Hybrids for road transport

Status and prospects of hybrid technology and the regeneration of energy in road vehicles

Technical Report EUR 21743 EN

Executive summary

This report analyses the status as regards hybrid technology and regeneration of energy in road vehicles and investigates the potential of hybrids in the medium and long term. The main goal is to present up-to-date information concerning the techno-economic characteristics of hybrid technologies, their potential areas of application and the outlook as regards the future evolution of efficiency and costs.

The analysis explores four main dimensions that characterize hybrid technology:

- The energy saving aspects of hybrids and the factors that affect fuel efficiency and emissions;
- The economic aspects of hybridization, including the cost of the required components, the resulting cost of use, and the market potential
- Life cycle issues of the technology with respect to its differences from conventional vehicles
- Technological issues, namely the possibility for synergies with fuel cells, the strategies of car manufacturers and a review of hybrid models available at the market.

<u>Energy saving aspects</u>

In conventional vehicles, energy losses from braking can reach up to 46% of all tractive losses. Hybrid vehicles can capture part of the braking energy, store it and use it to provide traction through an electric motor. In addition, hybrids allow a more efficient operation of the main power source and the reduction of idle operation. Engines are designed to meet high levels of peak power for acceleration, but are normally operated at only a small fraction of that power, where they are quite inefficient. A hybrid vehicle can reduce the associated energy losses by using the electrical storage device to either absorb or increase the output of the engine, allowing it to operate at speeds and loads where it is most efficient. Since part of the propulsion power for the vehicle is provided by the electrical storage device, the main power source (internal combustion engine- ICE) of the vehicle can be downsized, both in dimensions and weight. Downsizing also allows the engine to be run at a higher fraction of its rated power, generally at higher efficiency. Furthermore, the reduced weight of the engine has also a positive impact on fuel economy. The factors that influence fuel efficiency in different hybrid combinations are summarised in table 1.

Table 1: Factors of fuel efficiency in different hybrid combinations

Factor	**Series**	**Parallel**	**Mixed**
Optimised ICE-operation	+++	+	++
Regenerative braking	Only possible on driven wheels		
	++	F ++ / M +	++
Downsizing ICE	++	F +++ / M +	+++
Auxiliary power from battery	++	++	++
Conversion losses	---	-	--
Additional weight	---	F: -- / M: -	--
Flexibility in strategy	-	+	++

F: Full hybrid M: Mild hybrid

Hybrids can already provide significant energy savings, but still not sufficient to compete with conventional technologies and especially diesel. Especially for parallel hybrids, there is still room for further improvements in internal combustion engine efficiency, batteries and increased power electronics efficiency.

Economic aspects and market potential

The ‘marketing mix’ of hybrids is a combination of fuel economy (low cost of use), low emissions (environmental friendliness), modern design (fashion) and fast acceleration/ high maximum speed (performance). This comes at a cost, translated as a higher price compared to conventional gasoline or diesel cars, but the improved fuel economy can pay back a part or the whole of it. User choices depend on cost (purchase, use, maintenance, etc.), performance, reliability, safety, resale value, lifestyle, fashion and numerous other parameters than in most cases cannot be quantified or compared in an objective way.

At present, the higher purchase price, the lower expected resale value and the decreased fuel efficiency advantage outside urban areas lead hybrids to a weak competitive position in terms of overall cost per km driven. Both gasoline and diesel are cheaper options for most market segments and therefore currently dominate the market.

The projections for the future are more optimistic. If industry expectations prove right and hybrids achieve the price and efficiency targets identified in the survey, they will be close to diesel by around 2010 in terms of cost and will start to be competitive, especially in the medium segment for mainly urban driving. At that point hybrids will also make sense in terms of CO_2 reduction cost-effectiveness, since the cost difference with a comparable gasoline car will correspond to about 110 €/tCO_2. The reduction of usage costs after 2010 is expected to be slower, since the shift to full hybrids will be relatively more expensive compared to the benefit it will provide to the user (see Figure 1).

Updated information on fuel efficiency, costs and expectations for the future was collected and compared with the respective data and projections for other conventional and emerging technologies. This information was used, taking into account the different types of users, transport activity, urbanisation level and user preferences included in the IPTS Transport Technologies Model[1], to estimate the potential market share of hybrids (see Figure 1).

