

## Hybrid and electric vehicle development

The automotive industry continues to move towards offering ranges of cleaner vehicles against a background of difficult economic conditions. Hybrid vehicles are now a reality on our roads, and electric vehicles will be more present on manufacturers' assembly lines, accompanied by many announcements of public and private fleet deployment. At this time of pivotal changes, we assess the development of these new vehicles from the technical viewpoint, and explore their prospects in the market.

The electrification of mobility, especially on our roads, now seems one possible route to engaging in a medium- and long-term response to the two major challenges facing the road transport of people and goods: a drastic reduction in greenhouse gases (GHG) emissions and a reduced dependency on oil.

### A hybrid for everyone

As more and more hybrid vehicles enter the market, and every manufacturer offers at least one hybrid model, this may be an appropriate point to remember that there is no such thing as a standard hybrid vehicle or indeed a single level of hybridisation.

A hybrid vehicle is a vehicle that uses more than one type of propulsion. The most common hybrid vehicles at present are those powered by a gasoline-fuelled internal combustion engine and an electric motor, but it should be borne in mind that hybridisation may involve the use of all types of fuel, from gasoline and diesel to biofuels, natural gas and LPG. This fact means that the advantages of hybrid drive can be combined with the benefits delivered by these fuels in order to achieve impressive CO<sub>2</sub> and local pollutant levels. The first diesel-electric hybrid vehicle — the Peugeot 3008 HYbrid4 — has just been launched into the market.

Multiple degrees of hybridisation are therefore possible, and depend on the ratio between the power of the internal

combustion engine and the power of the electric motor used to propel the vehicle.

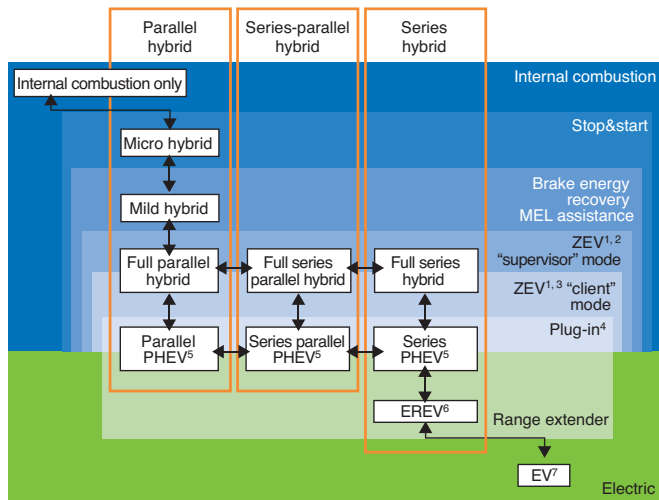
The first stage of hybridisation is the addition of a simple stop&start system: designed to shut down the internal combustion engine and restart it very quickly, this system is ideal for urban journeys. Next come the "mild hybrid" solutions that introduce brake energy recovery, and "full hybrid" configurations, which, in addition to "zero emission" operation in all-electric mode, can also — in some cases — be recharged using electricity or an external power source. These are the rechargeable or "plug-in" hybrids now emerging from manufacturers. In theory, increasing hybridisation delivers higher fuel economy, but is usually accompanied by higher costs. Lastly, at the end of the chain, comes the culmination of the electrified vehicles concept: the all-electric vehicle.

All these types of vehicles are generally grouped into three major hybrid vehicle families (Figure 1):

- the parallel hybrids, which are the most common, and include the Honda Insight (Figure 2). With two power sources, one electric and the other internal combustion, these vehicles use both sources for motive power and adjust the operation of each to achieve maximum efficiency. The other benefit is that these vehicles are not very different from conventional vehicles, and therefore need relatively few adaptations. On the other hand, the opportunities for exploiting hybridisation are more limited than with other types of hybrid;

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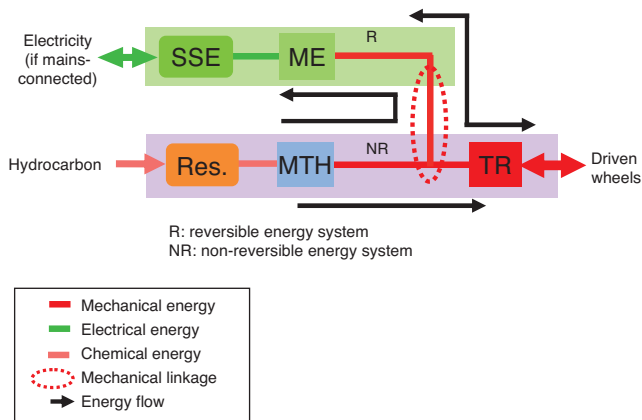
Fig. 1 – Hybrid and electric vehicle families



