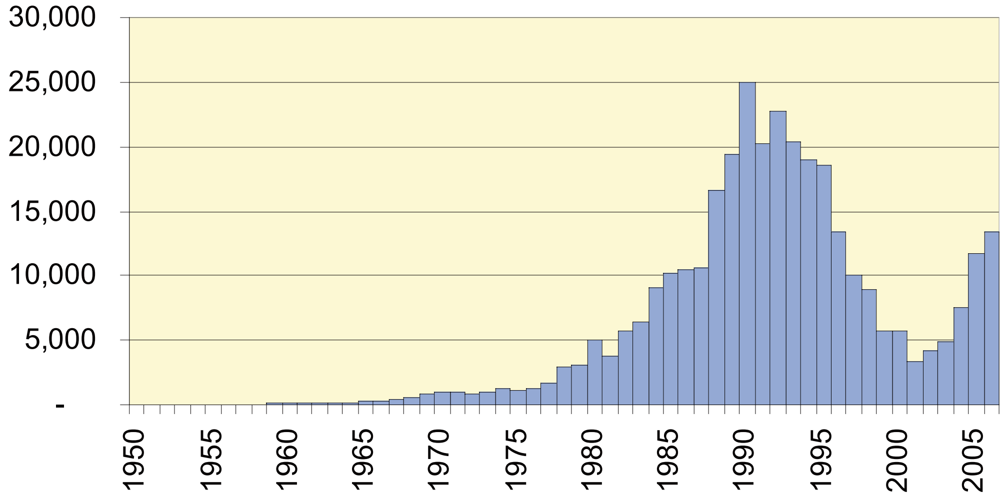

Figure 9 Vehicle age distribution in Tanzania by January 2007 [Tanzania Revenue Authority].

(>13 years), Ethiopia (90% of vehicles >10 years) and Kenya (13 years). Similar fleet averages are observed in other regions, including eastern Asia.

Fleet uptake of second-hand and new vehicles

Apart from Brazil, China and India, the majority of developing and transitional countries do not produce vehicles, but rather rely on imports. Most vehicles are imported second-hand; this is an important mechanism for the introduction of cleaner vehicles in new and developing markets.

Import technology and age restrictions and incentives can be introduced to improve the quality of vehicles entering a country and promote fleet renewal. In Kenya, for example, only models newer than seven years old can be imported. In Belarus import taxes are relatively high for older cars to discourage their import. Vehicle scrappage programs are also part of the fleet renewal process.

3 HEV Technical Considerations

In general, HEVs outperform conventional vehicles in terms of fuel consumption and pollutant emissions. However, the degree of HEV performance and cost savings achieved largely depend on its application (including the types of trips), the level of available technical service and maintenance, fuel price, and the availability of optimal fuel quality.

3.1 Basics of HEV technology

A conventional vehicle has a mechanical drive train that includes the fuel tank, the combustion engine, the gear box, and the transmission to the wheels. A HEV has two drive trains - one mechanical and one electric. The electric drive train includes a battery, an electric motor, and power electronics for control. In figure 10, the principal layout of a mechanical and an electrical drive train is shown.

In principle, these two drive trains can be connected with each other[18], sharing some components such as the transmission and gear box. The 'hybrid' denotation refers to the fact that both electricity and conventional fuel can be used. Current hybrid models all use gear boxes, but in the future a single one-gear transmission might be a reality for series hybrid configurations as the electric drive train can handle a wide variety of speeds and loads without losing efficiency. This is already used in Brazilian HEV buses.

Most hybrid passenger vehicles have gasoline engines, although hybrid diesel electric passenger vehicles are in development. According to International Energy Agency (IEA) scenarios - by 2050 almost all (99%) passenger vehicles will be HEVS and 69% will use diesel.[19]

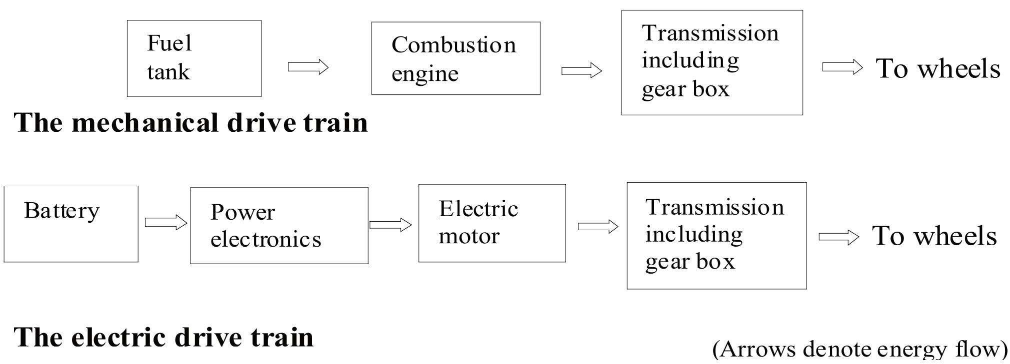

Figure 10 Basic outline of mechanical versus electric drive trains.

18 Different configurations exist for connecting the drive trains, e.g. series and parallel configurations. A good description of how these different configurations work, can be found at www.hybridcenter.org

19 According to the 'Fast km/l improvement' scenario of IEA's ETP 2008 model, by 2050 diesel hybrids will have a technology share of 69% and gasoline hybrids of 30% (Cazzola 2008]. Note this is just one of the three described scenarios.

3.2 Degrees of Hybridization

A petrol engine in a conventional car has an average engine efficiency [20] of 17%-20% under normal driving conditions. Most of the energy in the fuel is lost as heat and a smaller part as engine friction. However, of the remaining energy out from the engine approximately 10%-12% is lost during idling and another 20%-30% is "lost when braking. In conclusion, only 12%-14% of the energy supplied as fuel is actually used to move the car forward.

HEVs can deal with some of these energy losses using different kinds of technologies designed to harness and utilize 'lost' energy, as described in figure 11. The degrees ranging from 'mild HEV', to 'full HEV' and 'PHEV' refer to the technologies used and, in general, increased degrees of fuel efficiency.

Step	Technology	Degree of hybridization
1	Avoiding energy losses during idling by shutting off the combustion engine.	Mild HEV (e.g. Honda Civic)
2	Recuperating energy from regenerative braking.	
3	Using the battery energy to assist the engine and enable downsizing the engine	
4	Running the combustion engine at its maximum load, where the engine efficiency maximizes.	Full HEV (e.g. Toyota Prius)
5	Driving without the combustion engine running	
6	Enlarging the battery pack and recharging it with energy from a wall plug	PHEV (in development)

Figure 11. Degrees of hybridization

Step 1: the energy lost during idling can decrease substantially by allowing the combustion engine to shut down or run at maximum load to recharge the battery during this time.

Step 2: the use of an electric drive train enables the HEV to recuperate part of the energy losses during braking. The electric drive train can then be used "backwards" as a generator to charge the battery. Only with sudden and hard braking will the conventional brake pads be used. An important co-benefit of this system is the much longer life of the brake pads and the reduced cost for replacement.

Step 3: a normal combustion engine is typically designed for a maximum output of 60 to 100 kW. However, most of the time during normal driving the engine works at only 10 to 40 kW, resulting in low efficiency. In a hybrid, when higher power is needed, e.g. when accelerating or on uphill drives, extra power is temporarily delivered by the battery.[22] Thus, theoretically the engine size can be downsized to 15 to 30 kW, the average power needed during normal driving.