Even though hybrids have attracted a lot of attention and Toyota Prius is already in its second generation, the projections suggest that hybrids are not expected to reach a 2% market share before 2007 or 2008. As with all new technologies, an S-curve market penetration can be expected, that according to the baseline projection could lead to a 6% market share in 2010 and slightly above 12% by 2020. Increasing oil prices would certainly favour hybrid penetration in the long term. If prices, however, exceed US$ 80 per barrel, and if industry expectations prove right, fuel cells become competitive and start entering the market by 2020.

In terms of overall fuel consumption savings in EU-25, the impact from the simulated market uptake of hybrids was compared with the impact if no hybrids enter the market. Improvements in conventional technologies are expected to stabilise total demand around 170 Mtoe for the next 10 years, but they will be probably not enough to balance the expected increase in transport demand afterwards. Hybrids can extend the period of stabilisation by about 5 years, and at least limit the growth rate of fuel consumption after that. In terms of CO_2 emissions, these projections would correspond to 486.9 million tons in 2020 from passenger cars in the case of conventional cars only, while -with hybrids- emissions would be limited – in line with fuel consumption- to 468.9 Mt (see Figure 2).

Figure 1: Potential market share of hybrids in EU-25

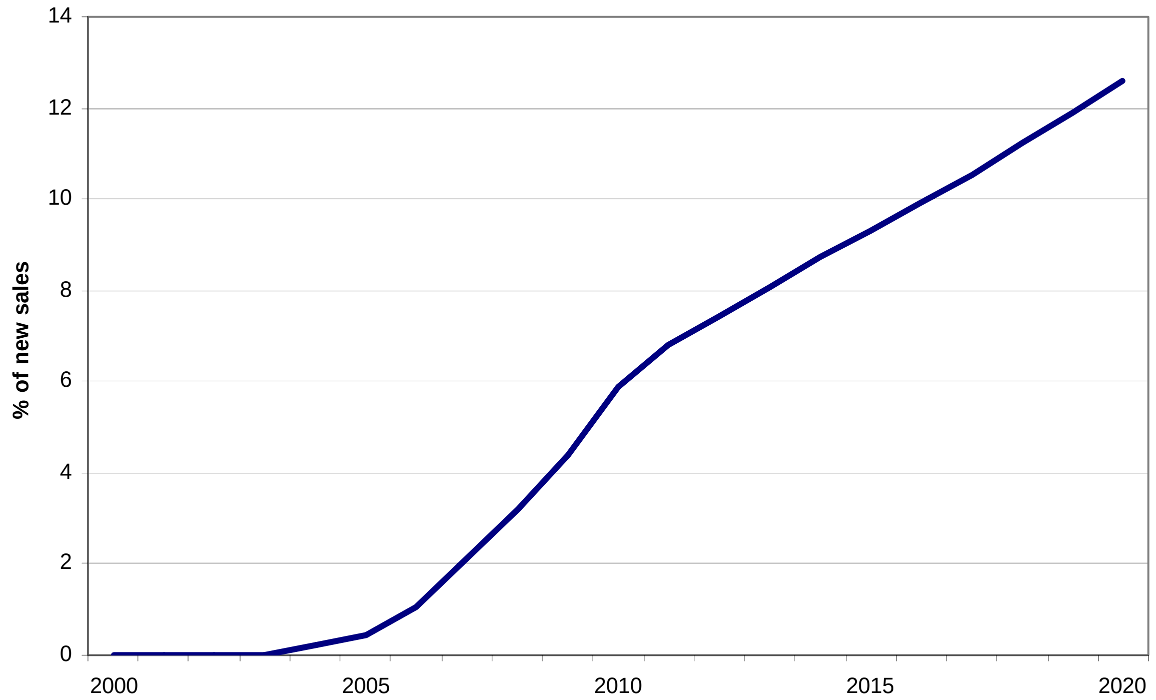
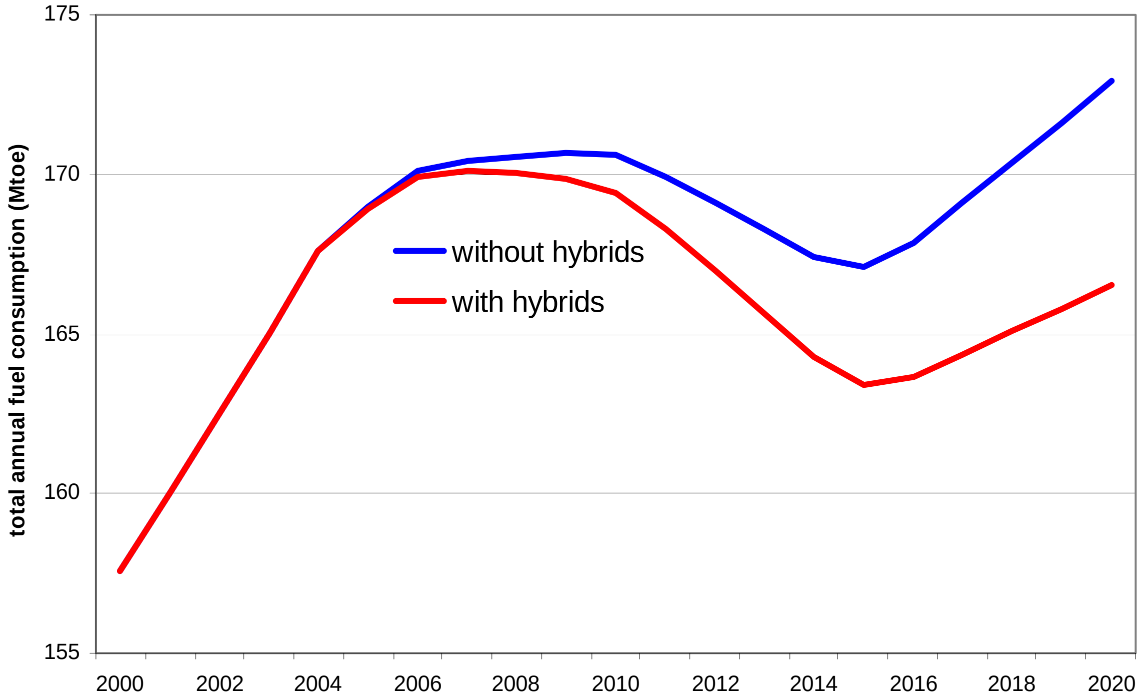


