Zero Emission Vehicle

September 2010

valeo added™

Automotive technology, naturally

Dear Sir/Madam,

While the need for individual transport continues to increase, the means available today are coming under intense scrutiny by society. Emissions from internal combustion engines are accused of contributing to global warming and the pollution of the atmosphere. And our oil resources are not inexhaustible. An alternative to the internal combustion engine has therefore become indispensable.

It is with great pleasure that we are sending you this White Paper, which shows how the electrically-propelled vehicle is now an alternative. But the road ahead is long and difficult, if the electric car is to become a means of mass transport.

The emergence of this technology may well have serious impacts on the automotive industry. Battery manufacturers and energy utilities may well take over an increasingly large proportion of the oil companies' business. New automakers and automotive suppliers may also emerge, especially in Asia.

Japanese manufacturers have taken the lead in the field of hybrid and electric propulsion. Their American and Chinese competitors now enjoy the considerable financial aids required to make up the lost ground. If the European automotive industry is to maintain its standing, then, it too, must benefit from an ambitious support program, in terms of research and development and industrial production.

The future success of the electric car also depends on the deployment of a coherent infrastructure for the recharging of batteries. This too demands significant funding, and it will be necessary to find an acceptable way of allocating this expense.

Are we capable together of meeting the conditions required, so that in the future – why not in 2025? – only zero emission vehicles are driven in our major cities?

I hope that this document will enable you to understand the challenges facing the extensive deployment of the Zero Emission Vehicle.

Henri Trintignac
Director, Electric Vehicle Activity

September 2010

ZERO EMISSION VEHICLES

1 History

For as long as the materials known at the time were unable to withstand the heat produced by combustion, the only efficient motors were those driven by wind and water. After a number of inconclusive attempts to use the wind to propel automobiles, in the 18th century engineers turned to the emerging steam engine technology. In the course of the following century, a number of steam-driven road vehicles were built, some of which were quite fanciful in design. But the size and weight of the boiler and the coal and water tanks meant that steam engines were unsuited to automobile applications.

The principle of the electric motor was demonstrated by Peter Barlow in 1828 and, on 1839, Moritz Hermann Von Jacobi's electric paddle boat was launched on the Neva in Saint-Petersburg. The engine caught fire after just a few minutes and Jacobi en concluded that electric propulsion was impossible! At the International Exhibition in Vienna in 1873, the French engineer Hippolyte Fontaine exhibited two dynamos. The two machines were mistakenly interconnected, and, when the first dynamo was switched on, the second one started turning too! Fontaine had discovered that power can be transmitted electrically.

From this point on, electric motors quickly challenged the internal combustion engine. On 16 May 1881, the first electric tram appeared on the Berlin-Steglitz line, replacing a horse-drawn tram. Just 10 days later, Gustave Trouvé sailed down the Seine in an electrically-powered boat. But when René Panhard and Émile Levassor's Daimler with its 4-stroke engine appeared in 1889, steam in road vehicles was replaced by the internal combustion engine, fuelled either by mains gas or benzine. By 1897, the streets of New York were full of electrically-powered taxis, while on 29 April 1899, Camille Jenatzy's named *Jamais Contente* (Never Satisfied) reached 105.88 kph.

Petrol cars eventually overshadowed their electrically-driven competitors thanks to their superior range, power and the ease and speed with which they could be refueled. While electric lighting became widespread in towns, electric sockets were still a rarity, and voltage and the type of current were not standardized.

In 1966, the recommendation by the American Congress to develop electric vehicles in order to cut atmospheric pollution in cities went unheeded. The same can be said of the first oil crisis in 1973 and OPEC's embargo of the United States.

It wasn't until 1988 that General Motors launched a research program into the series production of electric cars. The first result of the program was the GM Impact prototype, which was developed to meet the ZEV (Zero Emission Vehicle Mandate) regulation of the state of California, and eventually became the famous EV1. 660 vehicles were produced and leased to selected drivers. Between 1999 and 2002, GM produced 457 second-generation EV1 vehicles with nickel-metal hydride (NiMH) batteries with a range of up to 240 km. GM retrieved the rented vehicles, which were destroyed. Only a few cars were deactivated and can now be seen in museums and universities. GM was accused of caving in to pressure from the oil companies; a 92-minute film entitled "Who Killed the Electric Car?", which is still available on DVD, was made about the program.

However, in 1998 Honda, Nissan and Toyota respectively launched the EV Plus, Altra and RAV4 EV. More recently, a program was conducted in France between 1995 and 2005, involving the use of more than 10,000 electric cars by state-owned companies, such as the French postal service and electric power utility, and by the town of La Rochelle, which offered a 24x7 rental service at seven points within the city limits. The vehicles used were Citroën AX, Saxo and Berlingo, Peugeot 106 and Partner and Renault Kangoo – developed in partnership with Valeo and Leroy Somer.

In 2009, some 30,000 electric road vehicles were in use worldwide, including a number of pioneers like Tesla Motor's Roadster. 2010 will see the launch of electric models by traditional automakers, such as Mitsubishi, Nissan, PSA Peugeot Citroën or Renault, who have plans for volume production of electric vehicles. Most of their competitors will quickly follow suit.

Sources: GM, Honda, Nissan, PSA Peugeot Citroën, Renault, Toyota, EDF, www.veva.ca, wikipedia.org

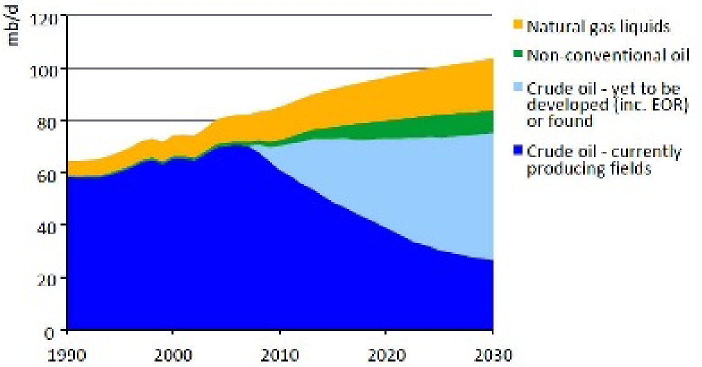
2 The car is currently in a period of transition

2.1 The issue of oil resources

The growth of our society has been fuelled to a large extent by the availability of cheap oil for about a century. But oil reserves, which took tens or hundreds of millions of years to form, are clearly a non-renewable resource, while demand is inevitably on the increase due to economic growth, especially in China, India and Brazil. Today, it is still very difficult to quantify the volume of remaining useable reserves and our ability to produce enough oil to meet long-term demand. Various studies, conducted using the Hubbert method, forecast a peak in production between 2005 and 2025. The World Energy Outlook 2008 study claims that an additional 45 million barrels per day will be required to meet expected demand in 2030. It is quite clear that within a few decades, our capacity to produce oil will fall significantly short of demand, if demand continues to grow, or even if it remains at current levels.

Consumption of crude oil in barrels per day

Country	2001	2007	Var.
United States	19 650 000	20 680 000	5%
Europe	14 590 000	14 390 000	-1%
China	4 570 000	7 578 000	66%
Japan	5 290 000	5 007 000	-5%
Russia	2 595 000	2 858 000	10%
India	2 130 000	2 722 000	28%
Brazil	2 100 000	2 372 000	13%
Other	24 746 350	29 478 664	19%
Total	75 671 350	85 085 664	12%



As the most profitable oil fields run dry, the oil companies are turning to less accessible deposits, located deep under the ocean floor or in polar regions. The energy and financial costs of extracting the oil are increased by the use of more sophisticated equipment that consumes more energy. Once the production equipment consumes one barrel of fuel in order to extract one barrel of oil, the oil field is no longer profitable, irrespective of the price per barrel!

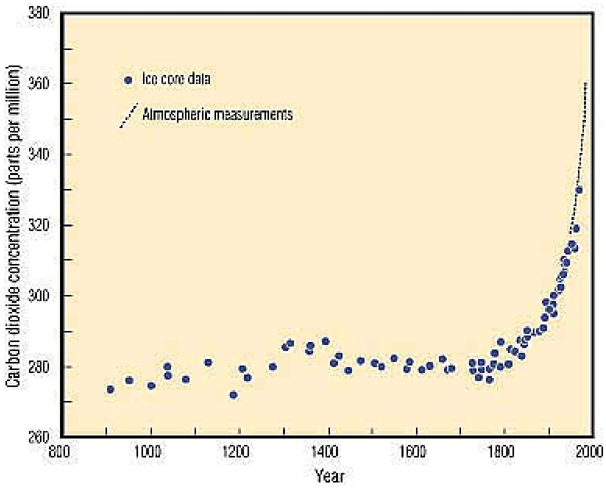
2.2 Global pollution and stricter regulations

The combustion of fossil fuels produces numerous pollutants: carbon monoxide (CO), unspent hydrocarbons (HC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), volatile organic compounds (VOC) and soot, which is also referred to as particles (PM10 for particles with an aerodynamic diameter of less than 10 micrometers). These harmful substances enter the atmosphere either by spontaneous mixing or during combustion. A number of studies have demonstrated the connection between the presence of these pollutants in the air and the number of deaths or hospital cases due to respiratory diseases, poor oxygenation of tissue by the blood, the worsening of cardiac insufficiency and carcinogenic effects.

Despite the drastic reductions brought about by regulations in the leading industrialized countries, some pollutants are still emitted on a massive scale. The United States, Europe and Japan have significantly cut emissions of VOC, HC and CO. Regulators are now targeting NO_x and particles (PM) through the introduction of new regulations. These new limits ad their dates of application were presented in a Valeo document entitled "The environmental challenges facing the automobile", published for the Valeo "Cars and Cities" Forum in March 2008.

Emissions of carbon dioxide (CO_2) are another significant consequence of the combustion of fossil fuels. CO_2 does not pollute the atmosphere, but it regulates the temperature on the surface of the Earth by contributing to the greenhouse effect. Greenhouse gases limit the reflection of the sun's energy into space. This balance establishes an average temperature on the Earth's surface of +14°C. Without the greenhouse effect, the average temperature would be about -18°C.

A century of intensive industrialization has introduced a significant additional volume of carbon dioxide into the atmosphere. Any combustion of carbon-based matter, such as petroleum, natural gas or coal, produces carbon dioxide. Agriculture, industry, transport and housing generate 22 billion tons of CO_2 every year. The chemical analysis of frozen carrots discovered in the Antarctic revealed that the level of CO_2 in the atmosphere in the Quaternary era varied between 180 and 300 ppmv (parts per million by volume). Currently, the level is about 380 ppmv and could rise to more than 560 ppmv by 2050. Between 1970 and 2004, CO_2 emissions rose by +145%. This increase is due to the production of energy (+145%), transport (+120%), industry (+65%) and agriculture (+40%). The consequences of global warming are spelt out in a Valeo document entitled "The environmental challenges facing the automobile".