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20 Engine efficiency = (Energy out from engine) / (Energy contained in the combusted fuel)

21 Driving at top speed or hill climbing can only be supported by the battery pack for a short time. This explains the lower top speed of HEV's. The 2nd generation Toyota Prius has a top speed of 170 km/hr (according to the manufacturer), which is lower than for similar sized conventional cars.

22 Note that driving at maximum power is good for engine efficiency, but not for the vehicles' fuel efficiency, as the losses for wind and wheel resistance increase exponentially with increasing speeds.

Step 4: an ordinary combustion engine (diesel or petrol) operates at maximum engine efficiency close to its maximum power. As the engine is smaller and the excessive delivered power is used for recharging the batteries, the combustion engine can run at its maximum load at most of the time.

Step 5: the possibility of driving without the combustion engine running, and thus zero emissions, can be especially advantageous when driving at low speed or in congestion in urban areas. The current limitation is that currently full HEVs have small battery packs, with battery-only mode viable for less than a mile at low speed. Larger battery capacity in the future will allow for longer battery-only operation.

Step 6: the next step in hybridization, plug-ins, rely on increased battery capacity to increase battery-only driving range - typically between 30-60 km. Because of the larger capacity, it is worthwhile to charge the battery from a conventional power plug. More information on PHEV function follows later in this chapter.

Plug-in hybrid electric vehicles

By enabling step 6, enlarging the battery pack and recharging it with energy from a conventional wall plug, vehicle fuel consumption will be reduced dramatically as it is partly exchanged with the consumption of electricity. As a result, the fuel reduction depends strongly on the distance driven after every recharge and on the capacity of the batteries installed. At the time of writing, PHEVs are still in the testing phase. The announced PHEV prototypes will have a battery-only range between –30-60 km. For many users this will be sufficient for a large share of the daily distance traveled.

Plugging in reduces air pollution at the vehicle tail pipe, but it may increase emissions at the power plant. The emissions at the power plant strongly depend on its electrical efficiency and the fuel burned. As a result the emissions related to recharging strongly depend on electricity generation in a country and on the time of the day the batteries are recharged as some fuels are more likely to be burned in off-peak night-time generation. Recharging PHEVs with power generated by renewables, including wind and solar electricity, can potentially lead to low or zero PHEV emissions.

A PHEV driver in the U.S., for example, is expected to achieve approximately a 15% reduction in net CO2 emissions compared to the driver of a regular HEV, based on the 2005 distribution of power sources feeding the U.S. electrical grid (Kliesch and Langer 2006). Additionally, for PHEVs recharged in areas or at night, where the grid is fed by power sources with lower CO2 emissions than the current average, net CO2 emissions associated with PHEVs will decrease accordingly. As recharging and associated emissions are moved from daylight hours to night time hours, the creation of ozone and smog is also reduced, as both are formed in a complex chain reaction involving sunlight and atmospheric NOx and HC (Advanced Energy 2007).

Spare battery power of PHEVs plugged in can also serve as a distributed and compact power supply when necessary. In this type of system stored battery power flows back to the grid through the wall plug. This can serve as a local emergency power supply and can be very practical in areas where the power supply is less reliable, e.g. in developing and transitional countries.

The influence of drive patterns

The advantage of an HEV compared to an ordinary vehicle is highly dependent on how the vehicle is driven under normal conditions (the drive cycle). The benefits of recuperating braking energy and reducing losses during idling are predominately gained during stop-and-go traffic, e.g. in cities. The benefits of optimal speed operation of the combustion engine are also enhanced during low speed driving in cities where the efficiency of a normal combustion engine is very low.

Passenger cars normally drive a little more than half of their mileage in urban traffic and the rest in highway traffic (a normal drive cycle). City buses with a lot of stop-and-go traffic have a lot to gain with hybridization, whereas highway trucks and inter-city buses gain comparatively less through hybridization. The combustion engine in a conventional freight truck already runs close to its maximum power and thus with high efficiency (step 3). Furthermore, little efficiency is gained from regenerative braking (step 2) and idling (step 1) in this type of drive cycle.

In developing and transitional countries the efficiency gain will be higher due to the fact that urban and peri-urban roads are often congested resulting in even more slow and stop-and-go traffic.

3.3 Technical Constraints

In order to drive HEVs in developing countries, some basic technical and service requirements must be met, e.g. requirements for fuel and battery quality and technical support infrastructure.

Fuel quality requirements

As explained in section 2.2, both conventional vehicles and HEVs with catalytic converters can be used with high sulphur petrol fuel as long as the fuel is unleaded. However, emission reduction technologies have a better efficiency with low and ultra-low sulphur fuels; the only technical *requirement* is unleaded fuel in order to ensure proper function of the catalytic converter.

This is very promising for the introduction of HEVs to developing countries, as unleaded petrol fuel is available in most countries. Since fuel requirements set by car importers and car manufacturers can differ from region to region, one should check the requirements set by them to ensure the vehicle warrantee is maintained. If modern emission control technologies are used, e.g. NOx traps or Diesel Oxidation Catalyst, low sulphur fuels (500 ppm or less) will be required.

Battery requirements

Since hybrid technology is relatively new, at least compared to the conventional drive train invented over 100 years ago, there have been reasonable concerns around technical failures when adopting this technology. The highest uncertainty remains around the battery lifetime, the cost of replacement, and the maintenance of advanced electronics. In terms of HEV production and scrappage, including battery packs, a life cycle approach should be used.[23]

Battery power – Until the late 1990s battery development was driven by the need for battery powered electric vehicles and thus aimed for high energy density (low weight per energy storage capacity; kWh/kg). With the launch of the first HEVs the focus shifted toward developing batteries suitable for hybrid applications instead, i.e. focusing on high power density[24] (low weight per power discharge ability; kW/kg). The first generation HEVs were sluggish since the battery development had not aimed for high specific power, i.e. they could not discharge energy quickly enough. This has been partly rectified by the development of improved battery types: nickel/metal hydride and lithium-ion batteries. Current HEV batteries provide the vehicle with ample power for driving but development is still ongoing, focusing on cost reduction and extending the lifetime.

The power required for HEV function is supplied by large battery stacks, usually between 50-70 kg for passenger cars [25] and 250-600 kg for bus batteries. Most HEV buses today are fitted with a lead acid battery, but the use of more advanced and expensive but better and longer lifetime nickel metal hydride batteries is increasing for buses as is already the case for passenger cars.

Battery life - Most HEV manufacturers provide long lifetime guaranties (e.g. 8 years or ~ 250,000 kms) for their batteries and electrical systems. The cost of replacing a HEV battery pack is now 2,000 USD to 3,000 USD including labor costs but prices are falling.

Battery disposal [26] - In the mid-1990s, there was a heated debate on batteries for electric vehicles, their after-life and the effect of metal "leakage" in the environment. Batteries would be recycled but there was a concern that a small percentage of the poisonous battery metals, especially lead and cadmium, would leak into the environment and affect human health and ecosystems. But recent battery technology development has made that debate outdated as battery development has moved away from lead acid and nickel cadmium batteries. Lithium-ion and nickel-metal hydride batteries, the most recent battery versions, pose no serious threat to the environment. However, the debate highlighted the need for an efficient recycling system for used batteries. Several manufacturers have started their own recycling scheme for hybrid batteries, partly as a consequence of "product after life responsibility" and also to recycle metals into new batteries. However, in many developing countries and transitional countries these advanced systems are lacking. Public infrastructure for recycling batteries and all other electric parts of HEVs, or mandating life cycle management from manufacturers, is a long-term requirement for hybridization.