Figure 2: Projected impact of hybrids on future fuel consumption in EU-25

[1] European Commission, Joint Research Centre, Institute for Prospective Technological Studies, “Dynamics of the introduction of new passenger cars technologies: the IPTS Transport Technologies Model”, Technical Report EUR 20762, Sevilla, June 2003.



total annual fuel consumption (Mtoe)
175
170
165
160
155
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
without hybrids
with hybrids

Life cycle analysis

The analysis of the amounts of materials used compared to their world reserves showed that we should not expect major shortages in the supply, but cost may become an issue. The increase in demand for metals used in non-lead batteries may be difficult to meet, and may lead to price increases. Several of these are by-products of mining non-ferrous metals and occur in rather low concentrations. Turning them into the main product of mining and smelting could prove expensive. The production of different battery technologies in parallel may lift some of the strain if they are based on different critical resources.

At present the NiCd, Ni-MH and Li-ion battery recycling techniques are still in their infancy. However, recently work has started towards such schemes by individual companies and larger consortiums. Furthermore, the European Battery Recycling Association (EBRA) has recognised the need to work towards an established system of advanced battery dismantling, disposal and recycling. The recycling issue is important also in the respect that Europe is a net importer of all of the critical materials, and recovery of the recycled streams to supplement the use of virgin material is important in terms of lowering the dependency on imports.

The life cycle of battery components can lead to discharges of toxic materials. These will increase drastically for the metals involved in batteries should there be a significant penetration of the market by these vehicles. On the other hand if lead-acid batteries used nowadays are reduced in size or phased out, there will be an offset in the impacts arising from their life-cycle. These however are issues that have to be examined with relation to specific pathways and should be the object of targeted Life Cycle Assessments.

The production of hybrid vehicles is more energy intensive. While this increase in energy demand, in the production stage, reduces the energy and CO_2 reduction benefits arising from the fuel economy over the life cycle of the vehicle, it is not large enough to outweigh them.

Technological issues

There are several uncertainty factors that influence the potential of hybrids and other technological options, and the impact of their introduction. Such factors include the technical and economic characteristics of each available technology, fuel prices, environmental limits, legislation, and manufacturers' strategies. Although hybrids are promising from the technical point of view, their market potential is questionable if no specific measures to support them are taken.

The situation as regards hybrids in Europe is awkward; policy makers are looking for a long term technological solution to decrease fuel consumption, CO_2 emissions and pollutants, and introduce stricter emission limits while investigating the options for the transition to hydrogen-based technologies in the long term. European car manufacturers respond to the market's need for high performance and less polluting cars by investing in diesel technologies. Japanese manufacturers are seriously investing in hybrids, aiming to capture what they see as a promising market segment, while US car manufacturers are starting to use hybrids to disguise the environmental impacts of the *Sport-Utility Vehicles* (SUVs) that consumers want.