- (1) ZEV: Zero Emission Vehicle
- (2) ZEV "supervisor" mode: ZEV mode managed solely by means of power plant control to optimise fuel consumption
- (3) ZEV "client" mode: ZEV mode activable by the driver
- (4) Plug-in: Mains-rechargeable batteries
- (5) PHEV: Plug-in Hybrid Electric Vehicle
- (6) EREV: Extended Range Electric Vehicle
- (7) EV: Electric Vehicle

Source: IFP Energies nouvelles (IFPEN)

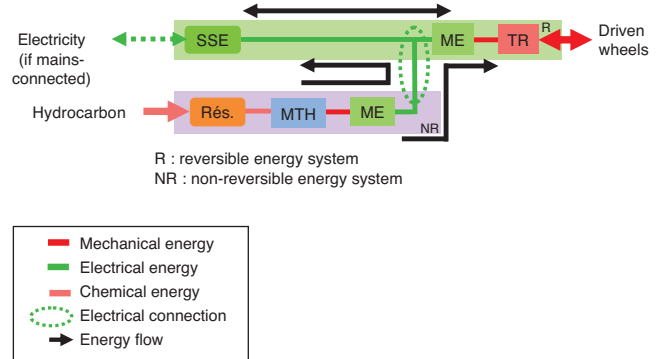
Fig. 2 – Parallel hybridisation



Source: IFPEN

in the series hybrids, which also have two power sources, only one of which – the electric motor – provides motive power (Figure 3). The ("range extender") internal combustion engine is used to recharge the vehicle's batteries and plays no role in propulsion. The main benefit here is that the internal combustion engine can operate at maximum efficiency independently of driver demand, but this arrangement requires the use of two electrical power sources (a generator and a motor) and a larger battery than that required by a parallel hybrid. Where this type of hybrid is also rechargeable, it may equally be referred to as a "Range-Extended Electric Vehicle" (REEV): examples include the Chevrolet Volt;

Fig. 3 – Series hybridisation

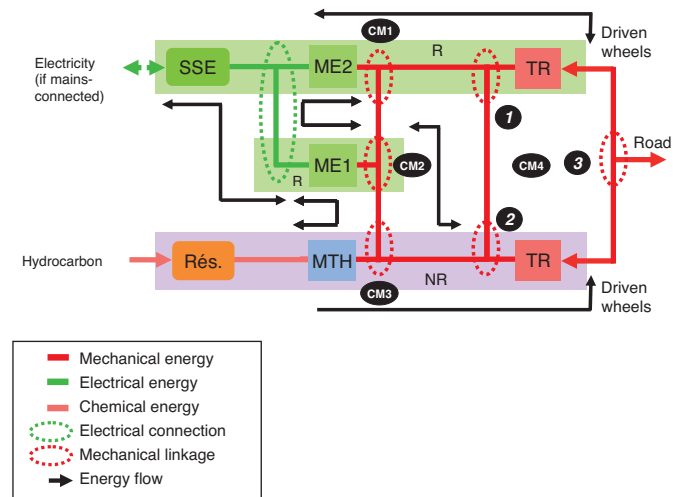


Source: IFPEN

in between these two, there are the series-parallel hybrids that combine features from both the previous families (Figure 4). The Toyota Prius is the perfect example of this type. This configuration is more complex, since it uses three energy systems and a series of possible electrical and mechanical connections between them.

Series-parallel configurations offer the greatest inherent potential for gain, since they make use of both types of hybridisation. However, to be successful, they must succeed in maximising the benefits of the series and parallel solutions, at the same time as minimising their drawbacks, which demands a great deal of attention when sizing components, in an arrangement where management and control are extremely complex.