23 http://lcinitiative.unep.fr

24 In the first HEV Prius in 1997 the power density of the battery was 800 W/kg. In the 2006 Prius model the power density of the battery has doubled to 1 800 W/kg.

25 The 2008 version of the Toyota Prius has a NiMH battery with a weight of 39 kg (Toyota 2008).

26 A number of evaluations of the current state of the art in HEV battery packs is available; Environmental Defense Fund has evaluated to lead-acid starter batteries: http://www.edf.org/documents/2894_FactSheet_batteryalts.pdf

Technical infrastructure and know-how

The rest of the electric system consisting of an electric motor and power control is regarded as reliable. With few moving parts, the maintenance needs are predicted to be low for this system.

However, the hybrid system includes parts that are high voltage and service personnel need to be acquainted with high voltage (140 to 280 volts) maintenance in order to avoid electric shocks. The hybrid systems currently on the market should be repaired and maintained by a trained technician from the manufacturer, which can be difficult to achieve in developing and transitional countries. However, with growing HEV use, care expertise will eventually be performed by conventional auto shops.

4 Economics of Hybrid Technology

The purchase price of a hybrid vehicle is higher compared to a conventional vehicle, both for passenger cars, buses, and trucks. However, given the lower fuel consumption, the total cost of ownership or life cycle cost of buying and using a hybrid can be equal to or even lower than buying and using a conventional vehicle - depending on yearly mileage and fuel prices. The life cycle cost does not only include the cost of purchasing the vehicle but also the cost of fueling and maintenance.

4.1 Passenger Cars

The retail price for a hybrid is roughly 3,000-6,000 USD more than a conventional model of a similar car.[27] This does not include the government rebates and incentives offered in some countries that can be anywhere from 300 to 7,000 USD. [28] The maintenance cost of owning a HEV is similar to owning a conventional car. Generally, the maintenance of a HEV can be expected to be less frequent compared to a conventional vehicle due to lower stress on moving parts, use of brakes, etc. However, the maintenance will require more trained mechanics and possibly specialized maintenance centers.

Figure 12 illustrates the total cost of ownership of a conventional passenger car and a hybrid passenger car. This is an example to show that the cost of fueling the car is a major share of the overall cost of owning a car. Thus, lower fuel consumption can compensate for the higher sticker price of an HEV.

27 A Toyota Camry is available as both a hybrid and a conventional version. In June 2008 the hybrid costed USD 5580 more than the conventional Camry with the same size engine, leaving taxes aside (USD 25860 vs. USD 20280). Source www.Toyota.com. The performance of the hybrid is even better as its combustion engine can be supported by the combination of its battery and the electrical engine. A Ford Explorer HEV cost approx. 26 000 USD whereas the non/hybrid model cost 20 000 USD. AllianceBernstein 2006: "Right now, they cost consumers 4,000 USD to 9,000 USD more upfront than comparable conventional vehicles, but mass production and further technological refinements should rapidly reduce their current price premium." 28 In the U.S. Hybrids purchased or placed into service after December 31, 2005 may be eligible for a federal income tax credit of up to 3,400 USD. Credit amounts begin to phase out for a given manufacturer once it has sold over 60,000 eligible vehicles. As a result, the income tax credit for the Toyota Prius has decreased from 3150 USD in 2006, to nil in 2008. In Sweden, private purchasers of the Prius (or any other vehicle in the environmentally less destructive class) are awarded SEK 10.000 (roughly 1700 USD or 1100 EUR) after six months of ownership, in order to stimulate sales and use of such vehicles. In the Netherlands, the government has decreased the income taxes for energy class A cars (such as the Prius) to 14%. The tax on all other class cars has been raised from 22 to 25%. As a result, the tax advantage of a Prius over a conventional vehicle can be 4460 EUR or 7000 USD (=11% x 26.000 EUR x 52% (income tax) x 3 yrs).

28 In the U.S. Hybrids purchased or placed into service after December 31, 2005 may be eligible for a federal income tax credit of up to 3,400 USD. Credit amounts begin to phase out for a given manufacturer once it has sold over 60,000 eligible vehicles. As a result, the income tax credit for the Toyota Prius has decreased from 3150 USD in 2006, to nil in 2008. In Sweden, private purchasers of the Prius (or any other vehicle in the environmentally less destructive class) are awarded SEK 10.000 (roughly 1700 USD or 1100 EUR) after six months of ownership, in order to stimulate sales and use of such vehicles. In the Netherlands, the government has decreased the income taxes for energy class A cars (such as the Prius) to 14%. The tax on all other class cars has been raised from 22 to 25%. As a result, the tax advantage of a Prius over a conventional vehicle can be 4460 EUR or 7000 USD (=11% x 26.000 EUR x 52% (income tax) x 3 yrs).

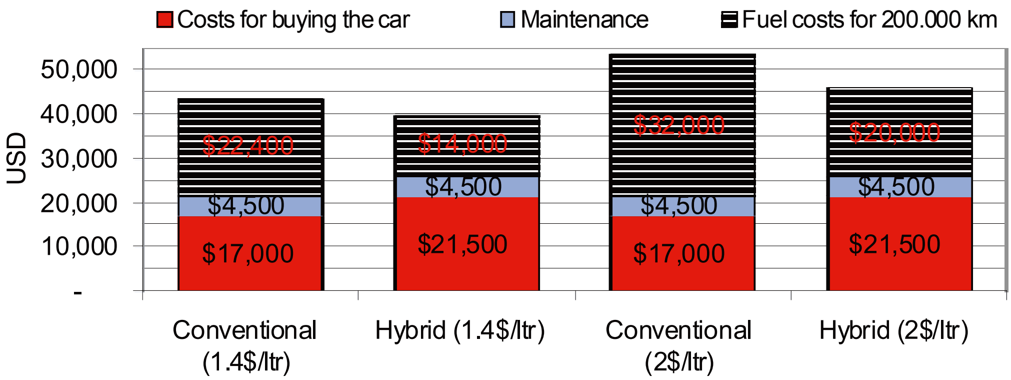


Figure 12 Example of the cost of ownership for a Hybrid, assuming fuel prizes 1.4 and 2.0 USD/L respectively, excluding any tax incentives

Assuming a vehicle lifetime of 200,000 kms, equal vehicle maintenance costs (~4,500 USD over entire vehicle life), a procurement price difference of 4,500 USD, and average petrol prices of 1.4 USD/L and 2 USD/L, then total cost of ownership differences are 3,900 USD and 7,500 USD respectively.

Figure 12 illustrates that an HEV can be cheaper to own compared to a conventional vehicle of the same size. Assuming a fuel consumption 20 km/L (= 0.05 L/km or 47 MPG) for the hybrid and 12.5 km/L for a comparable conventional car (= 0.08 L/km or 29 MPG), for each km driven 0.03 L of petrol can be saved with an HEV. With an expected life time of 200,000 km, total reduction in fuel consumption will be 6,000 L.

