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How is IFP rising to the challenge of low-carbon vehicles?

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Against a backdrop of volatile oil prices and climate change, the transport sector is faced with the dual challenge of diversifying energy sources and reducing fuel consumption as well as CO_2 emissions. These challenges can only be met by implementing a package of different technological solutions significantly cutting CO_2 emissions. Alongside the use of biofuels and the optimization of conventional powertrains, the gradual electrification of vehicles offers substantial potential in terms of optimizing energy management. Building on its expertise in the key areas of powertrain technologies, modeling, simulation and fuels, IFP is actively committed to research into low-carbon vehicles and is working in close partnership with industrial players.

Towards a complex and highly segmented market

What model of “low-carbon motorized mobility” can we hope to achieve in the short and medium terms? Not only do current lines of thinking relate to powertrains and energy sources but they also concern the way the transport sector is organized as well as changes in individual behavior. *“Only one thing is certain when it comes to the technologies”,* asserts Olivier Appert: *“there will be a range of diversified solutions, adapted to different market segments, from a technological and a regional point of view. There is no panacea. A single, universal model to meet every need for every market is a dream that must now be consigned firmly to the past. Solutions that are appropriate for the French market will undoubtedly be different from those aimed at the Brazilian, German, Italian and American markets”.* In some places, the vehicles in question will be designed for urban and city-center driving on the basis of local standards, while elsewhere the focus will be on a solution to meet the requirements of road haulage and captive fleets.

There are numerous potential configurations, starting with the primary useable energy sources: fossil fuels (oil, natural gas, coal), of course, but also renewable fuels such as biomass. These energy sources can be carried onboard vehicle in numerous forms (gasoline, gas oil, LPG, biofuels, synfuels and NGV). Where the two energy vectors – hydrogen and electricity – are concerned, they present the same advantages in terms of vehicle autonomy; *“but it will be at least 25 or even 30 years before hydrogen is widely used in the transport sector since there are a number of hurdles that still need to be overcome relating to production, distribution and onboard storage”,* specifies Olivier Appert. Finally, irrespective of what it happens to be, the onboard energy can be transformed within the vehicle into mechanical energy via different powertrain systems – internal combustion, as is the case with the majority of today’s vehicles, but also electric and hybrid solutions.

An array of electric vehicle solutions

“The current situation whereby 97% of vehicles are powered by an internal combustion engine using oil-based fuel is beginning to change”, observes Philippe Pinchon, Director of IFP’s Powertrain Engineering Technology Business Unit. “Although still marginal in terms of volume on a global scale, we are witnessing the significant development of biofuels and natural gas. And more recently, attention has turned to electricity. Over time, we will see an increase in the electrical power available on board vehicles for powertrain needs”.

There are numerous advantages associated with electric vehicles: no direct pollutant emissions, low noise emissions, highly efficient propulsion system, a variety of primary energy sources and potentially extremely low CO_2 emissions if the electricity is produced from renewable, nuclear or fossil energy with CO_2 capture and storage. Nevertheless, many technological barriers still remain, not least of which the batteries and their associated problems in terms of autonomy and cost. The other not inconsiderable challenge is to create the rapid recharging infrastructure so crucial to the development of a large-scale electric vehicle fleet; at the present time vehicles require between 8 and 12 hours to be recharged from the main-grid.

Between the current internal combustion vehicles and the all-electric vehicles mentioned above are the hybrid vehicles being developed using a range of solutions. Depending on their configuration and battery characteristics in particular, different models provide an electric autonomy of up to 150 kilometers but at an additional cost of around €18,000. The benefits in terms of reducing fuel consumption and hence CO_2 emissions depend on the degree of electrification: between 3 and 7% for *Stop&Start* models in which the IC engine cuts out immediately when the vehicle comes to a standstill and starts up again using the onboard electrical power of between 2 and 4 kW; 20 to 35% for *Full hybrid* models capable of operating on all-electric mode over very short distances of between 1 and 5 kilometers, using the onboard power of around 50 kW and the electric brake energy recovery system. For this configuration, the additional battery cost is estimated to be between €2,500 and €5,000. The final configuration under the spotlight is often presented as the second generation hybrid vehicle. These models – which can be recharged from the mains grid – could operate in all-electric mode in the urban environment for example and reduce CO_2 emissions for journeys of this type by between 50 and 90%, depending on the source of electric energy used.

