International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

The age of hybrid electric vehicles, their new advancements

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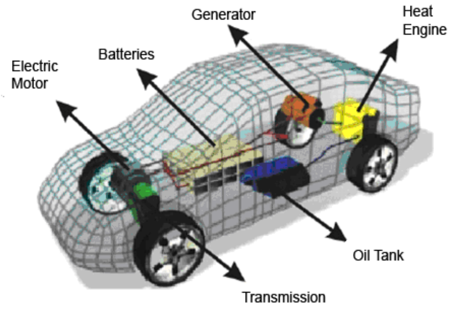
Received 05 June 2017, Accepted 10 Aug 2017, Available online 23 Aug 2017, **Vol.7, No.4 (Aug 2017)**

Abstract

HEVs are seen by some researchers as a very promising near-term technology for improving fuel economy and reducing emissions, particularly for Sports Utility Vehicles (SUVs). Proponents also argue that HEVs can provide improved performance for the customer and, in contrast to other advanced-technology vehicles, require no extensive new infrastructure. With many of the advantages but without the range limitation of electric vehicles, HEVs could have broad customer appeal. The modeling and simulation of vehicles is an essential stage in the design process. Early design stages focus of energy-modeling, where many component dynamics are ignored and the models only compute the energy flow through the models. This paper focuses on HEVs, compare them with other transporting technologies, modeling and simulations of subsystems that are unique to hybrid electric vehicles, the battery, electric machine, and inverter. The differences in fuel consumption, simulation time, battery SOC and battery capacity loss were analyzed and compared. The causes of the differences were determined, and the impact of each model fidelity was systematically evaluated.



Keywords: *Vehicle design; energy; battery; hybrid; modeling*

Introduction

As the world progresses technologically, an increasing amount of energy is consumed. Increasing the efficiency of primary energy consumers provides a potential offset to the increase in energy consumption. A graph of the world energy consumption from 1990-2040 is shown in Figure1. The world energy consumption is projected to increase by over 400 quadrillion Btu by 2040. Most of this growth is seen in Non-OECD regions, however OECD regions are still projected to increase in energy consumption. The U.S. energy consumption by source and sector is shown in Figure 2. The energy consumption by sector shows that 26.9% of the energy consumed in the U.S. is used for transportation purposes. Of this 26.9%, 92% comes from petroleum, while 3% comes from natural gas and 5% comes from renewable energy sources. Therefore, the majority of the energy used in transportation is non-renewable. This makes transportation a large sector to see improvements in energy consumption. Additionally, 71% of petroleum is used in transportation, meaning that increasing the efficiency of energy usage in transportation would decrease the overall petroleum consumption by a similar margin.

The projected fuel economy of various electrified vehicles is shown in Figure 3. As the degree of electrification in the vehicle increases, the fuel economy increases. However, for the vehicle to have an increase in fuel economy, it has to be designed properly. Battery modeling was divided into three subsystems, electrical, thermal and aging. Electrical models predict the battery voltage and state of charge. Thermal models predict the battery temperature. Aging models predict the loss in capacity and increase in resistance.

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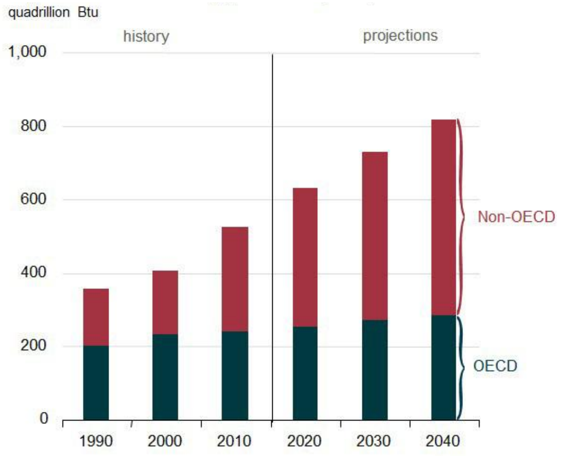

Figure 1- World Energy Consumption (results from "eia")