Fig. 4 – Series-parallel hybridisation



Source: IFPEN

In conclusion, all these subtle differences provide today's vehicles with a level of flexibility that enables users to select their preferred hybrid on the basis of the performance required. High performance, high efficiency and absolute silence in city centres are all possible niche

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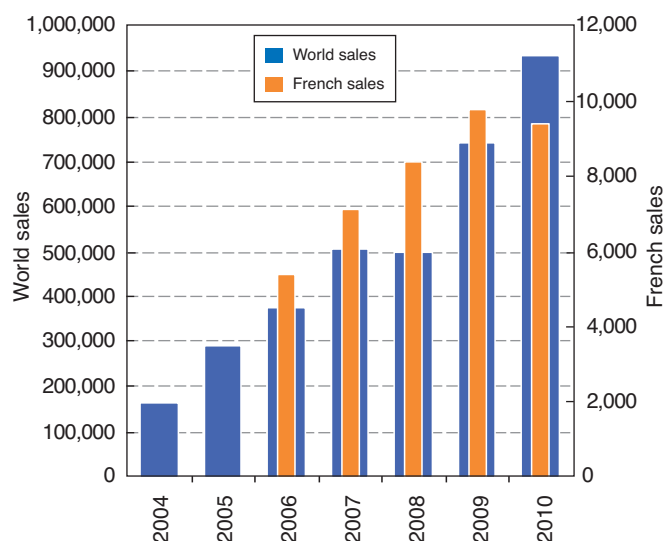
markets for these vehicles. All that is required is to size the various electric motors, internal combustion engines and batteries to suit the required application.

### A fluctuating market

Although the worldwide market for hybrid vehicles exceeded 940,000 units in 2010 (26% up on 2009), this trend covers a range of rather different situations around the globe. In France, sales of 9,443 units represented an almost insignificant increase over the figure for 2009. In the USA, sales trended sharply upwards in December 2010, with volumes 37% higher than those for November (Figure 5). This effect has been repeated since, with sales achieving monthly peaks in response to high fuel prices and the signs of economic recovery detected in the spring of 2011. At least, that was the case until the earthquake and tsunami threatened production and distribution of the many hybrid models produced in Japan. The hybrid market did not recover until October 2011, when production capacities were finally back on track.

However, despite logistical problems, Toyota still leads the market in terms of hybrid vehicle sales. This Japanese brand broke through the 3 million hybrid vehicle sales barrier in 2011, less than 21 months after selling its 2 millionth vehicle, whereas it had taken 10 years to sell the first million hybrid vehicles.

Fig. 5 – Hybrid vehicle sales worldwide and in France (2004-2010)



Source: CCFP, Automotive Innovation Platform

The market is accelerating not only in terms of sales, but also in terms of model availability. The most popular models are the Toyota Prius and Lexus CT 200h, the newcomer to the automotive landscape, which has shot straight to

the number 3 spot in terms of hybrid vehicle sales. Second place on the podium goes to the Honda Insight.

Rechargeable hybrid vehicles will be one of the new introductions of 2012. Four models (the Honda Fit, Volvo V60 Plug-in, BMW i8 and Ford C-Max Energi) will very soon join those rechargeable vehicles already available in the market, such as the Toyota Prius plug-in, Porsche 918 Spyder and Fisker Karma.

In electric vehicles, Chevrolet had sold only 5,000 of its Volt model by the end of October, despite forecasting sales of 10,000 units for 2011. The situation is a little more positive at Nissan, which has sold just over 8,000 of its Leaf model.

### What is the medium-term outlook?

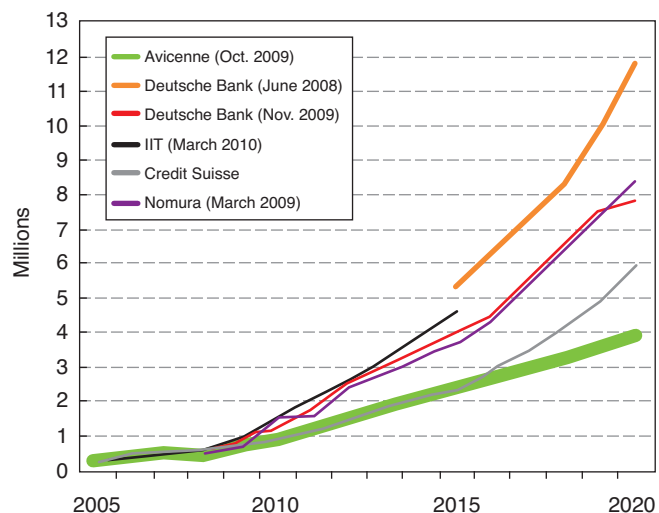
Looking to the future, the market for electric vehicles (whether hybrid or all-electric) remains very uncertain.