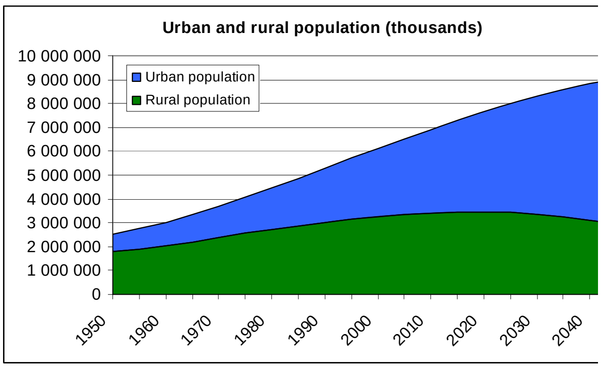


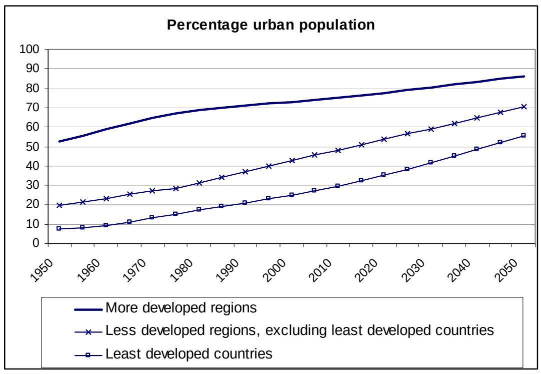
CO_2 emissions are directly proportional to the combustion of carbonaceous fossil matter, coal and oil. The main developed countries have introduced legislation designed to reduce emissions in the medium term caused by transport. Europe is leading the way in this field. While average CO_2 emissions from new cars sold in Europe for one NEDC was 154 g/km in 2008 and 163 g/km in 2007, a limit of 130 g/km will be applied to 65% of new cars in 2012 and 100% of new cars in 2015. Each automaker's target will be set according to the vehicle range. The average limit will be cut to 95 g/km in 2020.

When the leading industrialized nations met at the latest G8 summit in Italy in July 2009, they agreed to cut their greenhouse gas emissions by 80% by 2050, in an effort to limit global warming to no more than 2°C compared with the pre-industrial period. But many experts agree that this date is far too late and that greenhouse gas emissions must be cut sooner in order to limit the risk of humanitarian and ecological catastrophes.

2.3 Increasingly urban population

The population is moving into our cities. In 1950, 29.1% of the population lived in towns and cities. By 2005, this figure had risen to 48.6% and, according to the United Nations, should reach 69.6% by 2050. This preference for towns and cities applies to every group of the worldwide population, but the trend is more pronounced in the most developed regions, where the urban population is set to rise from 52.5% to 86% in one century. The main reasons behind this exodus are the mechanization of agriculture, the quest for employment and the comfort, services and cultural and tourist attractions offered by cities, not to mention demographic growth.





The unabated increase in the number of automobiles in urban areas has become a serious issue. They are blamed for causing congestion, atmospheric and noise pollution and of representing a danger for pedestrians and cyclists. In Europe, the cost of environmental damage caused by road traffic is estimated at about €100 billion per year, or 1% of the EU's GDP. More and more town and city authorities in developed countries want to reduce the numbers of cars in city centers, or even ban them completely. Prohibitive parking charges, pedestrian precincts and toll gates at the limits of major cities are becoming commonplace. At the same time, public transport services are being developed and new individual means of transport have appeared in an effort to solve the problems caused by congestion and pollution. Bike hire services, offering the possibility of picking up a bike in one place and depositing it in another, are available in many cities, including Paris, Lyon, Bologna, Parma, Berlin, Frankfurt, Cologne, Munich, Vienna, Brussels, Copenhagen, Barcelona, Oslo, London and Stockholm. Sales of motor-driven two-wheelers and motorbike taxis are on the increase. Since owning a car in the city can be both costly and inconvenient, attractively priced car sharing services have appeared that provide cars at any time on an on-demand or self-service basis. A number of rental operators already offer electric cars for hire in several cities, some of which, including Paris, have expressed an interest in a service on a larger scale.

A redefinition of cities is in the air. Some are already testing "ecological urbanism". In London, the Bedzed (Beddington Zero Energy Development) district has been built in order to prove that it is possible to reduce an urban zone's carbon footprint, with a 50% reduction in transport-related energy consumption as one of the stated objectives. To achieve this, the buildings are fitted with photovoltaic panels for recharging electric vehicles, but this mode of transport is not as yet widespread. Other "ecodistricts" are being tested, for example at Wuhan in China, at Fribourg-en-Brisgau, Hamburg, Hanover, Stuttgart and Berlin in Germany, at Cartierville in Canada, at Stockholm and Malmö in Sweden, and in Amsterdam, Rotterdam, the Hague and Utrecht in the Netherlands.

On a more ambitious scale is a project being launched in Abu Dhabi. The Emirate has begun building what it intends to be the world's first entirely ecological town: Masdar City (meaning "spring" in Arabic) expects to house 50,000 inhabitants in 2016. The goal is for the town to function without greenhouse gas emissions (CO2 and other), especially for its transport, which should feature a high level of energy efficiency. Favored means of transport are walking, cycling and a network of tramways for longer distances. The town's electricity is generated by a 100-megawatt solar power plant, which could be increased at a later stage to 500 megawatts. For individual journeys, it plans to use a mode of transport which has yet to be tested: PRT (Personal Rapid Transit), a system of several-seater vehicles operating on fixed tramlines, but with stations which can be individually selected.

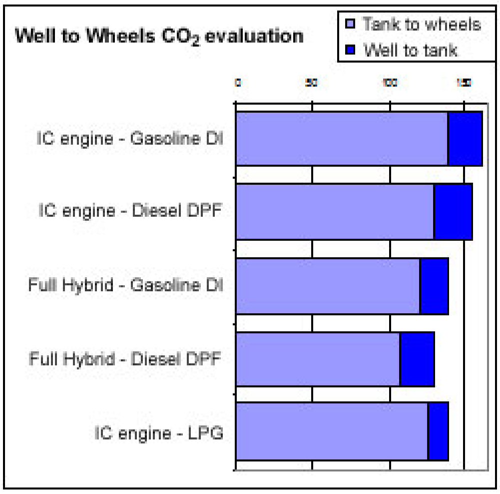
2.4 The alternatives to oil

It is now clear that one or several alternatives to oil will be necessary in the medium term and, consequently, must be developed today. The preponderance of oil as a source of energy for transport will not be replaced by another single source, but by a multitude of solutions, according to different needs, constraints and availability. The review of CO_2 emissions shown below is based on the average figures for a 5-seater vehicle from the most representative segment in Europe in the NEDC consumption cycle. This review also includes, to a very limited extent, other greenhouse gases, N_2O and methane, expressed in CO_2 equivalents (source: joint EUCAR, CONCAWE and JRC survey).

2.4.1 Gas

2.4.1.1 <u>LPG</u>

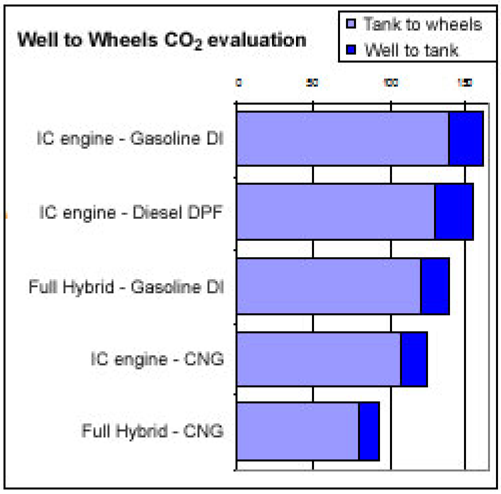
LPG (liquefied petroleum gas) is a mix of propane (C_3H_8) and butane (C_4H_{10}) that is heavier than air. It is produced directly when extracting or refining oil. LPG is usually sold in gas cylinders for domestic heating, cooking or the chemical industry. Transport only accounts for a small proportion of its consumption. It is only consumed in notable quantities by cars in a few European countries and Australia, although the market is growing in China and, perhaps, the United States.



Gaseous under ambient conditions, LPG is usually stored in liquid form at a pressure of 10 bars. It is used in cars with engines initially designed for petrol, both in single-fuel and dual-fuel (LPG and petrol) configurations. The tank(s) is installed in the place of the petrol tank, in free space under the car body

(MPVs and SUVs) or in the trunk. The high octane index of LPG means that the engine's compression ratio can be increased for greater efficiency. The most efficient systems inject the LPG in liquid form, but direct injection is not yet possible.

The other main advantage of LPG is that it can be used without making any major changes to the vehicle or the existing production and distribution infrastructures. But the well-to-wheel carbon imprint is only slightly better than that of petrol engines (DI, direct injection) and diesel engines (DPF, diesel particulate filter): at 141 g/km, compared with 163 and 146 g/km respectively for identical vehicle models. Moreover, the LPG market is restricted by the limited refining capacity, which is less than 5% of that of other fuels. Only 20 to 40 kg of LPG are produced for every ton of crude oil.



2.4.1.2 The CNG/LNG system

The largest deposits of natural gas (methane) contain more reserves that oil deposits. They are located in the United States, Russia, Canada, Iran, Qatar, Algeria, Nigeria, South Africa, Argentina, Australia, etc. The gas is transported through an extensive network of gas pipelines or, at a higher cost, it can be cooled to -162°C and transported in liquid form between special terminals by special methane carrier ships. In this case, the gas is referred to as LNG, or liquefied natural gas. For automobile applications, the gas is referred to as CNG, or compressed natural gas. The methane is stored on board the vehicle at a pressure of 200 bar in tanks measuring five times the volume of a petrol tank with an equivalent energy content. The beginnings of a distribution network already exist in cities, but a compression system is necessary in the refueling stations, since the pressure in this network is usually less than 30 bars. The acceptability of the tanks and the specific refueling operations are problems that require attention.

Engines designed to run on petrol can easily be adapted to CNG, but the compression ratio should be increased by about 30% in order to benefit from the increased efficiency. Natural gas is also well suited to turbocharged engines and hybrid powertrains.

Using natural gas in a converted internal combustion engine significantly improves the CO_2 balance, because the molecule (CH_4) contains only one carbon atom for every four hydrogen atoms (CH_4) and efficiency is improved by 10 to 15% compared with a petrol engine. The improvement in the CO_2 balance is all the more significant in full hybrid vehicles (see table). It should, however, be noted that the balance is negatively impacted by factors related to the distribution system. The total length of the gas pipeline and maritime transport both have a negative effect on the balance.

2.4.1.3 Biogas

Gas, consisting mainly of methane, can be produced by fermenting organic matter (BTL – Biomass-to-Liquid). Manure, harvest waste and household waste can all be used to produce gas. Biogas can also be made from crops, but the total cost of the operation is very high.

While the greenhouse gas balance varies from one process to another – the problem being methane leaks during the transformation process – at 32 g/km to 143 g/km, it remains very positive. Nevertheless, biogas can only account for a tiny fraction of the gas delivered by the existing distribution network.

2.4.2 Alternative liquid fuels

The advantage of alternative liquid fuels is that they can be distributed using the existing infrastructure used for gasoline and diesel. They can usually be mixed in different proportions and current vehicles can be adapted without making any major changes.