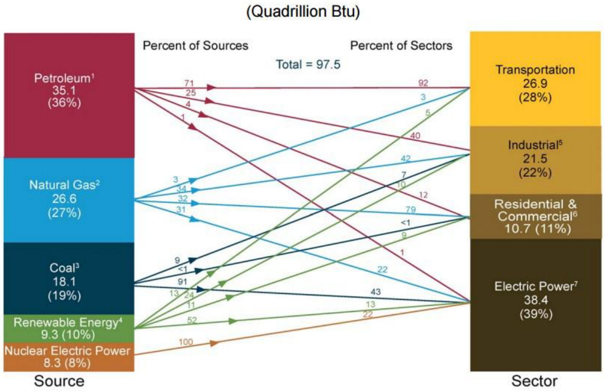

Figure 2- US Energy Consumption for Source and Sector

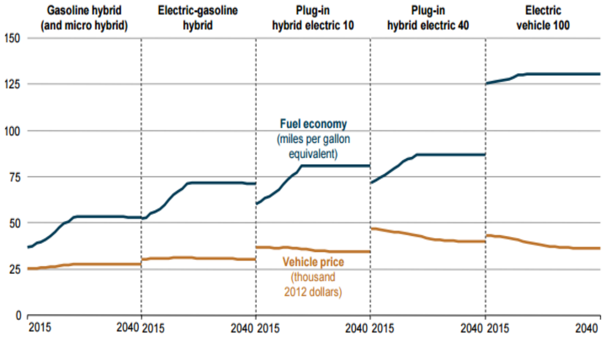

Figure 3- Fuel Economy Prediction of Hybrid Vehicles

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–WBCSD, 2004b Mobility, 2030]. 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,2008]. Significant fuel economy improvements in road transport are required to stabilize and eventually decrease greenhouse gas emissions from the transport sector. 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). 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 emissions 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 largescale hybridization of major vehicle markets can double efficiency in these countries by 2030. Even if vehicle kilometers 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 gig atone (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]. 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].

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.[6]

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.

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 CO2 emissions from fossil fuel combustion.

Hybrid electric vehicles, along with other cleaner vehicle technologies, are increasingly on the list of options. A 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. In addition, HEVs are not necessarily fuel specific; this technology is versatile and can be applied to CNG, diesel, and flexi fuel vehicles.

The main difference between the technologies considered is in fuel consumption and the resulting emissions of carbon dioxide (CO2). 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 CO2 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. 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.

Together with systemic improvements in traffic management, the increased use of non-motorized

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1.Cars, minivans, SUVs

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].

3. The technology required to improve efficiency of vehicles 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_3384443 0_1_1 1_1_1,00.html; In this document 'OECD' and 'non-OCED' is used to designate industrialized versus industrializing/rapidly industrializing countries.

5. In 2008 there were 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 an 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 Mobility, 2030].

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

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.

Cleaner Vehicles: Improving Efficiency, Reading 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.

Vehicle Fuel Efficiency & The Role of Hybrid Technology

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. 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 used, the quality of the fuel, vehicle maintenance, and driving conditions all play a role. 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 are also options; 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.

Structures of A Fuel Cell Hybrid Electric Vehicle

Introduction

Battery electric vehicles (BEVs) are powered by electricity stored in large batteries within the vehicles. These batteries are used to power an electric motor, which drives the vehicle. This system allows BEVs to operate with zero emissions at their point of use. Most new BEVs also use ‘regenerative braking’, which allows the electric motor to act as a generator in order to re-capture energy that would normally be lost through heat dissipation and frictional losses – this improves energy efficiency and reduces brake wear. BEVs benefit from the high levels of torque found in electrical motors as well as smooth gearless acceleration and deceleration. BEVs have no emissions at point of use and operate in almost complete silence, except for noise from the tyres. All of these factors make them ideal for inner city and urban usage. Although BEVs produce zero emissions at point of use, the source of the electricity must be taken into account when considering the wider scale environmental benefits; if renewable energy is used then electric cars can offer a much-reduced environmental impact over other vehicle technologies. A short summary of the main advantages and disadvantages of BEV technology include:

Advantages

- Zero emissions at point of use
- Torque and smooth response suited to urban driving
- Cheap to run
- Quieter operation

Disadvantages

- High capital cost (some companies like Tesla, Chevrolet and BMW produce cars with reasonable costs)
- Limited range in comparison with conventional cars
- Limited speed
- Slow recharge rate and limited dedicated quick recharge facilities
- Emissions can simply be transferred to production sources

Technology Details

Battery electric vehicles (BEVs) are powered by either a large electric motor connected to a transmission, or smaller electric motors housed within the wheel hubs. The energy used to power these motors comes exclusively from battery packs housed within the vehicles that must be charged from an external source of electricity (for smaller vehicles a household socket is a sufficient source).

The two types of BEV are illustrated above. As can be seen the two types are very similar, the key difference is the positioning and size of the electric motors. The central motor type is currently more common as it works on tried and tested principles of car design. It is also more suited to larger vehicles in which the motor must be quite powerful. The hub motor type, however, can avoid many of the transmission losses experienced in the central motor type but, at the current time, is more suited to smaller vehicles due to the power requirements of larger vehicles and as such is a less regularly used technology. BEVs also, usually, incorporate other technologies, which reduce energy consumption. For example, regenerative braking, which allows energy that would otherwise be wasted as heat during braking to be recycled back into the electrical storage system. This improves the overall efficiency of the car and can significantly improve the range of the vehicle. Another example is that because of the nature of electric motors, no energy is consumed when the vehicle is at a standstill, thus conserving energy further.

Battery Types

There are a number of rechargeable battery technologies that have been used or are likely to be used in the future for hybrid and electric vehicles. The principal technology types are described briefly below, with table 1 providing a summary of their performance characteristics.

Battery Technologies

Lead acid (Pb-acid)

Lead-acid batteries are the oldest type of rechargeable battery and have a very low energy-to-weight and energy-to-volume ratio. These factors mean that lead acid batteries take up significant amounts of space within vehicles and add significant amounts of weight. However, they can maintain a relatively large power-to-weight ratio and are low cost making them ideal for use in road vehicles.

Nickel Cadmium (Ni-Cd)

Nickel Cadmium give the longest cycle life of any currently available battery (over 1,500 cycles) but has low energy density compared to some other battery types. Cadmium is also toxic – a hazard to both humans and animals, so its use (mainly in domestic applications), is being superseded by Li-ion and NiMH types, in part forced by EU legislation.

Nickel-Metal-Hydride (Ni-M-H)

The Nickel Metal Hydride battery technology is similar to a NiCd battery in design, except cadmium is replaced making it less detrimental to the environment. NiMH batteries can also have 2-3 times the capacity of an equivalent size NiCd, with much less significant memory effect. Compared to lithium-ion batteries, energy capacity is lower and self-discharge is higher. Applications include hybrid vehicles such as the Toyota Prius, the Toyota RAV4-EV all-electric plug-in electric car, and consumer electronics.

Lithium-ion (Li-ion)

The relatively modern lithium-ion battery technology has a very high charge density (i.e. a light battery which stores a lot of energy). Current limitations include volatility, the potential for overheating, high cost, and limited shelf and cycle life. The technology currently has widespread use in consumer electronics (e.g. mobile phones) but has only recently begun to be used in transport applications (e.g. the Tesla Roadster electric car and in Prius conversions to a plug-in hybrid). General motors and Toyota are now also moving towards using more Lithium-ion batteries.

Li-ion polymer

This is a similar technology to Li-ion, but typically has slightly lower charge density, greater life cycle degradation rate and an ultra-slim design (as little as 1 mm thick). Disadvantages include the high instability (see the glossary (Appendix 4) for further information) of overcharged batteries and if the battery discharges below a certain voltage it may never be able to hold a charge again.

Sodium Nickel Chloride (Na-Ni-Cl)

Sodium Nickel Chloride, also known as the Zebra battery, belongs to the class of molten salt batteries. These use molten salts as an electrolyte, offering both a higher energy density, as well as a higher power density making rechargeable molten salt batteries a promising technology for powering electric vehicles. However, the normal operating temperature range is 270–350 c·, which places more stringent requirements on the rest of the battery components and can bring problems of thermal management and safety. Furthermore, there are also significant thermal losses when the battery is not in use. The higher the energy density the further the distance that vehicles can travel and therefore a breakthrough in the batteries' energy to weight ratio could increase the marketability of battery electric vehicles.