Solutions offering variable benefits depending on the electricity source

In order to evaluate and compare the various solutions outlined above, we have to calculate the CO_2 emissions from production of the primary energy source to its use or 'from well to wheel'. More generally, these life cycle assessments (LCAs) carried out for a vehicle make it possible to measure its energy footprint, from raw material production and operating modes through to vehicle recycling processes. *"We have done this calculation for different configurations of hybrid and electric vehicles and compared the results with those obtained for a medium-sized diesel sedan weighing 1100 kg and emitting 130 g/km of CO_2 equivalent",* explains Philippe Pinchon. The findings: apart from when the electricity is produced from coal, as in India and China, in which case emissions actually increase, all hybrid and electric solutions are beneficial.
However, the improvement potential varies greatly depending on the source of the electricity. The lowest CO_2 emissions – less than 20 g/km - are obtained in France in the context of electricity generated by nuclear power, for an electric or hybrid vehicle that can be recharged using a second generation biofuel (ethanol in the case of this study). On average, in Europe, emission reductions of up to 50% are possible with electric vehicles. Where hybrid vehicles are concerned, the average reductions using the standard European test cycle are between 15 and 45% depending on the fuel used by the internal combustion engine, with natural gas outperforming diesel and gasoline.

What impact in terms of cost?

"We compared the costs associated with this medium-sized diesel sedan with those associated, on the one hand, with an electric vehicle with a range of 150 km and on the other hand with a rechargeable hybrid vehicle with an electric autonomy 25 km", adds Philippe Pinchon. These calculations were based on a battery currently costing 600 €/kWh, fuel costing 1.1 €/liter and electricity costing 0.1 €/kWh, including taxes. The results showed that it would cost twice as much to acquire an electric vehicle as an internal combustion vehicle – mainly due to the high cost of the battery – and that a hybrid vehicle would be 30% more expensive. *"Nevertheless",* he underlines, *"if we take into consideration running costs in terms of energy and maintenance, the difference in price falls back to 30% between the electric and internal combustion vehicle – roughly equivalent to the aid available to*

purchase such a vehicle – and the costs of the internal combustion vehicle and the rechargeable hybrid are identical". Moreover, if we manage to halve the cost of batteries, to 300€/kWh (the ambitious target set by manufacturers) and in the inescapable context of rising fuel prices (taken for the purposes of this study as being 1.5€/l on the basis of 150 dollars per barrel), the electric vehicle may ultimately become a viable competitor, comparable to the running cost of a rechargeable hybrid vehicle, provided the battery can be made to last for the duration of the vehicle's life.

Finally, the lowest additional cost (between €200 and €5,000) concerns hybrid vehicles, associated with reductions in CO_2 emissions that vary considerably - from 3% to 40%. The best performance is demonstrated by the *Full hybrid*, such as the 3rd generation Prius, which emits 89 grams of CO_2 per kilometer. Reductions of up to 90% can be envisaged with electric vehicles, provided that a low-emitting source of electricity actually exists, but the additional cost is high (between €15,000 and €18,000). Between these two solutions, rechargeable hybrid vehicles represent the best compromise.

Still much research and development work to be done

First and foremost, R&D efforts need to be directed at increasing the energy and power density and reducing the cost of batteries while ensuring optimum safety conditions. Lithium-ion and lithium-polymer represent real progress in terms of onboard power compared with lithium-metal-hydride batteries. But they are more expansive and raise a number of problems regarding safety. What's more, there are issues surrounding lithium reserves.