2.4.2.1 Les agrifuels

Ethanol is produced by fermenting sugar made mainly from sugar cane, maize, wheat and sugar beet. Bio-diesel, or Diester, is made from rape seed or sunflower seeds. CO_2 emissions from agrifuels are determined by a number of highly variable factors, including the transformation processes and the specific impact of intensive growing. This last point is one of the most difficult to quantify. On the one hand, the use of nitrogenous fertilizers is the main source of emissions of nitrous oxide (N_2O), which has global warming potential that is 300 times higher than that of CO_2. On the other hand, a study by R. Righelato and D. Spracklen published in “Science” in August 2007 confirmed that the balance is disastrous when indigenous forests are cut down to make way for single-crop systems that release between 100 and 200 t of carbon per hectare. We would have to consume agrifuels produced from these crops, rather than fossil fuels, for between 50 and 100 years in order to compensate for this initial emission. The same researchers calculated that the reforestation of the same surface area would capture between two and nine times more carbon in 30 years, than would be avoided by producing biofuels.

A survey conducted in 2009 by the French agency for the environment and energy management came to similar conclusions. By way of example, it suggests that, without taking changes in plant coverage into consideration, the growing of soya to make biodiesel would cut greenhouse gas emissions by 77%, but that in actual fact it would cause them to rise globally by a factor of 4 to 5 compared with diesel, if one hectare of tropical rain forest is used for single-crop farming.

More recent developments aim to produce second-generation biofuels from organic waste, such as wheat straw or sugar beet pulp. But a lot of uncertainty still surrounds the cost factors and the capacity to produce in industrial quantities. Studies have shown that a well-to-tank balance of between +40 and -117 g/km (the negative value corresponds to the absorption of CO_2) could be achieved, depending on the process and basic matter. On the basis of a tank-to-wheel value of 136 g/km, the overall balance of CO_2 emissions would be between just 176 and 19 g/km, depending on the processes used.

2.4.2.2 Synthetic fuels

Synthetic petroleum substitutes can be made using the Fischer-Tropsch (FT) process. A number of processes have already reached different states of progress:

- GTL (Gas-to-Liquid) uses natural gas. When used in a mix with gas oil or pure, they do not achieve any well-to-wheel gains in CO_2 emissions at all.
- CTL (Coal-to-Liquid) fuels, which are obtained by gasifying coal, are only acceptable if the production process involves the capture and storage of CO_2. Otherwise, the well-to-wheel emissions are approximately 2.3 times higher than those of fuels made from petroleum.

2.4.3 Hydrogen (H_2)

Hydrogen (H_2) represents an alternative to the electrical means of storing energy. The fact that the hydrogen molecule does not contain any carbon atoms means that its combustion does not locally produce any CO_2, unspent hydrocarbons (HC) or carbon monoxide (CO). But there is hardly any natural hydrogen in a combustible form on planet Earth. One of the fundamental laws of thermodynamics states that extracting the two hydrogen atoms from the water molecule consumes far more energy than is produced by the combustion of the same hydrogen. Therefore, 97% of the insignificant quantities of hydrogen currently produced is made by reforming methane (CH_4). This process consumes proportionally more gas than when it is directly burned, and the loss of yield inherent in the process results in at least twice as much CO_2 emissions as the direct use of methane.

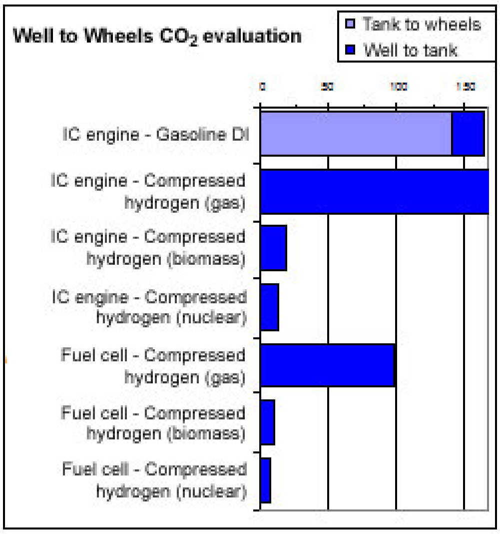
Hydrogen is about eight times lighter than methane and must therefore be compressed to very high pressures or liquefied in order to be stored in significant quantities. At a pressure of 700 bars, 1 kg of H_2 occupies a volume of 23 liters. Liquefying hydrogen for cryogenic storage at -253°C consumes at least 30% of the hydrogen's initial energy content, but it does allow 1 kg of hydrogen to be stored in a volume of 14 liters.

The distribution of hydrogen also involves problems related to both cost and safety and it is clearly impossible to build a network of gas pipelines connecting every service station. While it may be possible to transport hydrogen in road-going tankers, at least 19 special trucks would be necessary to carry the equivalent of one petrol tanker in terms of energy content. Moreover, filling tanks with hydrogen is potentially dangerous.

Hydrogen can be used in internal combustion engines or in fuel cells.

2.4.3.1 Hydrogen internal combustion engines

A number of prototypes are currently being tested. Even if these tests confirm the absence of local CO_2 emissions (a few grams are emitted by the combustion of the lubrication oil), this concept still faces some major problems. The engine generates less specific power than the petrol version, mainly due to hydrogen's need for a lot of combustion air and the large volume that it occupies when injected in the gaseous state. The high combustion temperature, which theoretically can reach 3,000°C, produces NO_x, which are also greenhouse gases. In fact, these vehicles are not classified as ZEV – Zero Emission Vehicles. It is also difficult to control the combustion process, because the flame front propagates extremely quickly.



The CO_2 balance is determined mainly by the method used to produce the hydrogen: electrolysis fed by a nuclear power station or by a renewable energy source, a solution that produces fewer emissions. The reforming methods that are currently used produce between 5 and 10% more well-to-wheel emissions than gasoline. Storage in liquid form generates even more CO_2 emissions than high-pressure storage.

2.4.3.2 Hydrogen fuel cells

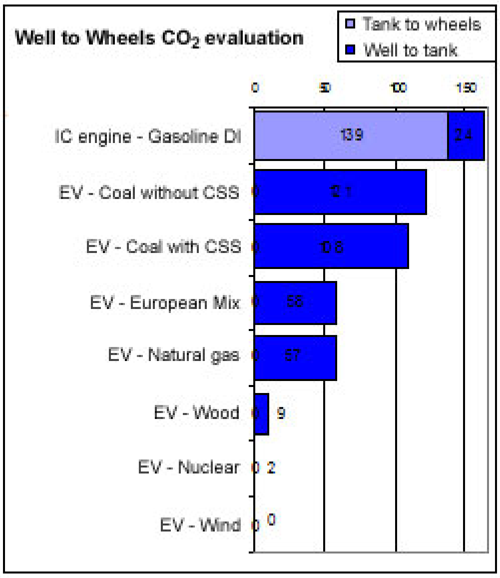
Hydrogen fuel cells perform an operation that is the reverse of water electrolysis. They combine hydrogen and oxygen to generate electric power (and a little heat that can be used to warm up the passenger compartment) and produce only water (H_2O). This good result can be explained by the fact that the combustion of hydrogen is replaced by a chemical reaction. The drive train requires efficient batteries capable of providing extra power when the vehicle accelerates and recovering energy when it decelerates. But long and costly research is still necessary in order to optimize fuel cells in terms of costs, reliability, durability and operating temperature ranges. Moreover, announced future developments in battery technology could reduce interest in the use of fuel cells to power vehicles.

The same logic applies to their CO_2 balance as to that of hydrogen in an internal combustion engine, but with far better results.

2.4.4 Rechargeable hybrid and electric vehicles

Electric vehicles are powered by their batteries. The so-called "range extender" variants are fitted with an internal combustion engine coupled to an electric power generator that recharges their batteries. This concept is similar to that of the rechargeable series hybrid, the only difference being the storage capacity of the batteries. These three types of vehicle are described in greater detail in the next chapter. Electric vehicles do not locally emit any CO_2 or pollutants. But their well-to-wheel balance includes the emissions generated by the production of electric power. Therefore, the global balance is determined by the process used to generate the electric power, with significant variations from one process to another.

The electric power may be generated in an oil-, gas- or coal-fired power station. There are still many coal-fired power stations in operation, especially in China, that emit high volumes of CO_2. At 121 g/km, the CO_2 balance of an electric vehicle that charges it batteries with electric power from a coal-fired power station is quite poor. While research into carbon capture and storage (CCS) may be ongoing, certain estimates forecast a reduction of just 13 g/km. Coal will still be a significant source of electricity in 2050 according to the WETO-H2 survey, which predicts that more than 50% of thermal electricity will be generated in infrastructures fitted with CO_2 capture and storage systems. Gas-fired power stations emit about half as much CO_2 as their coal-fired equivalents, due to their greater efficiency and the fact that the methane molecule contains just one carbon atom for every four hydrogen atoms. The few power stations in operation that use biogas made by fermenting biomass make an insignificant contribution. Thermal power stations could generate electric power by combusting renewable organic matter (plants, trees and animal, agricultural or urban waste), but the waste produces much less energy that fossil fuels. Nevertheless, the estimated balance of just 9 g/km, is very positive.



Renewable energy sources are very well suited to the production of electric power, since they do not emit any CO_2 once they have been installed. The oldest renewable source is hydraulic energy, which depends on the water cycle. Other emerging renewable sources include wind power, solar power (photovoltaic cells) and geothermal power, which is extracted from the heat in the earth. Their CO_2 balances are very positive, but production is determined by random conditions, such as the wind or the sun. Since the power cannot be stored as electricity, it must be consumed immediately, meaning that the source of production must be part of an extensive network capable of modulating the quantity of power according to the immediate demand.

In nuclear power stations, the steam turbines are driven by the heat released by the nuclear fission of uranium, a non-renewable fuel, whose radioactive ore is contained in the substrata of the planet. The first commercial nuclear power station, with an initial capacity of 50 MW, came into service in 1956, at Sellafield in the United Kingdom. Nuclear power stations are capable of generating considerable volumes of electric power and can adapt to fluctuations in demand of 5% per minute, between 30% and 100% of their maximum output. They are not dependent on oil resources. The CO_2 emitted by our standard vehicle when powered by nuclear electricity is estimated at 2 g/km, which is mainly due to the handling of uranium (extraction, transport, etc.).

Consumption of non-fossil electric power in 2006 (billions of kWh)						
	Hydroelectric	Nuclear	Other renewable sources	Total	Total consumption	% of non-fossil
North America	671.18	890.61	130.18	1 691.97	4 543.66	37%
Central and South America	639.61	20.91	25.20	685.72	801.67	86%
Europe	532.00	958.05	183.53	1 673.58	3 296.57	51%
Eurasia	243.53	240.19	3.33	487.05	1 196.44	41%
Middle East	23.23	0	0.13	23.36	558.40	4%
Africa	90.92	10.07	2.31	103.31	480.00	22%
Asia and Oceania	796.58	540.43	69.63	1 406.64	5 501.88	26%
Worldwide total	**2 997.06**	**2 660.26**	**414.31**	**6 071.63**	**16 378.62**	**37%**

Therefore, the CO_2 emissions of an electric vehicle are determined mainly by the percentage of electric power that is generated by the different means of production. In 2006, 37% of electric power consumed worldwide was generated from renewable or nuclear resources. The figures in Central and South

America are particularly good, due to the number of hydroelectric power stations. Developed countries, which are also faced with increasing demands, are relying on the deployment of new nuclear power stations and/or renewable energy sources, such as geothermal, sun and wind power or biomass and waste.