Rechargeable batteries typically self-discharge more rapidly than disposable alkaline batteries (up to 5% a day depending on temperature and cell chemistry). Modern lithium based batteries however, show improvements in this respect. Battery lifetime should be considered when calculating the cost of ownership as batteries wear out and need to be replaced. This rate depends on a number of factors such as how often the vehicle is used and how much it is charged and discharged. The vehicle manufacturer will be able to advise how best to look after the battery to extend its life.

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, 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. 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 but in that exact time, it goes upper than 2 million [EDTA, 2008]. This growth is increasing very fast and companies' production is more than 5 million in 2017.

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 absorbers are an energy efficient and cleaner vehicle option. 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 turnover 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

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 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[7] 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 principles 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,[8] whereas a retrofitted CNG bus can use anything between 10-40% more energy. particulate matter, NOx and HC, rather than increased energy efficiency.

Comparison of CO_2 & 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.

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

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

However, with the use of advanced emission control technologies. Therefore, the main benefits associated with CNG buses include reduction of pollutants such as particulate matter, NOx and HC, rather than increased energy efficiency. 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 CO2 than an engine in a conventional vehicle. However, all HEVs today require emission control technologies (e.g. catalysts) in order to meet emission standards. 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. 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.

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. 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. 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.

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 km. 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 km. Under average conditions, half of the vehicle kilometers driven by a PHEV could be driven on battery power alone with a range of 50 km.

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.

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.[9] 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:

1.An expensive fueling infrastructure must be set up for producing, transporting, and storing large quantities of hydrogen.

2.The production of the hydrogen requires a lot of electricity, making hydrogen more expensive (and perhaps more unsustainable, depending on electricity production) than the fuels it would replace.

3.The vehicle fuel cell is expensive technology- a regular saloon car fitted with a fuel cell costs about 1 million USD.[10]

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 expected to reach the mass market in the next few years 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].

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.

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 principle, Mechanical and electrical drive trains can be connected with each other,[11] 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.[12]

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.

3.1 Fuel Quality Requirements

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.

3.2 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.[13] 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 (low weight per power discharge ability; kW/kg).[14] The first generation of 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[15] 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 - 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.[16]

But recent battery technology development has made that debate outdated as battery development has moved away from lead acid and nickel cadmium batteries. Lithiumion 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.

Technical Infrastructure & 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 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.

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. With growing HEV use, care expertise will eventually be performed by conventional auto shops.

Hybrid Electric Vehicle Modeling

Modeling is extremely important for the system level design of vehicles, including hybrid-electric vehicles. Modeling typically reduces the cost and overall time associated with the design process. Simulators can be modified and used for comparison purposes much easier and quicker than prototypes. For these reasons, vehicle modeling and simulation is a tool that is utilized by many research organizations and companies to design vehicles. As early as 1997, computer simulations were used to predict maximum acceleration and fuel economy measures over various drive cycles [Wasacz, Bryon, 1997].

The simulator was designed to be modular, meaning that each component, such as the engine or transmission, is contained within a single subsystem with only that component. This allows a single component to be changed easily and without impacting other components in the simulator. The individual models of the components are energy-based, so that the individual dynamics of components are assumed negligible as compared to the entire vehicle. In this simulator, a driver with a throttle was modeled, similar to a human driver and an accelerator pedal. This forces the driver to change the speed of the vehicle in accordance to a desired velocity profile, as opposed to calculating the loads on the drivetrain given the speed. The simulator now must take corrective action if it falls off the desired velocity trace, similar to a real-world driver controlling an actual vehicle.

This style of simulator that uses a driver and torque requests to determine speed is called a 'forward' simulator. This differs from a backwards simulator that constrains the vehicle speed to a given cycle, which by doing so doesn't incorporate the system dynamics into the model.