Japanese hybrid models available in Europe have captured only a small segment (<0.5%) of total sales, while diesel cars have surpassed 50% of new registrations in many countries. In fact some European automakers tend to ignore or dismiss hybrid technology as an overly complicated half-solution that introduces extra weight and hampers performance. Instead they tend to favour diesel technology improvements and fuel cell research as the way forward. In their view hybrids are only an interim measure, filling the gap until fuel cell cars become available. In this respect, they claim that similar results can be obtained by improving diesels and giving them and even bigger share of the fleet, while intending to introduce fuel cells vehicles the soonest possible.

Conclusions

The outlook for the technological development and the costs of hybrids looks positive, but it is still too early for them to become a mainstream technology. According to both manufacturers and researchers, the efficiency of hybrids is expected to improve significantly while the costs of manufacturing are expected to fall significantly in the next 5-10 years. In fact, the most advanced hybrid model in the market, the Toyota Prius, has been voted 'Car of the Year 2005', as a sign of recognition by journalists covering the automotive world of the innovation that hybrid technology can bring. However, economies of scale in manufacturing and improvements in battery size, life and cost will still be necessary in order for the technology to be competitive in the market.

The additional car components required for hybridisation can raise the price of the vehicle by 15-20%, a cost that can still not be justified by the fuel savings they bring. The expectations for the future are more optimistic; fuel efficiency can still increase while the cost of the components can decrease as the technology matures and economies of scale are achieved. There are a few technical limitations that have to be overcome first, namely related to the capacity and durability of the batteries and, as all new technologies, the long term reliability of hybrids has to be demonstrated. Those technical, economic and reliability factors limit the short term market potential of hybrids. The analysis of the information available today suggests that they will start to be competitive against conventional gasoline and diesel technologies in Europe only after 2010.

Even when hybrids do become competitive, their improvements in terms of fuel efficiency will not suffice to counterweight the impacts of the increasing transport demand. Even if both conventional and hybrid technologies improve their fuel efficiency according to expectations, the total demand for fuel and the resulting CO_2 emissions will keep growing in EU-25. Hybrids could thus serve as a medium term solution mainly, in order to slow down the trends until a more efficient technology, ideally fuel cells, is mature.

In relation to other environmental impacts, hybrids rate very well in terms of pollutants (NO_x, CO, PM, etc.), while their main disadvantage could prove to be the increased demand for materials required for the production of their batteries, as the substances involved come from limited resources and could also be toxic if released to the environment. In fact, the hybrids' advantage in terms of local pollution is the main driver for their introduction in California, where strict emission limits apply. But it is still questionable whether users would be willing to pay a higher price for a cleaner technology, unless regulation or subsidies are present.

The technological choices in Europe in order to improve fuel efficiency and environmental performance in road transport seem to be favouring improved diesel technology, at the cost of hybrids. Although hybrids are expected to be cleaner and more efficient than improved diesel vehicles, diesel is still the most cost efficient option. In addition, diesel is a proven technology and the European car manufacturing industry has a vested interest in it. This can partly explain the fact that European manufacturers seem to be indifferent to hybrids and virtually offer no hybrid options.

Hybrids could also play a role in the transition towards hydrogen and fuel cells. Depending on the speed of development of fuel cells and on whether hydrogen- internal combustion engine combinations will be necessary in the development path, hybrids can be an important supplementary technology. Whichever the path of fuel cell development will be, the expected improvements of hybrid technologies seem to be sufficient to prepare the ground for efficient fuel cells after 2020.

Seeing the development of hybrids in the context of developments in conventional and fuel cell technologies, it can be concluded that hybrids will probably not find room in the European market as a stand-alone technology. They will have a role though as a ‘bridge technology’, first in the form of mild hybridisation of conventional vehicles and –in the long term- as a supplementary technology to fuel cells to allow energy regeneration.

Concerning the policy implications, there is a need to set-up stable policy objectives, sending clear messages to the stakeholders. Regarding the issue of fuel efficiency and its repercussion on policies addressing security of energy supply and global warming, it seems that an adequate pricing scheme would be sufficient for the market to select the most cost-effective option. The situation would be different for policies addressing air quality, where intervention can have the form of stricter emission limits or subsidies. Depending on the specific local conditions, such measures could be cost-efficient in the case of hybrids and could be an option to be considered by policy makers at that level.