Savings can be calculated using current fuel prices. In the U.S., for example, where fuel prices are lower due to lower fuel taxes, the cost calculation is less clear; fuel price is crucial for the short-term economic viability of HEVs for consumers. However, note that in the EU, Japan and the U.S., tax breaks or subsidies are available to make HEVs more financially attractive.

Fuel price 'break even' point

From similar calculations as described above, one can estimate which countries should accept HEV technology easily because of fuel price that falls above a given 'break even' price. Assuming additional costs for a HEV at 4,500 USD, fuel consumption and a lifetime mileage as described above, the Fuel Price Beak Even Point is 0.75 USD/L.[29] Global fuel prices as described in Annex D can be used to identify the Hybrid Potential for all countries. Note that fuel prices are from November 2006.

29 With a fuel consumption improving from 12.5 to 20 km/L, the lifetime (200,000 km) fuel consumption reduces from 16,000 L to 10,000 L. So the additional investment of 4,500 USD, saves you the consumption of 6,000 liters during its assumed life time.

Payback Period(Years)		Fuel Price (Usd/l)			
		1.00	1.40	2.00	2.50
Annual mileage (km)	10,000	15.0	10.7	7.5	6.0
	20,000	7.5	5.4	3.8	3.0
	30,000	5.0	3.6	2.5	2.0
	50,000	3.0	2.1	1.5	1.2

Figure 13 Payback period of an HEV example as a function of annual mileage and fuel prices, assuming the extra procurement cost for the HEV is 4,500 USD and fuel efficiencies of 12.5 km/L and 20 km/L for the conventional and hybrid vehicles respectively.

Payback period for HEVs

Investment decisions are often based on the payback period, which is a period of time required for the return on an investment to repay the sum of the original investment. As an example, assuming an annual mileage of 30,000 km and a fuel price of 1.4 USD/L, an HEV running 20 km/L consumes 1,500 L of petrol fuel per year, while a conventional car running 12.5 km/L consumes 2,400 L per year. The annual fuel cost savings are 900 L x 1.4 USD/L = 1,260 USD/yr. As the HEV is approximately 4,500 USD more expensive than its conventional counterpart, the pay back period of the hybrid system is 4,500/ 1,260 = 3.6 years to the break even point. Depending on investor requirements, this period might be short enough to justify an investment in HEVs. However, developing countries are often plagued by high inflation rates, which can reduce the acceptable pay back periods significantly.

Comparing the costs for buying vehicles

An often overlooked fact is that in order for a clean diesel vehicle to attain the same emission reduction levels as a petrol hybrid, it needs to install emission reduction technologies for PM and NOx. PM filters are voluntarily installed in some new models already, depending on local vehicle emission standards. However, with a future mandatory introduction of selective catalytic reduction systems or NOx traps the price of clean diesel vehicles will most likely go up. Today, the price for particulate filters with combined NOx reduction technologies is 600 to 1,000 USD for passenger cars and 10,000 to 20,000 USD for buses, but the prices will most likely go down with time and more widespread introduction (MECA 2006).

The price gap between HEVs and conventional vehicles is expected to come down as markets mature and HEV technology is further developed (cost-buy down effect) on one side, and stricter emission regulations forcing diesels to include more advanced and costly emission control technologies, on the others side. There will, however, be a price gap for some time between HEVs and conventional vehicles due to the double drive trains. It is estimated that by 2030 HEVs will be 1,400 USD more expensive than a similar turbocharged petrol vehicle (Kromer and Heywood 2007).

4.2 HEV Fleets – Diesel and Petrol

For passenger vehicles used in large fleets, the payback time is much shorter as fleet vehicles are typically driven more frequently than privately owned vehicles. The benefit of paying more up-front for the vehicle in exchange for lower fuel cost is greater for fleet vehicles. A number of private, government and municipality owned fleets all over the world have started introducing HEVs.

Passenger car fleets

King County is an example of a municipality with a long history of hybrid vehicles. By the beginning of 2008 King County in the U.S. state of Washington maintained a fleet of approximately 190 HEVs running on petrol fuel. Furthermore, they procured a PHEV and a heavy duty hybrid truck. The PHEV and hybrid truck were procured as part of a demonstration project, but the hybrid passenger vehicles have already proven their value, as the newest hybrids are replacing the retired ones from 2001 (King County 2007).

In New York City, about 1400 taxis (from a fleet of over 14,000) are HEVs, making it one of the biggest global hybrid vehicle fleets. When compared to the Ford Crown Victoria widely used as a taxi has and with a fuel economy of 15.7 L/100km, the HEV replacement will halve the taxi fuel consumption (USEPA 2008).

Hybrid bus fleets

The cost of HEV buses differs a lot between manufacturers and price development is strong; as the market develops the price will become more comparable. The technical varieties differed a lot in the first HEV buses on the market. However, today the best HEV buses are all series configuration offering greater fuel economy and lower operational cost.

Figure 14 contains a summary of the additional costs of hybrid buses and one CNG bus in five different cities in North America. Details of these fleets can be found in Annex B.

The HEV technology premiums are all within the range of 32-57% of the price of a state of the art diesel bus. However, for all these examples purchase costs for the hybrid buses were agreed upon long before the publication of the evaluation reports. Since then, the HEV technology has become more mature and the premiums have decreased.

Assuming typical fuel bus economies of 1.4 km/L and 1 km/L for hybrid and conventional buses respectively, with every km driven by the hybrid bus .3 L of fuel is saved. Depending on the annual mileage and the fuel price, one can calculate the pay back period of the additional 95,000-240,000 USD investment. For example, with a fuel price of 1.4 USD/L, after driving 400,000 km, fuel costs of 168,000 USD are saved with the hybrid technology investment.

	Connecticut Transit (CTTransit) (Foyt 2005)	NYCT 2006 purchases (Bartnitt and Chandler 2006)	NYCT 2003/ 04 purchases (Bartnitt and Chandler 2006)	Houston Metropolitan Transit Authority (Metro 2007)	British Columbia Transit (BCT 2005)
Purchase costs state-of-Art Clean Diesel	320,000 USD	350,000 USD	290,000 USD	unknown	424,000 USD
HEV Bus purchase cost	500,000 USD	500,000 USD	385,000 USD	unknown	664,000 USD
HEV Premium	**180,000 USD**	**150,000 USD**	**95,000 USD**	**120,000 USD**	**240,000 USD**
CNG Bus purchase cost	n/a	n/a	320,000 USD	n/a	n/a
Fuel economy Improvement	+10%	?	HEV: +37% (CNG: -25%)	+25% expected	+58% expected

Figure 14 Examples of Hybrid Transit Bus Fleets

4.3 Additional Costs

While the maintenance costs of CNG and HEV passenger cars are comparable or even lower than their diesel and petrol counterparts (assuming the technical infrastructure is available), the maintenance costs of CNG and HEV diesel buses and trucks have initially been reported as being higher than the standard diesel trucks. This is mainly because the larger HEV and CNG vehicles are newer and much fewer in number.

New York City Transit reported maintenance costs for the HEV buses were almost twice as high as with ordinary diesel buses. However, these buses were prototypes and it is expected that maintenance costs will drop significantly with experience and development.

The delivery company UPS reported that their CNG delivery trucks also had higher maintenance costs compared to diesel delivery trucks, but most of this had to do with the introduction of a new vehicle technology.