An electric car with a range extender emits CO_2 only when the internal combustion engine recharges the batteries. A rechargeable hybrid car also emits CO_2 when its combustion engine is used to recharge the battery and/or to drive the wheels. The overall carbon footprint of these two types of vehicles remains largely favorable compared to conventional vehicles with combustion engines.

Sources:

- BMW
- CIA World Factbook
- EUCAR, CONCAWE et JRC (the Joint Research Centre of the EU Commission)
- Energy Information Administration – EIA (Section of the US Department of Energy)
- IFP (Institut Française du Pétrole)
- Intergovernmental panel on climate change
- NASA
- NationMaster
- Nations Unies
- Renault

3 Overview of zero emission vehicles (ZEV)

Vehicles classified as ZEV do not produce any local emissions of harmful gases or CO_2. While fuel cell vehicles may be available at some time in the distant future, the storage of electric power is currently the only series-produced technology capable of driving a road vehicle without any emissions.

3.1 Battery-powered electric vehicles

As mentioned in 2.4.4, BEVs, or Battery Electrical Vehicles, are driven exclusively by one or more motors powered by the electric power that is stored in batteries. An electronic control system manages both the engine's power, as requested by the driver, and the recovery of kinetic energy during deceleration. The transmission may comprise just reduction gearing, and maybe a differential, reverse gear, a starter, and acceleration and deceleration with an energy recovery system, that are permanently and directly available, without any jolts are jerks caused by the motor(s). Lithium-ion batteries, which are already used on small electronic devices such as mobile phones, offer storage capacity four times greater than lead batteries. For example, the vehicle can be recharged using an ordinary 110/220-volt socket (slow charge) or with an additional tri-phase 32-amp power source (semi-fast charge). The latter solution should also become available in towns or in car parks.

The range of BEVs depends directly on the batteries' capacity and on the consumption, both for their propulsion and for continuous thermal comfort. The first-generation models, which will be marketed by the end of 2010, offer a range of between 100 and 250 km, depending on the design, the type of journey, speed and driving style. The limitation is not a technical one, given that you can always attach a sufficient number of batteries, but an economic one. Because the cost of the batteries is particularly high, the designers have to make a compromise between the vehicle's final cost and its range. This factor, together with all the advantages mentioned previously, means that electric vehicles are particularly well suited to use in and around towns and cities.

3.2 Range-extender electric vehicles

So-called Range Extender Battery Electrical Vehicles (REBEV) are also driven exclusively by electric power, but they are fitted with an electric generator and a fuel tank, rather than large batteries. But they are equipped batteries whose range is sufficient for most common driving situations. Different surveys have found that between more than 80% of daily trips are no longer than 50 to 60 kilometers.

The internal combustion engine is only used for longer journeys. All of the mechanical power is used to drive the electric generator. The current generated is used either to drive the electric motor(s) or to recharge the batteries, depending on the immediate needs. In this case, the car operates like a series hybrid vehicle.

The internal combustion engine is usually less powerful than the electric motor(s), which can be simultaneously powered by the current from the batteries. The range depends mainly on the capacity of the fuel tank. By way of example, for the Chevrolet Volt, GM has announced a range of 60 km in electric mode, while the total range is more than 500 km.

3.3 Rechargeable hybrid vehicles

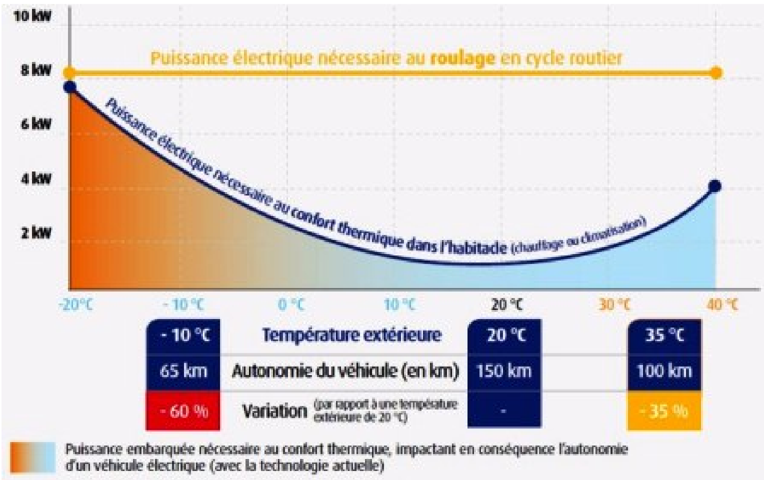
Plug-in Hybrid Vehicles, or PHEVs, are fitted with two drive systems: an internal combustion engine and an electric motor that can be combined in a number of ways¯in parallel, in series, power division, or others. The vehicle can be propelled by both systems, or by one or the other. The electrical energy is stored in batteries which can be recharged either when stopped, using the electrical network, or by taking on some or all of the combustion engine's energy. In electric mode, this vehicle can travel in urban and suburban traffic conditions over a distance of several dozen kilometers. The dimensions of the batteries are generally reduced compared to those of range-extender electric vehicles, in order to restrict the extra cost, as this type of vehicle includes a very high level combustion powertrain. The electric motor and the control electronics must be capable of withstanding the increased stress of the entirely electric traction system, which is more powerful and can be used over longer distances than in most non-rechargeable hybrid vehicles. The electric architecture must be designed accordingly, in order to guarantee uninterrupted operation and improved yield.

The total range of this type of vehicle depends mainly on the capacity of the tank, as is the case for range-extender type vehicles. Numerous market surveys come to the same conclusion that, in the medium-term, the majority of hybrid cars will have to offer a battery recharging facility.

3.4 Other specific features of electric vehicles

A number of electric vehicle projects are based on platforms initially designed for internal combustion propulsion. Replacing the internal combustion engine and its transmission with a system that includes an electric motor, a UPS, charger, voltage converter and reduction gear does not pose any special problems in terms of dimensions, since this equipment occupies a reasonably small volume. The main problem is the batteries. For an equal storage capacity, lithium-ion batteries respectively represent 14 and 19 times more volume and weight than a fuel tank. If no major changes are to be made to the body shell, then the batteries can only be installed in the drive shaft tunnel, in the space under the seats, in the spare wheel compartment, the boot or the engine compartment. The battery pack also includes mechanical, thermal and electronic protective devices that may weigh more than 200 kg. Therefore, attention must be paid to the distribution of the weight in order to obtain the lowest possible center of gravity. The additional weight may also require reinforcements for the body shell, the running gear and the steering system. The ideal position for the batteries is in the center of the chassis and as low as possible. Platforms that are not developed especially for this type of propulsion may require major modifications.

In an electric vehicle that cannot recover the heat provided by the combustion engine, the heating and air-conditioning functions in the cabin have to be reconsidered, in order to restrict the quantity of energy taken from the battery. In extreme winter conditions, the power consumed by the heating system becomes equivalent to the power required for the powertrain. It is therefore necessary to add an independent heating system, such as electric resistors, or equipment that consumes less of the battery's power, such as heat pumps, or a heat storage system.



At high ambient temperatures, the air conditioning can consume as much as one half of the power needed to propel the vehicle. In addition, it is becoming increasingly beneficial to drive the compressor using a dedicated motor, rather than the vehicle's drive motor in order to optimize comfort, power consumption and range. In this case, the compressor no longer needs to be located in the engine compartment and can be moved closer to the cabin.

3.5 Pros and cons of ZEV vehicles

3.5.1 Pros

No emissions

The fact that ZEVs do not produce any emissions is valued especially in urban areas, where the high numbers of vehicles driven by internal combustion engines significantly increase air pollution. According to the PEACE survey, in some European cities the average PM10 concentration (particles with an aerodynamic diameter of less than 10 micrometers) occasionally exceeds the limit defined by the WHO (World Health Organization) of 40 micrograms/m^3. The record appears to be held by Athens, with a measured concentration of 99 micrograms/m^3. In rural regions, located a few dozen kilometers from the large urban centers, the average value is less than 22%.

Silent operation

Noise can also have harmful affects on health, including stress, insomnia, effects on the cardio-vascular, immune and endocrinal systems, or even impacts on mental health. Electric vehicles are so quiet that artificial noises are used to warn pedestrians, who are used to noisy vehicles. It is only when pedestrians come across a full-electric hybrid vehicle that they realize just how quiet these vehicles are.

Driving comfort

The electric car is also notable for the ease and comfort it offers to the driver: No gears to change, no clutch, no danger of stalling, no vibrations and virtually no mechanical noises inside the cabin. The electric motor offers uninterrupted driving power, with no abrupt changes. These features offer a calm, stress-free drive. An electric engine is capable of delivering its full torque from standstill (0 rpm), while even the most recent diesel engines only deliver their maximum torque at 1,400 rpm, and gasoline engines have to accelerate to between 2,500 rpm and 16,000 rpm (F1), depending on the type of engine. This means that electric vehicles can accelerate very quickly from low speeds. By way of example, the Bolloré Bluecar, which is driven by a 50 kW electric motor, can accelerate from 0 to 100 kph in 10 seconds, while an internal combustion engine would require nominal power of at least 85 kW to achieve the same performance in a car of identical weight. Electric vehicles also possess the ability to recover the energy produced when decelerating sharply, for instance when the accelerator is released. This function limits the use of the brakes, and allows the speed to be modulated more effectively, especially when driving in towns.

3.5.2 Cons

Autonomy

The low energy density of its batteries means that the range of a BEV is much shorter than that of a comparable gasoline- or diesel-fuelled vehicle. The latest developments achieve a range of between 80 and 250 km. Therefore, they can only be used for the short everyday journeys of no more than 50 to 60 kilometers that account for 80% to 87% of vehicle usage. There are two possible solutions. The first involves providing quick-recharge terminals capable of recharging batteries to 80% in 30 minutes. The second is to provide a service to replace the batteries automatically in a few minutes. This concept involves using robots to replace the 150- to 250-kg batteries. These systems could only be handled by qualified personnel. This system will be introduced in Israel en 2011. This weakness could be addressed by range extender vehicles and rechargeable hybrids, which represent a comprise between combustion vehicles and all-electric vehicles.

Charging network to be created

Installing a slow-charge station in someone's home does not present any serious difficulties, apart from the matter of the availability of a garage. The problem of installing them in public places is, however, a different matter. Sufficient coverage of the zone has to be guaranteed, in order to satisfy current users' needs, and reassure future buyers. Determining where to put them, and what percentage should be respectively slow and fast charge, needs to be defined. The fast ones are significantly more costly, so there would probably be less of them. The other problem inherent in cities is the lack of surface area: you only need to look at the difficulties involved in installing bicycle rental stations, which can only be done by partially converting pavements and removing parking places. Nevertheless, in the United States, where 450 customers tested the Mini E, users showed a distinct preference for charging their vehicle at home rather than using the terminals in town. Half of them routinely recharged their vehicle every day, even when it was not necessary. Consequently, they made very little use of external recharging infrastructures.