Once developed, vehicle simulators can be used in many stages of the vehicle design process. One common use of vehicle simulators is to analyze a

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9 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]

10 Technical costs and challenges [UNEP, 2006] 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]

11 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

12 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.

13 http://lcinitiative.unep.fr

14 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 doubled to 1 800 W/kg.

15 The 2008 version of the Toyota Prius has a NiMH battery with a weight of 39 kg (Toyota 2008) [Toyota, 2004].

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

specific component in the vehicle powertrain. A study was performed that analyzed the impact of an electrically-variable transmission (EVT) on the vehicle powertrain, as compared to conventional and parallel HEV vehicle configurations [Holmes, Alan, 2000]. This study used the different transmission models combined with control strategies suited for each powertrain configuration to show significant improvements in fuel economy using an EVT. Another common use of vehicle simulators is in control development. This requires the models produce accurate outputs, yet also run fast enough to be implemented in real-time. In 1997, a vehicle simulator was used to develop a supervisory control strategy using neural networks and fuzzy logic [Baumann, Bernd, 1997]. In 1999, an approach to determining an optimal control strategy focusing on energy management was developed using dynamic programming [Brahma, Avra, 1999]. This tool determines the optimal power output of components, such as the engine or electric machine, to achieve a certain goal, such as minimizing fuel consumption. In 2004, an optimal control strategy for a known vehicle cycle was developed using Pontryagin's minimum principle, and then adapted to be used when the future drive cycle isn't known [Wei, Xi, 2004]. In 2009, Lorenzo Serrao implemented and compared three optimal control strategies, dynamic programming, Pontryagin's minimum principle, and equivalent consumption method, using energy flow through a vehicle simulator [Serrao, Lorenzo, 2009].

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 CO2 reductions in personal mobility. Encouraging hybridization of vehicle fleets through enabling policies and incentive structures can serve to lower both conventional and CO2 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.

The benefits of Electric Hybrid Vehicles:

1. Their fuel saving is about 38% in the city and 20% on the highway in comparison with conventional vehicles and 40% to 60% less than conventional vehicles for PHEVs.
2. However, HEV emissions vary by vehicle and type of hybrid power system, but they are often used to offset fleet emissions to meet local air-quality improvement strategies. PHEV emissions are lower than HEVs, because they are driven on electricity some of the time.
3. HEVs cost $0.05 to $0.07 per mile in fuel, compared to conventional vehicles, Which cost $0.1 to $0.15 per mile in fuel. This cost is going lower for PHEVs and it's $0.02 to $0.04 per mile in fuel, when running on electricity.
4. HEVs can fuel at gas stations or public fueling sites and it is possible at even home for PHEVs. [Serrao, Lorenzo, 2009]

In order to reach the global CO2 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. The increasing rate of producing HEVs shows that the companies change their view and they consider the profit of producing HEV, EV and FHEVs for their customers and environment (Figure 4).

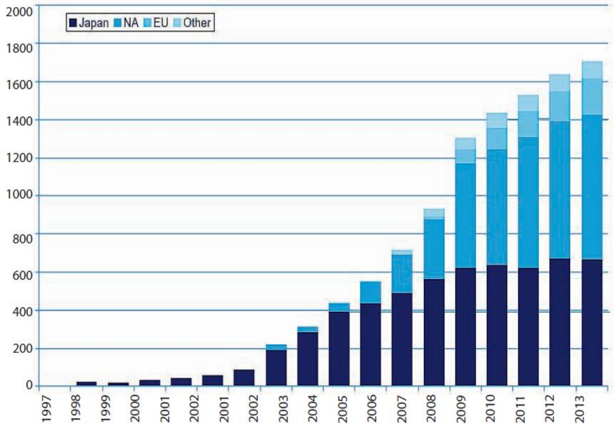

Figure 4- Global Hybrid Vehicle Assembly by Region 1997 - 2014 (thousands). An October 2007 Prognosis of the future global hybrid vehicle production [Wei, Xi, 2004]

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The National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy; NREL is operated by the Alliance for Sustainable Energy, LLC. DOE/GO-102011-3386 • October 2011.