In principle, CNG and HEV diesel buses should not have much higher maintenance costs than standard diesel buses. With time and more experience the maintenance cost will go down with skilled personnel and adequate availability of spare equipment

5 Policy Measures

The four key policy-relevant and consumer choice advantages of HEVs over conventional and comparably clean and efficient technology (clean diesel, CNG) can be summarized as follows:

- **Emissions** – Available HEV technology will decrease emissions of conventional air pollutants substantially as compared to a standard vehicle on the roads today. While similar emission reductions can be achieved with, e.g. CNG and clean diesel vehicles with advanced emission control technologies, the HEV combines both non-CO2 and CO2 reductions.

- **Energy** - HEVs decrease fuel consumption substantially compared to conventional vehicles used today and also compared to CNG and the new generation of cleaner diesel vehicles. Calculations have shown that over the average HEV useful life time savings can amount to 6,000 L of fuel.

- **Life Cycle Cost** – While HEVs are more expensive initially, the fuel savings are recouped based on mileage and driving conditions. Analysis has shown that the HEV life cycle cost, including the cost of purchase, fuel and maintenance costs, is, in most cases, less than owning a conventional vehicle. However, these calculations are strongly dependent on fuel prices, taxes and rebates.

- **Strategic Stepping Stone Technology** - HEVs, plug-in hybrids, full electric vehicles, and fuel cell vehicles share basic technologies such as electric motors, batteries, and power electronics. Therefore, HEVs and plug-in hybrids function as stepping stone technologies to the large-scale electrification of fleets that is required for a long-term reduction of CO2 emissions from road transport, and a low carbon transport sector.

While these technologies are still maturing, hybridization of fleets can start making a significant dent in transport energy usage today, and can help countries meet fuel independence and efficiency targets in the next few decades. Improvements in traffic management, promotion of non-motorized transport modes, and higher rates of public transport usage will also contribute to long term changes in travel preference and emission reductions. An approach to integrated transportation, in particular the provision of mass transit at low cost, is crucial for managing mobility and emissions in rapidly developing countries – particularly at the urban level. In low income countries, mobility for most users means greater access to public and non-motorized transport, even as car fleets grow.

The emergence of second-and-third generation biofuels from cellulosic feedstocks are also promising technologies for reducing the carbon intensity of fuels and travel modes.

5.1 Developing An Enabling Environment

Fuel economy policies

Putting in place fuel economy targets and policies that support more ambitious, mandatory fuel efficiency standards that are fuel and technology neutral is a first step to improving the performance of road transport and car fleets. Providing a clear, predictable policy and a simplified legislative framework that details both the fuel economy objectives, the means for reaching them (e.g. import standards, vehicle motor technology improvements in manufacturing countries, use of biofuels, minimum efficiency requirements for vehicle components such as air conditioners, among others), and a mutually agreed timeframe for implementation is crucial for industry and the private sector. Such an approach would provide both importers and manufacturers with adequate lead time and will provide the regulatory certainty required in a sector where technology investment and development and production cycles are long. For vehicle importing countries, turnover of vehicle technology in fleets can be up to 20 years, so early policy and standard development and implementation is needed.

Fuel economy or CO2 emissions standards are an effective way of overcoming the natural aversion to investing in fuel economy technologies that result from unstable oil prices. There is a range of approaches to standard setting (see Figure 15 by the International Council on Clean Transport for a summary of fuel economy standards in place and under development around the world), but there is increasing global convergence around fuel economy targets. The European Union, Japan and the United States are on track to meet the 50% reduction in new car fuel economy needed by 2030 in OECD countries to put the world on track for a 50% increase in fuel economy by 2050. These initiatives are opportunity to highlight the need for a global approach to improving automotive emission (both CO2 and non-CO2) standards.

The U.S. developed its Corporate Average Fuel (CAFE) efficiency standards in 1975.[30] This early framework formed the basis for increases in fuel efficiency for cars and light trucks (a 40% increase over 2007 by 2015) in recent years. At the same time, following years of

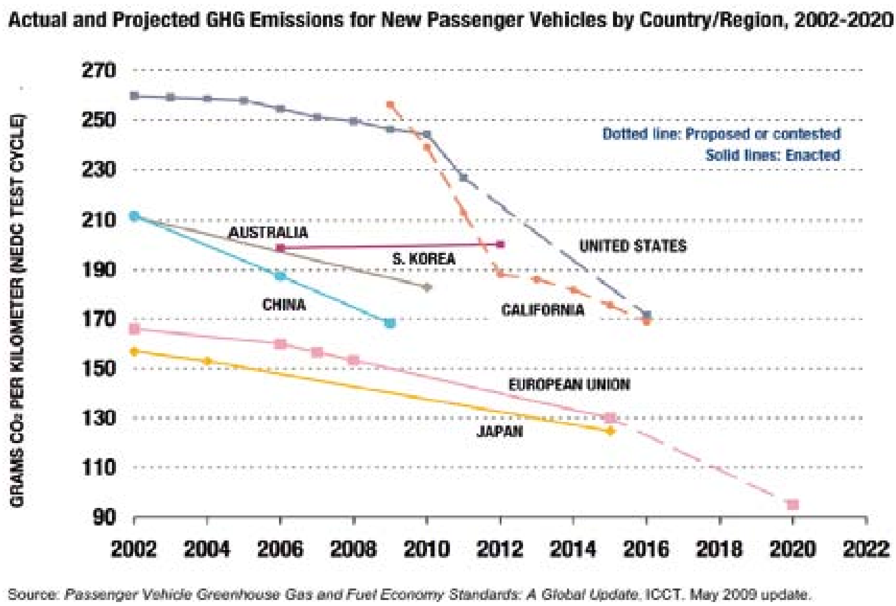


Figure 15 Actual and Projected GHG Emissions for New Passenger Vehicles by Country/Region, 2002-2020

30 US CAFE km/L value is about 12% higher than EU's (NEDC) km/L values (ICCT July 2007 - "Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A global Update", Feng An, Deborah Gordon, Hui He, Drew Kodjak and Daniel Rutherford.

voluntary industry standards, the European Commission is now negotiating a significant mandatory improvement in efficiency over the next few years (120g CO2/km by 2012). Both sets of policies and standards put the U.S. and the E.U. on track for the 30% fuel efficiency jump required in the next few years, and the 50% total needed by 2030 to stabilize road transport emissions.

Vehicle taxes and incentives[31]

Many governments tax vehicle purchases and most levy an annual tax on vehicle ownership or charge for an annual permit to drive on the roads. These ownership and/or circulation taxes can be differentiated on the basis of vehicle fuel economy or CO2 emissions. This can help is improving fleet-wide economy, and can also prevent the use of natural technology improvement rates in favor of power and weight, rather than improved fuel efficiency. For example, over the last few decades conventional petrol vehicle technology has shown a natural rate of improvement of around 1% a year. In the United States, almost all of this potential has been taken up in power and weight increases, leaving fuel economy roughly constant over the past 25 years. In Europe, in the past decade about half of the potential was used for performance and half of it to improve fuel economy (Heywood, 2008).

Using differentiated vehicle taxes according to fuel efficiency or CO2 emissions is one way to apply the 'polluter pays' principle to higher emission cars while providing incentives for ownership of lower emission cars less. Many countries are using this approach to stimulate the electrification of fleets - for example, in Japan tax incentives for fuel efficient vehicles were introduced in 2001 and helped to accelerate the early introduction and use of fuel efficient vehicles, with 80% of passenger cars clearing the 2010 fuel efficiency standards by 2004.