Infrastructure cost

The cost of equipping a zone in the city, or even in the suburbs, can become very high. This is probably the most problematic issue, and one which will condition the success or failure of electric vehicles. The cost of a slow charge station is estimated at between one and two thousand dollars in the individual's home, two or three times more in a public place, and 15 to 20 times more for a fast-charge station. Who will fund them: the users, the local authorities, in the form of taxes or subsidies, or the "polluters"? For the latter, it should be noted that the electric car does not meet all the needs of users, and the internal combustion engine will still be necessary for some time. Companies could also become involved, if it enabled them to restrict their CO2 emission quotas. The alternative, which is to have an automatic battery exchange service, also poses an economic problem. This system increases the operating costs of the infrastructure considerably, given the necessity of having a large number of batteries in stock for recharging.

Cost of batteries

Another obstacle in the way of the large-scale deployment of electric cars is the cost of lithium-ion batteries, which is currently about €500 per kWh. Specialists are focusing on this point, since a car requiring 20 kWh would need a battery costing €10,000, or almost one half of the cost of the car! In the medium term, it is quite probable that the cost of these batteries will drop to about €300/kWh or even less. Battery suppliers will also have to take on the cost of recycling their products. In return, they will recover some of the lithium and recycle it in their production chains. It would also be preferable to cut the consumption of electric power, in order to reduce the quantity of energy loaded in the vehicle. The energy needed to power the car and its lighting, heating and air conditioning currently represents consumption of around 0.2 kWh per kilometer. New developments capable of limiting consumption to 150 Wh/km would cut the costs of batteries by 25%. Another solution is to reduce the capacity of the batteries used, but that would obviously be done to the detriment of the vehicle's range.

For the user, the high cost of buying the vehicle, dictated to the cost of the batteries, would be compensated by a particularly advantageous cost per kilometer in comparison with a combustion engine vehicle. The first reason for this is the cost of the kWh, but it is also true that, in most countries, electricity is not taxed as highly as fossil fuels. The second reason is the superior efficiency of an electric powertrain, which can reach 65% to 80% on an NEDC, compared with 15% for an internal combustion engine. The third reason is that a substantial part of the kinetic energy can be recovered when braking and decelerating. An alternative solution for reducing the cost of batteries is the range extender vehicle, as it requires a lower capacity of electric energy.

It is quite probable that vehicle rental will be the most affordable offer for buyers. By way of example, in France the monthly rental fee for a Mini E is €475 and €499€ for the Peugeot Ion. In the USA, the Chevrolet Volt can be leased for $350 per month for 36 months with an initial downpayment of $2500, which almost the same price as for the Nissan Leaf, which costs $349 per month for 36 months, with a downpayment of $1999. In another solution, Renault will propose to separate the ownership of the vehicle and the batteries. Customers will be able to buy or hire a vehicle by taking out a subscription that includes battery hire and new mobility services. Renault aims to propose an electric vehicle at a price comparable to that of a diesel internal combustion vehicle of similar size and with similar equipment (after deduction of state aids).

Sources: Bolloré, BMW, Chevrolet, General Motors, Nissan, PSA, Renault, Valeo

4 Short- and long-term market estimates

4.1 Factors affecting the ZEV market

It is very difficult to estimate the number of ZEV in the coming years, because there are so many imponderables and parameters that must be taken into consideration. But such estimates are essential in order to anticipate the development model of this new type of vehicle. Consequently, it is most important to try and anticipate all these parameters, while bearing in mind the potential risks that are inherent in making estimates of the future market.

4.1.1 The cost

As mentioned in 3.5.2, cost is one of the main problems facing electric vehicles, mainly due to the price of lithium-ion batteries. Electric cars will be in competition with internal combustion vehicles in urban areas. While the price of batteries is expected to drop, the price of oil is rising significantly, despite substantial fluctuations. In 2003, the price of a barrel of oil was $30, before rising to $70 in 2006, and reaching an all-time high of $140 in the summer of 2008. Certain analysts, including Arjun N. Murti from Goldman Sachs, predicted that the barrel of oil would reach $200 by the end of 2008, but the slump in manufacturing and economic activity resulted in a global drop in the demand for energy. As a result, the price of a barrel of crude oil dropped to $40 in early 2009, before rising back up to about $70. The short-term price of oil remains very uncertain, but the long-term trend will probably be upwards, despite the unpredictable yet significant fluctuations due to the resonance caused by a limited offer and a demand that depends on economic activity, which is in turn determined by the price of oil. The date when the two curves meet – when the rise in oil prices will make the cost of batteries more attractive – is a decisive factor for the ZEV market.

But a strong and durable rise in the price of oil will tend to cause an increase, through a knock-on effect, in the cost of all other energy sources.

So-called non-polluting vehicles already enjoy State-funded aids in a number of countries, in a bid to encourage tax payers to contribute to the reduction of air pollution and CO_2 emissions. By way of example, the British government is offering aids of up to €5,800 (£5,000) for anyone who buys an electric car. Since they are classified as ZEV, electric cars will probably continue to be subsidized in the years to come. Therefore, if the extra cost of an electric car compared to a comparable gasoline car is estimated at between 12,000 and 15,000 €, and its operating cost offers a gain of between 8,000 and 9,000 €, the aid should be around 5,000 €.

This incentive is also due to the fact that their high cost could seriously limit sales. AS States derive part of their revenues from heavy taxes on fuels, it is likely that they would not be able both to lose part of these revenues and to finance the purchase of electric cars. It is therefore in the interest of governments to provide public funds for research and development for ZEV right away in order to limit the total cost of the budget of subsidies for electric cars, which could mushroom if they are a commercial success.

4.1.2 Changes in antipollution regulations

Developed nations started introducing regulations limiting atmospheric pollutants in the 1990s. Today, emissions of particles and nitrogen oxide (NO_x) take top priority. New internal combustion vehicles often have to have combustion control systems, exhaust gas post-treatment and engine control systems, such as the Stop-Start, thereby increasing their build costs. These regulations impact diesel engines in particular. A number of cities have already introduced traffic restrictions based on the homologated emissions of each model and such measures may be introduced elsewhere. Additional restrictions will apply in the event of severe atmospheric pollution.

Internal combustion vehicles are also faced with a determined effort to cut levels of greenhouse gas emissions. By way of example, the European Union will impose a limit of 130 g/km of CO_2 to 65% of vehicle sales in 2012, and has announced plans to impose a limit of 95 g/km at a later date. If the limit is exceeded, manufacturers will be required to pay a fine of €95 per vehicle sold for every g/km of excess CO_2. Surveys indicate that these new regulations will add an average of €1,300 to the price tag of cars.

All these restrictions that apply to internal combustion vehicles will boost the development of ZEV.

Maurizio Maggiore, European Commissioner, at the Future Mobility Forum on 10 March 2009. "Crisis or no crisis, today we cannot put a stop to technological development. Because a major environmental crisis is on the horizon. The green car has arrived, be it for noble ecological reasons, or for strictly opportunistic reasons to do with energy security. And it has arrived for good! All that remains to be decided, is who will make and market it. The United States has already discovered that relying on obsolete technologies is a high-risk strategy."

4.1.3 Political and industrial will

The ZEV market may be boosted by the desire to put an end to the domination of oil. Governments, automakers, energy utilities and service companies have already signed numerous contracts. By way of example, on 21 January, 2008, the state of Israel entered an agreement with Better Place and the Renault-Nissan Alliance for the large-scale distribution of ZEV vehicles.

Other countries, which are also keen to become leading players in the automotive industry, are prevented from exporting internal combustion vehicles by their industrial and technological capacities. The electric car represents an opportunity to enter the automotive market on an equal technological footing. These countries include China and India. In China, the government has set itself the target of 50% of car sales powered by electricity in the country by 2020.

The ZEV only makes any ecological sense if the production of electricity produces genuine gains in terms of air pollution and CO_2 emissions. It is only credible if the power network includes a high proportion of nuclear power stations and/or renewable or natural gas energy sources.

4.1.4 Local intentions

The market for captive urban or suburban vehicle fleets is especially well suited to the characteristics of electric cars. A single recharging station in the place where the vehicles are kept is sufficient; it is therefore unnecessary to invest in numerous stations along their route. This market may include a range of urban delivery services (post, foodstuffs, equipment, etc.), assistance services or transport of persons (taxis, minibuses).

The characteristics of electric cars also meet many consumer needs. A number of agreements already exist with local authorities, for example in California and in Japan. The electric car market would be boosted if more large towns and cities followed the example set by La Rochelle in France, which invested in a fleet of special vehicles and a network of car parks fitted with recharging terminals.

4.1.5 Customer needs and expectations

The electric vehicle market also depends on how users accept the vehicles. Electric vehicles can offer the same or superior levels of comfort, safety and performance as conventional cars. But there are two factors that may be detrimental to the growth of the electric vehicle market: range and cost. It will be necessary to make sure that the range of each product is accepted and understood by users. The use of electric vehicles and the concerns of certain motorists could be addressed by a network of quick-recharge or battery replacement stations. Customer needs and the possibility of a single family possessing one or two vehicles also influence the type of ZEV.

As briefly mentioned in 3.5.1, the cost per kilometer of an electric vehicle may be 4 to 6 times less than that of an internal combustion vehicle, but the cost of purchasing the batteries is very high. The offer will probably tend towards a system in which battery packs or vehicles are available for hire. Premiums for purchase and/or subsidies provided by local authorities may also be made available, provided that the States are capable of making up for the loss in revenues from tax on fuels.

4.1.6 The fear of change

Some people are always more or less reluctant to change, for reasons of conformism, difficulty in adapting or unfamiliarity. This factor acts as a brake when it comes to selling a new concept. It is also worth noting that the development of the ZEV represents a threat to some of the industries that are economically dependent on oil.