As far as hybrid vehicles are concerned, Figure 6 shows a series of recently-published scenarios, which illustrate a very broad range of possibilities. Currently approaching 1 million units, it seems likely that the market will exceed 4 million in 2020, but the most optimistic projections envisage as many as 12 million hybrid vehicles sold by this date, which would represent between 10 and 15% of the total automobile market. But behind these figures, it is important to identify the types of hybridisation and how they break down (the simple stop&start solution may become widespread much more quickly as a result of its low cost). It is clear that we are only at the beginning of the hybrid vehicle era, and that these vehicles offer great potential. The possibilities they offer for combining many different types of fuel, and their compatibility with today's dominant model of the multipurpose vehicle (where operating range is the key challenge), mean that they have the potential to establish themselves worldwide. The only downside is the fact that the additional cost of these vehicles remains high and that existing tax subsidies (a €2,500 bonus is offered in France) still seem difficult to do without.

The issue of all-electric vehicles is much more complex. The chicken/egg paradox is regularly heard in an attempt to explain the difficulties involved in kick-starting the market for electric vehicles. In practical terms, without recharging infrastructures, journeys are impossible, and therefore vehicles are not selling. And without vehicles on the road, no one wants to invest in these infrastructures. But for all manufacturers, the key barriers to development of this market remain: the need to improve vehicle range and the ability to offer vehicles that are financially competitive with traditional vehicles (the issue of battery cost).

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Fig. 6 – Scenarios for hybrid vehicle sales worldwide 2010-2020



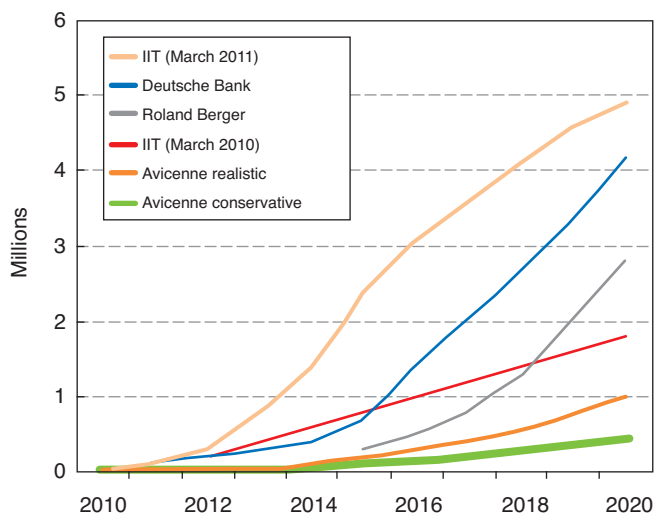
Source: Avicenne Energy, *The rechargeable battery market, past and future, 2011*

Nevertheless, there is no lack of manufacturer-driven initiatives. Chevrolet and Nissan have been offering electric models since 2011. Renault and Nissan hope to have sold 1.5 million vehicles by the end of 2016, and have invested €4 billion in this sector. The Renault Fluence ZE is now on sale, as is the electric Kangoo, and the brand with the diamond badge has won a contract to supply 15,600 of its electric vehicles to the French government, EDF, Veolia and La Poste. The remainder of this contract has been placed with PSA Peugeot Citroën (for 3,900 vehicles), with a further 3,000 being sourced from Bolloré, Ford and Heuliez Mia.

Ambitious as it is, the Renault-Nissan target provides a good illustration of the fact that the market for electric vehicles is likely to take off less spectacularly than that for hybrids, because the problems involved are very different.

Figure 7 shows that a market of between 1 and 2 million electric vehicles in 2020 would be a great success (and represent between 1 and 2% of the total automobile market) for a sector that is only at the beginning of its development.

Fig. 7 – Scenarios for electric vehicle sales worldwide 2010-2020



Source: Avicenne Energy, *The rechargeable battery market, past and future, 2011*

2012 is likely to be the year in which we see sales of rechargeable hybrid or plug-in vehicles really take off. By extending the vehicle hybridisation concept beyond on-board energy recovery, manufacturers can now offer large volumes of rechargeable hybrid vehicles and mains-rechargeable electric vehicles. With their offer of many different combinations of fuels and real operational flexibility, these hybrid vehicles are adaptable to all kinds of uses and capable of reaching all markets by offering significant reductions in greenhouse gases emissions, depending on the recharging method and the type of electricity involved. Lastly, in terms of electric vehicles, we have never before seen so many manufacturers preparing to launch so many new models (mostly vans) during the year. It will be interesting to see how this market takes off in a downbeat economic climate, but one where environmental concerns nevertheless remain.

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