Research also needs to focus on improving the electric motor itself as well as various auxiliary components, such as air conditioning. Another key component is the vehicle supervisor, the central nervous system of the vehicle that manages onboard energy, powertrain systems, braking and communication between the various infrastructures. The point is that hybrid vehicle architectures are complex. Numerous operating modes are possible, from 100% internal combustion to 100% electric, via energy recovery during braking whereby the battery can be recharged when the vehicle is inert. The two powertrain systems (internal combustion and electric) can also be used at the same time, 'in parallel', to gain additional power. *"We're working on internal combustion engines that are far less powerful - and hence more fuel-efficient and less polluting – and for which additional power during some driving phases can be provided by the electric motor",* specifies Philippe Pinchon. The battery can also be recharged using the internal combustion engine while the vehicle is running. What's more, the internal combustion engine can also be used solely to charge the battery powering the electric motor driving the vehicle. This is known as 'series' architecture. Finally, as is the case with the Toyota Prius, it is possible to combine the two hybrid architectures, series and parallel.

Bringing electric vehicles to market more quickly

"The downside of these highly complex architectures is the length of time potentially required to take them to market", warns Philippe Pinchon. *"This is why we're devoting significant resources to speeding up the process of getting electric vehicles to market, in terms of both design using virtual models – in other words computer simulations – and test bench validation".* With this in mind, work began in 2008 to develop a semi-virtual test platform called HyHIL, in partnership with D2T, Renault, G2ELAB and LMS. A Predit labeled platform supported by the French Interministerial Fund (FUI) and the Mov'eo competitiveness cluster, HyHIL makes it possible to test an actual internal combustion engine, in the virtual hybrid vehicle environment, using real-time simulations of the powertrain components, from electronic control and batteries to vehicle – and even driver – behavior. The whole concept hinges around a much reduced design and development phase for new hybrid architectures. The platform also enables onboard supervisor software to be developed for the purposes of vehicle energy management, which is crucial to making the best decisions at all times –

on the basis of circumstances -, optimizing the battery charge, reducing fuel consumption and improving drivability.

With respect to batteries, IFP researchers have developed detailed operating simulation models, capable of predicting their lifespan and state of charge, as if they were being used in real conditions. These models have been validated on test benches used to simulate the operations of commercially-available batteries, of up to 500 amps and 500 volts, i.e. electrical power of 120 kW, at temperatures ranging from -40°C to +60°C. IFP has also developed battery calculator electronic control software making it possible to maintain battery lifespan.

Lastly, IFP is a major player in the Mov'eo DEGE R&D platform based at the Versailles Satory site. The purpose of this integrated experimentation and computing platform is to speed up the development and validation of hybrid and electric vehicles. It is supported by the Mov'eo competitiveness cluster and various industrialists (D2T, PSA Peugeot Citroën, Renault, Valeo) and brings together the major public players in the field (IFP, Inrets, Cetim and the University of Versailles Saint-Quentin-en-Yvelines). These testing facilities should make it possible to provide standardized qualification methods for the most critical components.

IFP's achievements in the field of hybrid vehicles

IFP has been involved in a number of projects relating to electric vehicles:

- the optimization and calibration of PSA's HDI diesel engine in 2006-2007 which will be integrated into the manufacturer's hybrid vehicle to be released on the market in 2011;
- the *Full hybrid* natural gas vehicle developed in 2006 with GDF Suez from a Prius model – the CO_2 emissions associated with this vehicle are 76g/km, as yet unrivalled by any other vehicle in the category;
- the Vehgan, a natural gas *Micro hybrid* vehicle developed between 2006 and 2008 with GDF Suez, Valeo, Inrets and Ademe using a Smart base with CO_2 emissions of 84 g/km.

IFP is also involved in two projects being supported by Ademe's Research Demonstrator Fund. The VEL ROUE project, with Michelin and Renault, is aimed at assessing the feasibility of a two-mode rechargeable hybrid light commercial vehicle, capable of running in all-electric mode at the rear and in 100% IC mode at the front, an ideal solution for the purposes of a delivery vehicle. The ELLISUP project, led by Irisbus, is aimed at developing two bus demonstrators and their recharging point: an electric bus and hybrid rapid recharge bus (around one hour).

IFP is also running its own projects, such as Flex Hybrid, a multi-fuel and multi-energy vehicle project, launched in 2008 for a two-year period. The aim is to design a rolling test platform for the purposes of testing various energy solutions, including batteries, power electronics, control laws, fuel, etc.