4.1.7 A market that still depends on external events

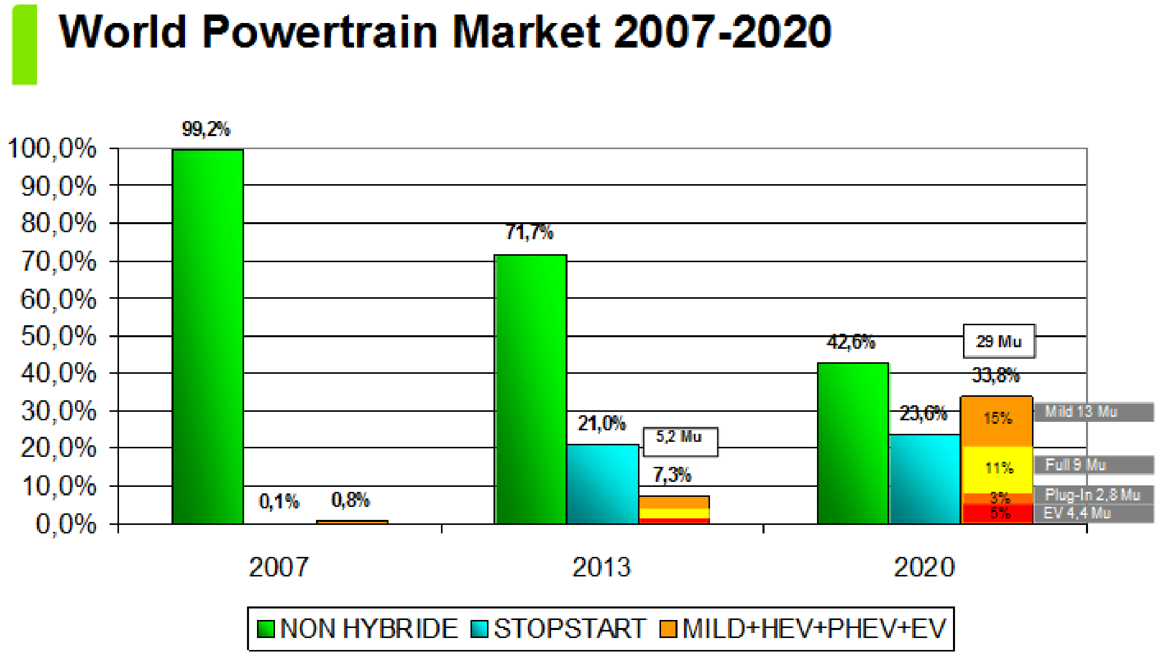
Major events can quickly and significantly impact the demand for ZEV. If an ecological disaster occurs due to global warming, then demand for ZEV could rise. In this case, a significant proportion of the population could suddenly restrict all forms of consumption that emit CO_2. The same applies to serious geopolitical tension with major oil exporters.

On the other hand, certain events could limit the growth of ZEV. By way of example, a long and deep economic crisis could boost sales in the very low-cost segment, from which ZEV are excluded due to the current state of technology, and of batteries in particular. Another risk is that the image of this type of vehicle could be impacted by a serious accident (exploding battery, electrocution, etc.).

4.2 Market estimate

Forecasts for the ZEV market range from the highly optimistic to the deeply pessimistic. One of the most optimistic surveys was conducted by the Roland Berger cabinet, which claims that 25% of vehicles sold worldwide in 2020 will be electric, and 50% in 2050. Similarly, Research and Markets announces that electric and rechargeable hybrid vehicles will account for 35% of the worldwide market in 2025, PHEV for 25% (chapter 3.3) and BEV for 10% (chapter 3.1)

Valeo estimates:



Strategy Analytics estimates that electric cars will represent 6% of the market, or 4.5 million vehicles, in 2015. Frost & Sullivan predict that the European market for electric vehicles will represent a mere 250,000 cars in 2015, whereas they had previously announced 480,000.

These divergences are due to the difficulty in making reliable predictions in view of the complex relations between the multitude of parameters involved. Come what may, a significant majority of the cars made in 2020 will still be internal combustion vehicles. Numerous technologies sold on a massive scale will reduce CO_2 emissions by improving the efficiency of engines and optimizing their use. The Stop-Start system and mild and full hybrids will be widely available. Valeo estimates that by 2020 electric vehicles – BEV and REBEV – will represent 5% of the world market, or 4.4 million vehicles, and that rechargeable hybrids – PHEV – will account for 3% of the world market, or 2.8 million vehicles. These volumes will be spread over four main markets: China, Europe, North America and Japan.

5 Technological challenges

5.1 First generation (2009-2010)

5.1.1 A major technology: the lithium battery

The major technological breakthrough that is inherent in the first-generation electric cars that are currently available, is the new lithium-ion battery. Lithium, a soft alkaline metal, is the lightest of all solid materials (mass density of 535 kg/m^3). Lithium salt in a liquid form is used for the electrolyte. Since they were first made available by Sony Energitech in 1991, lithium-ion (li-ion) batteries have become commonplace in small portable appliances, such as mobile telephones or laptop computers.

The batteries designed for automotive applications have a high specific energy (between 150 and 180 Wh/kg) and volume energy (between 120 and 160 Wh/liter), excluding the peripherals, such as the protective casing or the control and safety electronics. Performance is determined mainly due to the state of the art and the families of battery. By way of comparison, lead batteries deliver 30 to 40 Wh/kg and metal nickel-hydride batteries (NiMH), which are widely used in current hybrids, deliver between 80 and 110 Wh/kg. The advantage of li-ion batteries lies in the high voltage generated by each electrochemical element: between 3.1 and 3.7 volts, depending on the technology used, compared with 1.2 volts in NiMH batteries. Compared with NiMH batteries, they save almost 150 kg and 100 liters of space for the same equivalent on-board energy. Li-ion batteries also generate high charge and discharge power and do not suffer from the memory effect that requires the battery to be completely discharged after several cycles in order to avoid a drop in storage capacity. Lithium is available in large quantities in several places, predominantly in Latin America – Argentina, Chile and Bolivia – and in a number of regions in Asia, including Tibet. Recent reserves, with lower concentrations of lithium, have been discovered of late in Australia, Russia, the US (in particular in California), Canada and Afghanistan.

On the other hand, li-ion technology requires a number of safety devices that increase the dimensions, weight and cost. Batteries work optimally at between 0 and 40°C. Therefore, an air conditioning or cooling system is required, usually in the shape of liquid that flows between a heat exchanger and the battery pack. The batteries are also capable of withstanding the impacts that are inherent in a road-going vehicle, thanks mainly to the damping system built into the casing.

A number of types of lithium-ion are available that differ in terms of cost and specific energy. The main difference lies in the design of the cathode, which can be made of manganese (Mitsubishi i-MiEV, Peugeot Ion, Citroën C-Zero), lithium/nickel/cobalt/manganese, nickel/sodium (Smart ForTwo), nickel/cobalt/aluminium or phosphate (Renault, Chevrolet Volt/Opel Ampera). Lastly, while polymer lithium-ion and polymer metal lithium batteries (Bolloré Bluecar) generate less specific energy, their jelly polymer electrolyte, which is not liquid, is much safer.

5.1.2 New vehicle architecture

New BEV have ranges of between 80 and 250 km, but these figures cannot be directly compared due to the lack of standard test procedures (stable speed, urban cycles specific to a manufacturer, 10-15 cycle in Japan, the American FTP 72 standard, etc.). In order to reach a range of 350 km in the NEDC, the Tesla Roadster is fitted with a battery with a total capacity of 56 kWh. An urban family car, like the Citroën C-Zero, has a range of 130 km in the NEDC with a 16 kWh battery.

On platforms dedicated to BEVs or are that are designed for this type of drive right from the early development phases, the batteries are positioned as low as possible between the axles in order to achieve the best possible dynamic performance. This is the case of the Nissan Leaf and the Mitsubishi i-MiEV. On the other hand, platforms that are initially designed for internal combustion drive only are obliged to house the batteries in the boot, due to the shortage of space (e.g. Renault Fluence and Mini E). In any case, the chassis and running gear must be configured accordingly.

The Bolloré Bluecar is also fitted with ultra-capacities capable of repeatedly storing and delivering high levels of electric power of 20 kW/kg (between 300 et 2,000 W/kg for lithium-ion batteries and Hitachi has just announced a new generation capable of 4,500 W/kg). This feature is perfect for the frequent charging/discharging cycles of the energy recovery and delivery phases. These ultra-capacities are the perfect match for lithium-ion batteries, whose power is inversely proportional to their storage capacity. Ultra-capacities are capable of storing just 5 Wh/kg, compared with between 150 and 180 Wh/kg for lithium-ion batteries.

The time taken to recharge the batteries is a critical issue. Numerous manufacturers have claimed that the batteries can be recharged to 80% in 30 minutes on high-amperage terminals. While this may be sufficient for short trips in towns, it is not suited to longer journeys, even if electric cars are not really designed for long trips. Better Place, which has entered an agreement with the Renault-Nissan Alliance, proposes a completely different system, which involves the automated replacement of the 250-kg batteries by robots. On 12 May 2009, a demonstration carried out in Yokohama proved that the operation can be performed in just one minute and 13 seconds. The batteries in storage are recharged by the mains supply and by photovoltaic panels. However, the high cost of storing the batteries means that the economic viability of this concept remains to be proved.

Apart from the change to lithium-ion batteries, the technologies used in electric powertrains are partly derived from those used in the latest hybrids : electric motor, inverter, voltage converter, power electronics, etc. Rechargeable hybrids also feature a new powertrain option, in which the front axle transmits the power of the internal combustion engine and the rear axle transmits the power of the electric motor-generator. This concept allows the engines to be mounted in parallel, without making any changes to the internal combustion powertrain. It also allows for 4-wheel drive.

Most motors use three-phase current and are of the asynchronous permanent magnet type, but a few projects use synchronous machines with coiled rotors or hybrid synchronous machines. This decision depends on the automaker's priorities in terms of price and performance in the broadest sense (efficiency at the various points of use, control of revs and torque, response time, etc.). The asynchronous motor seems to be falling out of favor. The yield of the charger, which coverts the DC into three-phase AC between the batteries and the motor control system, is between 85% and 92%. Improving this performance would have a direct effect on consumption, range and the cooling system. A number of developments have already appeared on hybrid vehicles, including the increase of the motors' working voltage from 350 to 600 volts. The most recent chargers are liquid-cooled on both sides in order to improve the evacuation of the lost energy. The automotive industry is looking forward to chargers that are lighter and more compact. Currently, the power electronics of an 80 kW electric car weigh 20 kg and take up about 10 dm^3.

5.2 Second generation (2013-2014)

5.2.1 Powertrain

Lithium batteries must be developed further in order to cut their cost and increase their specific energy. But these two criteria are inversely correlated, and any progress will necessarily be a compromise. China hopes to become the leading supplier of low-cost batteries, but the technology used would only deliver 120 Wh/kg. In the short term, no radical changes are expected in terms of battery performance, but their long-term potential to progress remains significant.

A number of projects have also demonstrated that range can be extended by installing photovoltaic panels on the roof. The conversion of the sun's rays, which cost nothing, into electric power can produce up to 1.5 kWh a day if the car is exposed to daylight in fine weather. The latest generation of Toyota's Prius hybrid is already fitted with 56 W panels, but they are only used to power the ventilation system in the cabin. The further development of this technology should see 120 W/m^2 in the medium term and a connection with the battery charging system in order to extend the range. The Bolloré project announces gains of up to 15% in the most favorable cases. When the brakes are applied, it is still not possible to recover all the kinetic energy, due to the limited power of the motor-generator and the batteries. Progress in this field should extend the range significantly, especially in urban driving. The Mini E is the first electric car to go down this path. Up to 70% of the drive power is available as braking power by the motor, which then operates as a generator. In city driving, the car is slowed not by pressing the brake pedal, but simply by controlling the position of the accelerator.