An HEV on the market today will cost 10-20% more than a conventional vehicle on purchase. However, a HEV will increase fuel efficiency by 25 - 35% and the lifetime HEV cost of purchase and ownership is lower than a comparable conventional vehicle. Vehicles used in slow-moving urban traffic, e.g. city buses, taxis, delivery trucks and municipal service vehicles, stand to gain even more due to lower wear and tear and regenerative braking technology, thus reducing the payback period for HEVs in terms of fuel savings and lower maintenance costs.

As a rule, new competing technology is usually more costly than well-established conventional technology (e.g. conventional vehicle technology has been around for over 100 years). However, as HEV market share increases and producers gain experience from manufacturing, the cost of producing HEVs will also decrease. An initial subsidy or tax break should be considered for HEVs in some new markets – while perhaps not fiscally possibly in poorer countries, it should be considered in rapidly industrializing and middle income countries. However, this financial support should only be an initial support; the technology should become self-sustaining with greater market penetration.

When the first hybrid electric vehicles where launched in Japan, the government offered a subsidy of half of the extra incremental cost of buying an HEV as compared to a conventional

31 50by50, Making cars 50% more fuel efficient by 2050 worldwide to cut oil consumption and CO2, www.50by50campaign.org

car. In practice, this meant that each HEV was given a subsidy of around 2,500 USD. This subsidy expanded the market for HEVs substantially.

In the United States both state and national government schemes offer tax incentives or other subsidies to encourage HEV purchase recent economic stimulus packages are subsidizing electric and hybrid vehicle technology even further. The incentives are given both to private owners and to fleet owners. Subsidies include cash equivalents up to USD 4,000 and privileges such as free parking within designated areas (notably in central business districts) and permission to drive in priority lanes.[32]

Component standards and testing cycles

Globally and regionally harmonized vehicle fuel efficiency standards, taxation systems, vehicle emission testing cycles, and consumer information labeling systems contribute to more regulatory certainty for vehicle manufacturers with long investment and technology development time horizons. The inclusion of efficiency-improving vehicle components (e.g. low rolling resistance tires, low friction lubricating oils, air conditioners) in fuel economy tests will also ensure that they can be included in labeling and taxation systems that promote fuel efficiency. These simple components can affect vehicle fuel efficiency by over 5%, but they are not routinely included in testing cycles, therefore minimizing incentives for more efficiency.

Standardization has so far not been an issue for HEV component parts as the technology has drawn on other standards already in place, for example standards on high voltage systems. However, international standards for battery recycling practice and for battery charging technology would help to support the wider use of HEV technology and plug-ins in the future.

Fuel Taxes[33]

Fuel taxation has a direct impact on fuel economy. The 15% difference in the average fuel economy of United States and European cars is in large part a result of differences in the level of fuel taxes, although incomes and the design of US CAFE regulations (favouring light trucks over cars) also play a part. In most countries the primary reason for taxing fuel is that it is a relatively secure source of public funds; fuel demand is less sensitive to price than many other goods and services. And it might be argued that the existing high fuel prices already serve the purpose of a carbon tax. For example, existing fuel excise taxes in Europe equate to a rate of 200 to 300 Euros (EUR) per tonne of CO2 emitted by cars. In comparison, the Stern report on the economics of climate change calculated the cost of carbon to be EUR 60 per tonne of CO2 and carbon trades on the European Emissions Trading System at around EUR 25 per tonne of CO2

32 See www.eere.energy.gov for more information.
33 Ibid.

The relatively high tax on fuels in some parts of the world (notably within the EU and in Japan) is partly a policy to guide consumers towards less fuel consuming cars like HEVs. However, fuel taxes alone cannot induce fleet-wide adoption of HEVs; only when combined with a package of policy instruments and standards they can inspire more eco-friendly vehicle purchase. Fluctuating global fuel costs may also act as an incentive for more efficient technology.

Consumer Awareness and Education

The importance of information and awareness to government, industry and consumer groups on HEV technology and ownership should not be underestimated. Specialized knowledge exchange forums between policymakers and industry groups can serve to fast-track effective policies and incentive structures in non-OECD markets. Consumer groups, including automobile clubs, are direct communication providers for vehicle-related information. Accurate information on the life cycle costs, environmental benefits, and what to expect when owning a hybrid is an effective method to instill realistic expectations in consumers.

In the EU, information specifying the energy use and CO_2 emissions for new cars must be available on vehicles in showrooms, usually in the form of a label on the windscreen. In the U.S. the Environmental Protection Agency offers information on the environmental ratings of cars through its "Green Vehicle Guide" (www.epa.gov/greenvehicles). Consumer interest groups also play a role: the FIA Foundation for the Automobile and Society regularly rates vehicles in terms of environmental performance through its EcoTest programme.

Car equipment that provides instantaneous and average fuel consumption readouts or prompt gear shifts to keep engine speeds down supports ecodriving, or driving in a softer, more fuel conscious manner. The government of the Netherlands successfully stimulated widespread availability of such instrumentation on new vehicles at the beginning of the decade by reducing tax on suitably equipped cars.

Trade and Investment

Multilateral negotiations and bilateral or regional agreements between trading partners can also influence market access for the auto industry and can help to establish a global demand and trade in more efficient cars, including HEVs. The establishment of local production through foreign direct investment will also play a part. Secondary vehicle markets in non-OECD countries are greatly affected by technology and policy choices in primary markets. International vehicle import flows alone ensure that, with time, HEV technology will permeate new markets – but not necessarily in the volumes required. Whether or not HEVs are adopted on a wider scale will depend on the vehicle emission, import/export taxation regimes, fuel quality, and technology maintenance systems in place.

5.2 Leading by Example

In addition to direct financial support, tax incentives, and purchase subsidies that reduce the up-front cost of HEV ownership, governments can also encourage HEV adoption and wide-scale use through public procurement policies that favor low emission vehicles and contractors who use them. In young HEV markets, public measures to encourage technology adoption are extremely important for risk-averse consumers. Both government and major business fleet owners can help the development of hybrid vehicles by introducing them into their own fleets.

Government fleets are usually very visible and this gives a clear signal to consumers that this technology is viable. The initial market can act as a bridging market -pushing this technology to become more competitive. Hybrid vehicles are also good for fleets as fleet vehicles are usually driven more and thus the fuel economy benefit will be greater, and thus vehicle purchase and ownership even more cost-effective. Greener public procurement is a way of promoting cleaner vehicles, particularly in new markets.

5.3 Maintenance Training

Support is also required for repair and maintenance providers that specialize in HEV technology (e.g. training of maintenance personnel to handle high voltage systems, an electric engine, procurement of spare parts), in addition to the developing technical standards for the safe recycling of used batteries. Standards can also ensure that new HEVs are sold with suitable warranties on technology, thus reducing the risk for presumptive buyers.

5.4 Conclusion

HEV technology for both light and heavy duty applications is commercially available today and demonstrates substantial reductions in tail-pipe emissions and fuel consumption, even when compared to other available low emission technologies. HEVs are particularly effective for urban travel, significantly lowering pollutant emissions and providing cost-effective CO_2 reductions in personal mobility. Encouraging hybridization of vehicle fleets through enabling policies and incentive structures can serve to lower both conventional and CO_2 emission, thus improving public health, energy security, and reducing fuel costs. Continuing innovation in hybrid technology and a growing demand for cleaner vehicles will mean that costs are likely to fall, particularly in second hand vehicle markets.

While OECD countries need to be the avant-garde in doubling vehicle fuel efficiency in the next twenty years, the majority of vehicle growth will take place in non-OECD countries. Today, most countries do not have fuel economy policies in place. In order to reach the global CO_2 reductions required to stabilize greenhouse gas emissions and mitigate climate change, fuel economy policies and technology will need widespread use. This will only occur in the framework of efficiency-friendly economic and policy environments, and with the involvement of all sectors – from governments to manufacturers, importers and consumers.

Annex A: Current Market HEVs

Passenger cars

There has been a proliferation of new hybrid models and today most big auto manufacturers have at least a ready-made hybrid prototype for show, if not for sale. On the market Japanese manufacturers still dominate the number and varieties of models but U.S. manufacturers have recently begun to sell larger SUV hybrids. To date PHEVs are not available yet, as they are still in a test phase; the earliest mass market model is expected in 2010.[34]

Hybrid buses

Several bus manufacturers are now offering hybrid buses for sale on a commercial basis. The number of bus manufacturers that produce HEV buses has been steadily growing in recent years as a response to demand from governments.

Examples of manufacturers include Orion (member of the Daimler Chrysler group) that sells HEV buses in the U.S. and the Canadian transit bus company New Flyer that has made a hybrid bus with hybrid technology from GM. In Japan Mitsubishi and Hino have both launched hybrid buses and in Europe Breda-menarini Bus (Italy) is also selling hybrid buses.

Developing countries are also beginning to manufacture hybrid buses. In Brazil, Eletra Buses has made an advanced hybrid bus and in China the FAW Group Corporation and the Dongfeng Motor Corporation (DFM) have recently announced production of hybrid bus models.

Hybrid delivery trucks

Using hybrid technology for buses and freight trucks requires more careful analysis of how the vehicle is being used as each case usually proves to be unique and the benefits of using HEVs depend strongly on the specific driving conditions. In Annex B you will find some examples of bus and freight companies that evaluated both HEV and CNG options.

34 For an up to date complete overview of automakers statements and status of production, see http://www.calcars.org/carmakers.html.

Annex B: U.S. EPA Emission Comparison

	Conventional	CNG Vehicle	Mild Hybrid	Full Hybrid	Clean Diesel	Conventional Diesel
						
Make:	HONDA	HONDA	HONDA	TOYOTA	MERCEDES-BENZ	VOLKSWAGEN
Model:	Civic gasoline	Civic CNG	Civic Mild Hybrid	Prius Full Hybrid	E320 Bluetec Diesel	Golf Diesel
Year:	2008	2008	2008	2008	2008	2006
Vehicle Specifications						
Engine:	1.8 Liter, 4 cylinder	1.8 Liter, 4 cylinder	1.3 Liter, 4 cylinder	1.5 Liter, 4 cylinder	3 Liter, 6 cylinder	1.9 Liter, 4 cylinder
Transmission:	Auto 5 speed	Auto 5 speed	Auto Variable	Auto Variable	Auto 7 speed	Select 5 speed
Fuel Type:	Gasoline	CNG	Gasoline	Gasoline	Diesel	Diesel
Drive:	2WD	2WD	2WD	2WD	2WD	2WD
Vehicle Type:	Small Cars	Small Cars	Small Cars	Midsize Cars	Midsize Cars	Small Cars
Environmental Information						
Air Pollution Score (10 = best)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
Greenhouse Gas Score (10=best)	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible]
SmartWay Label:		Elite	Elite			
Fuel Economy						
City (km/L)	11	10	17	20	10	12
Highway (km/L)	15	15	19	19	14	17
Combined (km/L)	12	12	18	20	11	14
Emissions						
NOx (gr/km)	0.04	0.01	0.01	0.02	0.12	0.37
CO (gr/km)	2.6	0.6	1.3	1.3	2.6	2.6
NMOG (gr/km)	0.06	0.01	0.01	0.03	0.08	0.10
PM (gr/km)	0.01	0.01	0.01	0.01	0.01	0.05
Smog-forming Pollution: (kg/yr)	2.4	0.4	0.4	1.3	4.9	11.3
Greenhouse Gases Emitted (ton/yr)	6.3	5.4	4.4	4.0	8.2	6.6

Figure 16 Comparison of vehicle technology by fuel consumption and emission data, as published by the US EPA Green vehicle database (US EPA 2008).

Vehicle models are:

- a conventional passenger car, the Honda Civic, 2008
- the CNG version of the Honda Civic, 2008
- the mild hybrid version of the Honda Civic, 2008 (no electric only drive)
- the Full Hybrid Toyota Prius, 2008
- the Mid Size Clean Diesel Mercedes E320 Bluetec, 2008
- a regular Small Size diesel, the Volkswagen Golf, 2006

Data from U.S. EPA: www.epa.gov/greenvehicles. [35]

35 In this report the EPA test results are used as EPA publishes results from many different vehicle types. The FIA is doing a similar test for vehicles that are available in Europe. FIA uses a slightly different test drive cycle, resulting in slightly different results. The FIA results can be found on www.ecotest.eu.

Annex C: Examples of Public Bus Fleets

New York Transit Company

The New York Transit Company (NYCT) was early to adopt hybrid technology (Barnitt and Chandler 2006). The "Clean Bus Program" includes CNG buses, retrofitting diesels using ultra low sulphur diesel (less than 15 ppm), and hybrid buses since 1998; in 2005 NYCT had 325 hybrid buses and 481 CNG buses of their total fleet of 4,489 buses. The main driver for the push for alternative buses has been air quality.

The experience so far indicates fuel savings in the expected range and higher maintenance cost as the technology is new. In 2000, the NYCT rider's council published an analysis of the CNG and HEV options for New York (Sigall 2000), that can serve as a good example on cleaning up a bus fleet using new technology.

Connecticut Department of Transportation and CTTransit

A comparison of four different state of the art buses with conventional fleet averages (Foyd 2005):

a. clean-diesel buses operated on 'Number 1' diesel fuel (Sulphur level < 500 ppm)

b. clean-diesel buses operated on ultra-low sulphur diesel fuel (15 ppm or less) and fitted with diesel particulate filters

c. hybrid buses operated on 'Number 1' diesel fuel, d. hybrid buses operated on ultra-low sulphur diesel fuel and fitted with diesel particulate filters

The fuel economy of the hybrid buses is about 10% better than of the clean diesel buses, resulting in estimated lifetime fuel savings of about 28,300L of diesel - fuel savings were smaller than expected. The hybrid buses were about 180,000 USD more expensive (500,000 USD vs. 320,000 USD); therefore the break even point is only viable with subsidies for bus purchase (depending on the fuel prices).

Note that the tested buses a. and c. can also be operated in developing countries, if diesel with sulphur levels < 500 ppm is available. The Partnership for Cleaner Fuels and Vehicles (PCFV, www.unep.org/pcfv) is working to reduce sulphur levels to 50 ppm world wide.