The most significant short-term progress will come from the electronic motor management systems. While these motors are already outstandingly efficient, the same cannot be said of the chargers and the voltage converters. According to the EPA method in force in the United States, General Motors has announced a consumption of 25 kWh per 100 miles in city driving, or 160 Wh/km, for its REBEV Volt model, a figure that will be even much lower with the second-generation vehicles. Efficiency will be improved by reducing the intensity flowing through the power electronics and, consequently, by increasing the voltage. New technologies will also allow the weight and dimensions of the power electronics to be reduced. And the specific and volume power of the motors will have to be improved. Certain applications will also be capable of working with two-gear transmissions in order to improve the efficiency of the powertrain across a broader speed range.

A dedicated platform will allow the entire architecture of the car to be reviewed, from the distribution of volumes to the use of motors installed in the wheels. Frost & Sullivan predicts that the ECM (Electric Corner Modules) concept could account for a million vehicles in Europe by 2020. This technological breakthrough, which already exists in a number of concept cars, represents a significant step forward in terms of space requirements and opens the way for an in-depth rethink of automotive architecture. The powertrain is also simplified: no need for a differential, easier control of dynamic stability and lighter and more compact 4-wheel drive. The reduction of local stress in the body shell will also reduce weight. But this concept faces a number of technological challenges. In the absence of a differential, the distribution of the torque between each motor must be controlled by a global management system of the car's dynamic behavior, including stability control. One critical point is the substantial increase in non-suspended weight, which could be overcome by active electric suspension.

All the projects unveiled thus far have been fitted with a simple transmission reduction system. It is tempting to look into the use of two-speed gearboxes. The engine would work more often in its zone of greatest efficiency and the top speed could be increased without losing any capacity to accelerate. However, most constructors believe that it is preferable to opt for mechanical simplicity to avoid extra costs. To be acceptable to customers, the gear change must be made without any interruption in torque. This can only be achieved by installing additional devices, such as clutches and a planetary gear or an idler.

5.2.2 Comfort and safety equipment

Cutting the power consumption of electric cars aims both to increase their range and reduce the quantity of on-board batteries, and, as a consequence, to reduce their weight and cost. Reducing the weight of any part also, to a certain extent, allows for lighter vehicle structures, thereby achieving even greater weight gains than those made by the part alone, and increasing the vehicle's range. Reductions in consumption will not only be achieved by improving the powertrain, but also by optimizing the comfort and safety equipment.

The electric heating system powered by the battery, based on the Joule effect with the current technology of PTC (Positive Temperature Coefficient) elements, is one possibility that directly impacts range. Other developments will allow the energy losses in the powertrain to be recovered (batteries, power electronics and motor) in order to heat the cabin. Another possibility is the use of heat pump-like devices derived from a modified air conditioning system.

Air conditioning also consumes a lot of power. Equipment suppliers will have to optimize the power consumption or aircon systems. Achieving this goal will be made all the more difficult by measures to ban air conditioning systems in new vehicles in Europe based on fluorinated greenhouse gases with a global warming potential greater than 150 on 1 January 2011. This law will outlaw the R134a that is currently used. One of the most promising solutions is the fluid HFO 1234, which demands only moderate investment. Another possibility is the fluid R734a, which is more efficient but more costly. Heat insulated passenger compartments would also reduce exchanges with the air outdoors and sun rays. It would also be useful to be able to remotely control the heating and air conditioning systems in order to prepare the cabin when the vehicle is being recharged from the mains, without using the energy of the batteries.

Power-assisted equipment will also have to be adapted. Consumption of power steering, which already uses electric power and is more efficient than older hydraulic systems, will have to be further reduced. Alternatively, lighter vehicles whose weight distribution does not overload the front end of the car, could do without power steering. Brake assist systems, that draw their energy from the negative pressure created at the inlet of gasoline engines or from a vacuum pump in diesel engines, will have to rely on electricity. It is also probable that, in the longer term, fully electric brake-by-wire systems will be introduced. In this case, calipers fitted with hydraulic pistons will be replaced by an electric motor controlled by an ECU that manages the assist function, the distribution of braking power between the wheels and all the functions of a stability control system.

Finally, lights can also consume more than 400 W. The spread of xenon lights and/or LED-based lights (Light Emitting Diode) are also quite acceptable, if not costly. Most of the power used by the lighting system in a typical driving cycle is in fact consumed by the daytime lights that are now compulsory in an increasing number of countries. LED-based systems appear to be the best solution for this function.

6 Essential coordination between different players

The deployment of electric vehicles depends not only on their technical progress, but also on a series of services that they require in order to operate. All the service providers involved must coordinate their actions in order to provide end users with a product that is functional, attractive and mature.

> "We must not make the same mistake as in the 1990s, when we focused on technology and neglected after-sales".
> A statement made by Chantal Jouanno, French Secretary of State for the Ecology, on 17 February 2009.

6.1 The automotive industry

Power struggles between automakers may be affected in the future by decisions taken by government authorities. Today, Japan appears to possess a slight lead when it comes to supplying large volumes of electrified vehicles, thanks mainly to the early commitment made to hybrid cars, starting with the Toyota Prius, and then purely electric solutions (Mitsubishi, Nissan, Subaru). In an effort to make up lost ground, the United States has launched a massive aid program to help its automakers reach the same level of technology as the competition. The European Union is being more cautious. But European manufacturers could also slip behind technologically, if they are unable to benefit from the same advantages.

The development and industrial production of electric vehicles demand very ambitious measures. Support from governments is essential if two generations of vehicles are to be developed at the same time. The first generation, due to reach the market in 2011, should prompt and increase demand. The second generation, which will be launched in 2014, will face the difficult task of making ZEV competitive, without any tax breaks. If the two generations are not developed simultaneously, then there is a danger that governments will not be able to foot the bill of the tax incentives in a booming market. In this case, market growth could be crippled, since the investments made in the deployment of infrastructures would no longer be profitable and the target clientele would be disappointed.

Any subsidies must not neglect Tier 1 equipment suppliers and their partners. They are both major players in the automotive industry, who make a fundamental contribution to innovation by adapting their products and essential components to electric vehicles. Just like the automakers, they are an integral part of the innovation chain.

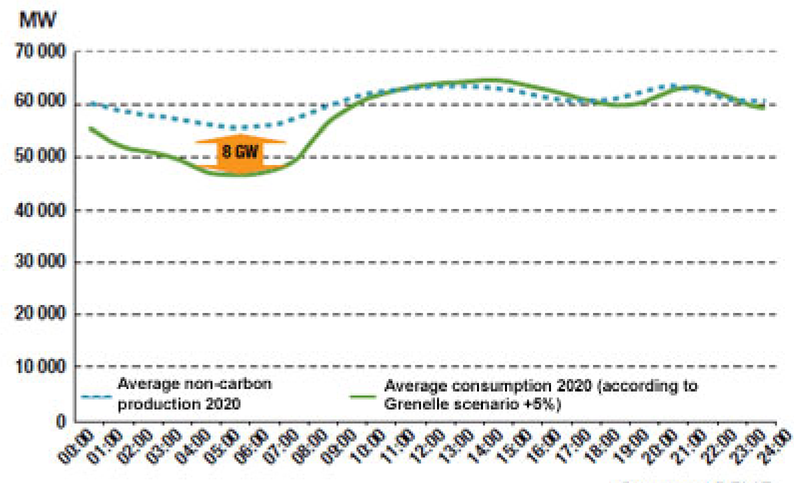
From a technical perspective, each component must be optimized not only individually, but also together with the rest of the chain. Equipment suppliers and automakers must work together in order to deliver a coherent and efficient system. They must remember that the integration of the powertrain in a vehicle impacts the distribution of weight and volume and the comfort and safety systems.

New technologies must be standardized, especially with regard to the definition of electric connections and the characteristics of the current. This requires coordination between industrial manufacturers and the operators of the infrastructure. Both the service providers and the automakers will have to standardize their products if the concept of automated battery replacements is to be developed. Finally, automakers and the authorities will have to draw up standards to compare the range and the consumption of REBEV vehicles in combustion mode.

6.2 Power utilities

Does the emergence of the electric vehicle necessarily require the construction of new electric power stations? The answer differs from one country to another, since the current potential to generate electric power is highly disparate. By way of example, according to the IEA (International Energy Agency), the average consumption of electric power per inhabitant in China in 2006 was 2,179 kWh, 5,828 kWh in Europe, 7,702 kWh in Japan and 12,924 kWh in the USA. The impact of the introduction of electric automobiles would differ from one country to another.

A survey by France's ADEME (environmental and energy management agency) has shown that the impact of recharging electric vehicles depends very much on the method chosen. The most suitable method consists in recharging the vehicle at the user's home at night, when the demand for electricity is low. In this case, ADEME estimates that 4 million vehicles could be serviced in France in 2020 using only non-carbon electric power. This figure comfortably outstrips all forecasts of electric vehicle sales. On the other hand, very high numbers of quick recharges that require more power, during the daytime could result in the need to import current when the demand is high (during very cold spells). The situation could become problematic if neighboring countries were in the same condition. Such recharges could also cause drops in voltage that could only be avoided by power stations, probably thermal, that are kept on standby. This problem also applies to the automated replacement of batteries, which could result in high consumption at peak periods (e.g. the holiday season).



Source: ADEME.

Another study conducted in the United States by the National Renewable Energy Laboratory (NREL) in the Department of Energy came to the same conclusions about night time charging. It added that a 50% penetration rate of rechargeable hybrids (PHEV) would only increase demand for electric power per inhabitant by about 5% to 10%, and would not require any additional production capacity. This survey was based on the use of a PHEV vehicle with a 20-mile range in electric mode.

Issues of electric power consumption due to charging that could appear in the medium term must be addressed by coordinating the offers provided by automakers and the government authorities. While electricity already costs less at night in most countries, it would be beneficial to offer both consumers and businesses an even greater difference in price for slow charging during the same periods.

The impact of recharging electric vehicles on the network is a complex affair and has been studied by the power utilities from every angle. By way of example, the German power utility E.ON has launched the project "Assessing the System Benefits of Dual Use Electricity Storage" with a view to investigating the benefits of interconnecting large numbers of electric vehicle batteries when they are recharging. E.ON, which operates on most markets in the northern hemisphere, believes that the mains network could act as an energy reserve capable of regulating peaks and troughs in consumption. This concept requires the use of two-direction electric networks capable of managing safety issues, operations and pricing.

6.3 Infrastructure operators

The deployment of a complete recharging infrastructure must address factors regarding distribution, safety and billing. The means of distribution determines the type of recharging terminal, their location, number and accessibility. The deployment of such a system requires effective coordination between the public authorities, energy utilities, manufacturers and service companies. Funding is the key to the successful creation of an infrastructure. The high costs could represent a serious obstacle to the deployment of electric vehicles. Depending on the national and local political will, funding could be provided by one player or spread between several local authorities and transport service providers. Several contracts have already been signed in a number of countries and cities.

By way of example, the Israeli government, in cooperation with the Californian company Better Place, and further to an agreement signed with the Renault-Nissan Alliance, plans to build a nationwide network of 500,000 recharging stations by 2011.