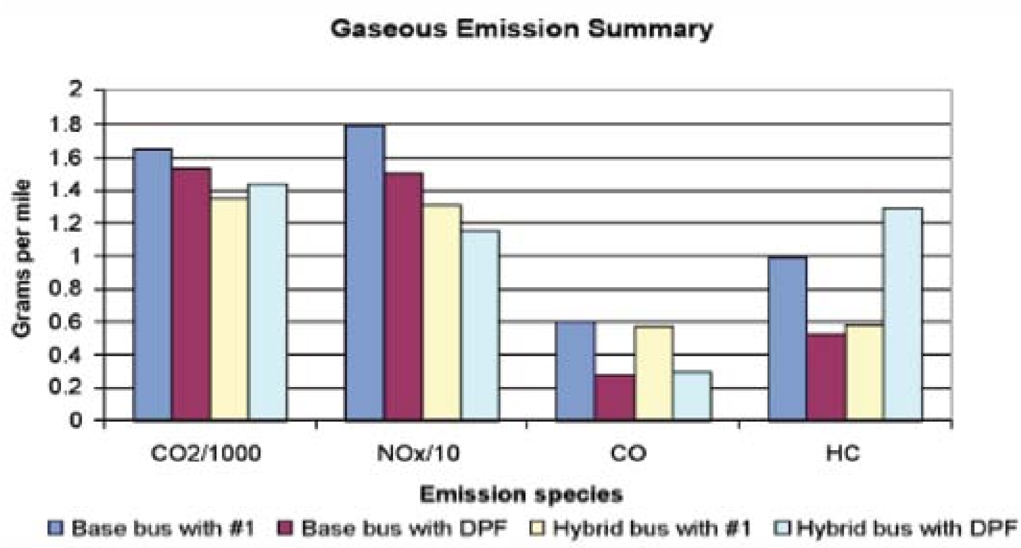


Figure 17. Emissions of buses in NYC, with different engines and fuels

Hybrid trucks fleets

A Canadian study on the feasibility of hybrid refuse trucks in a city environment showed that the fuel and maintenance savings achievable with an electric parallel hybrid system resulted in a payback time as low as four years, assuming diesel prices of 0.80 USD/L. With diesel prices of 1.2 USD/L the payback time will decrease to 3.2 years (Drozdz 2005).

King County Municipality described in its *Annual Report of Environmental Purchasing* the hybrid truck purchased to maintain traffic lights and roadside trees. Both activities involve a lot of stop and go traffic and the trucks lift uses the energy stored in the battery, so the motor does not need to be running for it to operate. This technology has achieved a 25% reduction in fuel consumption compared to conventional diesel trucks; this led to the purchase of two more trucks in 2008 (King County 2007).

A number of global delivery companies such as the FedEx, DHL, TNT and UPS have all tested hybrid delivery trucks and are also slowly beginning to introduce them into their fleets.

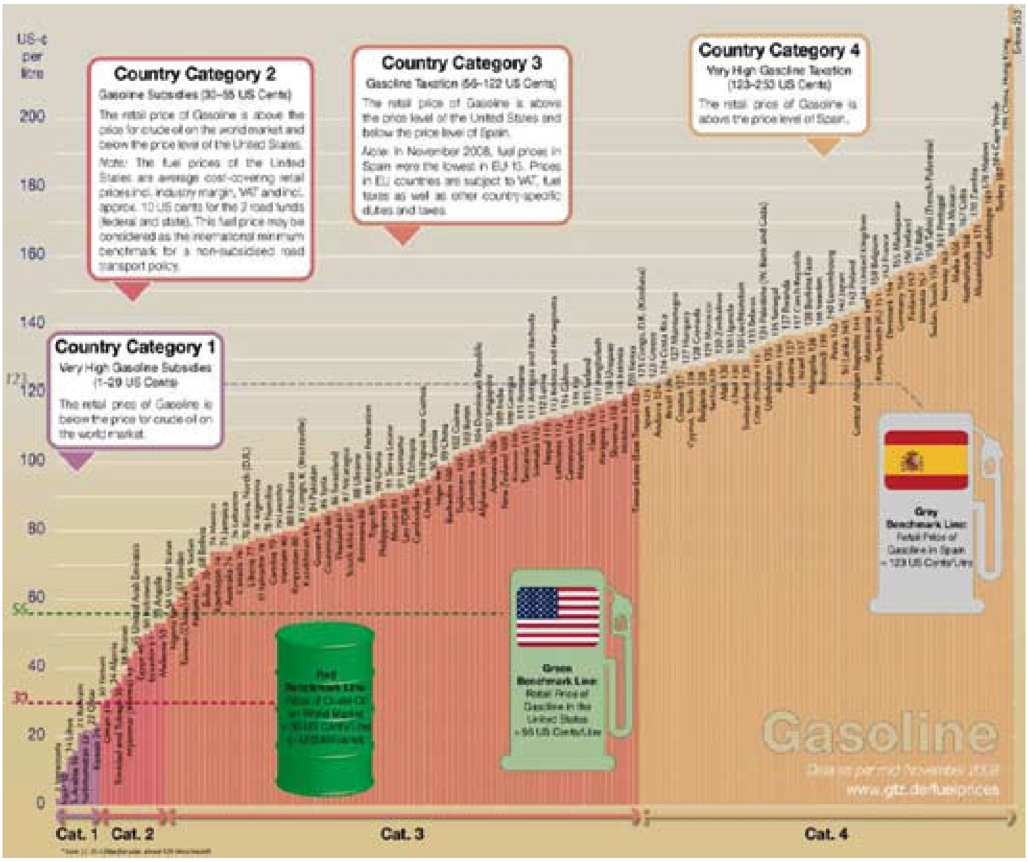
FedEx has together with Eaton Corporation developed a diesel HEV delivery truck launched a pilot project of 20 HEV diesel trucks (in 2003). The Eaton truck is a medium weight pick-up delivery truck typically operating within urban areas with lots of stop and go traffic. FedEx announced in 2003 that it intends to replace its entire fleet of 30,000 medium weight pick-up/ delivery trucks into HEV diesels in 10 years. FedEx is aiming at a 90% emissions reduction of harmful emissions and 50% more mileage per gallon of fuel without losing present functionality and cost-effectiveness.

DHL is testing two new delivery trucks, an HEV diesel truck (26 ft) and a full electric truck (14 ft). The electric vehicle will have a range of 40 miles. The HEV diesel is intended to move large containers. It is designed to improve fuel economy by 30-40% and reduce emissions up to 90% while significantly extending engine life and component life cycles.

UPS has a large fleet of CNG delivery trucks running (over 900) of a total fleet of 88,000 package cars, vans, tractors, motorcycles. Since 1998, UPS is also testing hybrid delivery trucks. In 2004 UPS tested a second generation HEV delivery trucks and in May 2008 announced the order of 200 hybrid electric vehicles and 300 CNG vehicles. According to UPS, the hybrid-electric power train achieves a 40% improvement in fuel economy and a 90% reduction in emissions compared to the non-hybrid version. Therefore the 200 new hybrids are expected to save 666,000 L of fuel per year and cut CO_2 emissions by 1,786 tons annually (Langlois 2008).

Annex D: Global Fuel Prices

The pay back time for the extra costs of a HEV as compared to a conventional vehicle, strongly depends on the fuel price. In the figure below, you will find the petrol fuel prices through 15 November 2008 for all countries. They can be used to get an indication of the hybrid potential in each country (GTZ 2009).



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