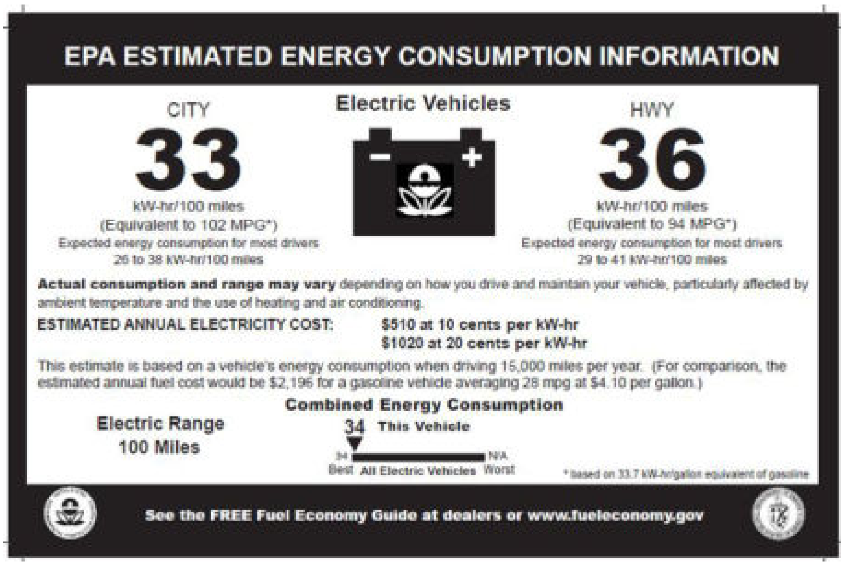
The EV Project is one of the biggest projects to build recharging infrastructures in the United States. ECOtality, which specializes in the transport and storage of electric power, will install 11,000 terminals in 15 major cities, both in private dwellings and public places. It will also deploy a fleet of 4,700 Nissan Leaf vehicles. This contract includes the EV Micro-Climate program, which coordinates government organizations, public services, automakers and regional and strategic organizations in order to promote the adoption of electric vehicles that are connected to the mains network. This program also plans to raise public awareness.

100 electric cars and LCVs made by the Renault-Nissan Alliance will be tested in the Paris region for from January 2011 to July 2012 as part of the SAVE project. . Consumers, professionals and local authority employees will be provided with charging facilities developed with the power utility EDF at home, in the workplace, in car parks or on the public highway. An experiment on a similar scale has been underway in Austria since June 2009. The Vlotte project includes 45 vehicles, mainly Th!ink models, but also electric versions of the Fiat Panda, Fiat 500 and Mazda 2 and Mitsubishi i-MiEV models. Another example is the VERT (Véhicules Electriques pour une Réunion Technologique) project on Reunion Island, which will test electric vehicles in combination with charging facilities fed by dedicated means of generating renewable energy, and in particular photovoltaic systems.

The growing number of recent initiatives have demonstrated that infrastructures can only be effectively deployed if the different players are well coordinated.

6.4 Governments and local authorities

Local authorities can also support the launch of electric vehicles by committing to purchase significant volumes. This idea has been extensively used in Japan to support the launch hybrid vehicles and is also being used to boost the development of fuel cell cars. This is the case in China and the United States. In France, the State has signed a letter of intent with a number of enterprises (the French Post Office, EDF, Vinci, Veolia, France Telecom, GDF Suez) with a view to buying 100,000 electric vehicles over a five-year period. It would also be useful to organize information or incentive campaigns for the general public highlighting the individual and collective benefits of zero-emission transport.



It is surprising to note that the public authorities in the United States currently convert the consumption of battery electric vehicles into the equivalent fuel consumption! The Department of Energy uses a calculation based on the urban and highway EPA cycle that takes account of all the parameters (energy ratios, well-to-tank energy consumption, etc.) and adds a bonus for the non-consumption of fossil fuels. The Mini-e, a BEV version of the Mini, boasts a label claiming “33 kWh/100 miles (equivalent to 102 MPG)” in City mode (2.3 l/100 km). A coefficient of 82.049 Watt-hours per gallon is applied.

The cohabitation between combustion and electric vehicles poses a problem with regard to the funding of the road infrastructure (roads, bridges, information systems, etc.). These costs are paid by the State, which funds them partly with the taxes on fuel consumed by road-going vehicles. Would it be equitable if only internal combustion vehicles were taxed in order to fund the maintenance and the development of the road network? The State could claim part of the income of the service providers that manage payments at the recharging terminals, but what about users who recharge their vehicles at home?

6.5 New players

The deployment of the electric car will inevitably see a confrontation between established manufacturers and new suppliers. The former are currently faced with ever stricter standards applying to pollutant emissions and the reduction of fuel consumption by combustion vehicles. This technical challenge impacts the cost of the end product, but it also raises a barrier against possible competitors, who, inevitably, are technologically less mature. The electric car removes this barrier and therefore represents a serious risk for the established manufacturers. The same applies to their specialist subcontractors (exhaust systems, foundries, engine parts, etc.), who will suffer from a drop in demand for internal combustion engines. This opportunity will be seized by new players (Bolloré, Tesla, Th!ink, etc.) and new equipment suppliers, who will provide the motors (PML Flightlink, TM4, etc.) or the power electronics. It is also an opportunity for developing nations, including India and China. In China, the development of the electric car will also limit the ecological impact of the country's economic growth. Between 2005 and 2030, the Chinese automotive market is expected to grow ten-fold. Some of the Chinese automakers could then enter the worldwide top 10, in particular on the electric car market.

While most battery suppliers are well known manufacturers or the result of specialized joint ventures, some of them may be new to the automotive industry. Given the importance of batteries for this type of vehicle, both from the economic and technical perspectives, these new players will play an increasingly important role in the automotive industry, and in other industries too. Their emergence will occur at the cost of the powerful oil industry. One notable trend is the increase in technical and financial partnerships between battery suppliers, automakers and equipment suppliers that aim to conduct joint developments. The basic product – the battery – becomes a series of battery packs that also manages the operational and safety functions.

Finally, if rental operators are to enter this new market, then new service companies will emerge to install and fund the infrastructures and/or means of payment.

7 Valeo's products: ZEV for all

Valeo, with its partners Leroy Somer and GKN, is also developing a line of second generation powertrains at affordable prices. Its goal is for the cost of the electric motor as a whole, including inverter, charger, voltage converter and reduction gear, eventually to be equivalent to that of the gasoline-driven powertrain (engine, gearbox and differential) which it is replacing. Overall cost represents a major condition if second-generation rechargeable electric and hybrid car are to be available for mass distribution at economically viable prices without governmental aid for buyers.

Efforts to cut prices concentrate on three levers:

- The reduction of the cost of the electric powertrain.
- Energy Consumption. At the same range, cutting energy consumption will allow the capacity, weight and cost of the batteries to be reduced. This reduction of energy consumption will apply to the electric powertrain, temperature control of the cabin and the lighting.
- Increasing the lifetime of batteries through improved thermal control and by limiting peaks in consumption of current.

Moreover, the specific and volume powers of this range of powertrains, which are due to be launched at the end of 2012, will also be superior to those of the first generation.

7.1 The French electric power consortium

To become a leading global player in the electric powertrain market, Valeo has signed development agreements with major industrial partners. This joint development will provide the most complete final product offer, based on the best technological choices available. In addition to Valeo, this consortium also includes some of the leading equipment suppliers in their fields, such as Leroy-Somer, Johnson Controls-Saft, GKN, Michelin and Leoni.

- Valeo is an independent industrial group entirely focused on the design, manufacture, and sale of components and systems for cars and trucks. The automotive supplier’s skills and know-how cover the workings of the motor, vehicle safety, battery efficiency and interior temperature control.
- Leroy-Somer is a world leader in drive systems and industrial alternators. This subsidiary of Emerson employs 8,000 people worldwide, including almost 4,000 in France. Leroy Somer makes high-performance synchronous electric motors incorporating its unique technology that offers efficiency close to 98%.
- Johnson Controls-Saft is a joint venture between a leading battery manufacturer and one of the biggest automotive equipment suppliers. Many hybrid vehicles are already fitted with batteries made by the Group. Johnson Controls-Saft supplies the lithium-ion battery system.
- GKN is a worldwide supplier of sophisticated products to leading manufacturers of light vehicles, aircraft engines and equipment for agriculture and the construction industry. GKN completes the drive train with an axle reduction gear and half shafts. These components transmit the power from the motor to the wheels with minimum losses, while limiting vibrations and noise.
- Michelin sells high-technology tires for all types of vehicles, road maps, guides and digital services. The company is also famous for having invented the radial tire, a technology now used by every manufacturer. Michelin makes tyres with very low rolling resistance, which help to extend the range of electric vehicles. They achieve this performance without compromising vehicle safety or the durability of the tyres. Michelin also inputs its expertise in driveline and wheel-mounted motors (the Active Wheel project).
- Leoni develops high-voltage cables that connect the various components of the drive train (electric motor, battery, UPS, converter, etc.). Its broad range of products, offering optimal weight and costs, covers all the configurations and needs of electric vehicles.

Valeo and its partners are able to address all technical issues relating to rechargeable electric and hybrid vehicles, and to offer every possible type of powertrain architecture.

7.2 Innovations in the powertrain

Valeo's second-generation powertrain is the result of several technological innovations. It represents an important step forward in the development of the zero-emission vehicle.

7.2.1 Combining the charger and the converter

The converter transforms the direct current from the battery and the voltage converter into a three-phase current for the electric motor. It also manages the electric power according to the instructions given by the accelerator pedal and other control functions, such as traction control, cruise control and stability control. The charger receives the alternating current through the mains connector and transforms it into direct current with a voltage adapted to the battery pack. These two systems are usually separate and independent and the vehicle is charged when at a standstill.

But this charging system is heavy, unwieldy and expensive. Valeo has innovated by using the converter and part of the electric motor in inverted mode, since these parts are idle at this time. As a consequence, considerable savings are made by doing away with the dedicated charging system. This new system is compatible with slow charging and average power charges of 43 kW or more. This innovation cuts costs, as well as the size and weight of the electronics. The converter could be adapted thanks to its "triple H bridge" configuration, allowing the charging system to be connected to the central points.

Another advantage is that, if one of the phases fails, the system continues to function in two-phase mode, which is impossible with a standard synchronous motor.

7.2.2 High voltage

In order to optimize the efficiency of the motor at low revs, the voltage is gradually adapted between 410 and 900 volts by a programmable device. The highest value is reached above nominal revs. This very high voltage used to power the motor and the converter is then constant and completely independent of the battery's state of charge.

A higher voltage allows the intensity in the systems to be reduced. As a consequence, losses are limited and the yield of the powertrain is increased by up to 20%. The energy saved extends the range of the vehicle accordingly. Moreover, the cost of the product is cut, because less silicon is necessary. Finally, the charge system can easily be adapted to the different supply voltages on different markets (e.g. 100 V in Japan and 240 V in Europe).

7.2.3 Other innovations

The entire powertrain has been designed to work with a motor running at particularly high revs. This technological option not only cuts costs, but also reduces the size and weight of the motor, thereby improving range or allowing the capacity and cost of the batteries to be reduced.

The power electronics are positioned as close as possible to the motor windings for a more compact and reliable system. The electrical losses inherent in the length of the cables are also limited.

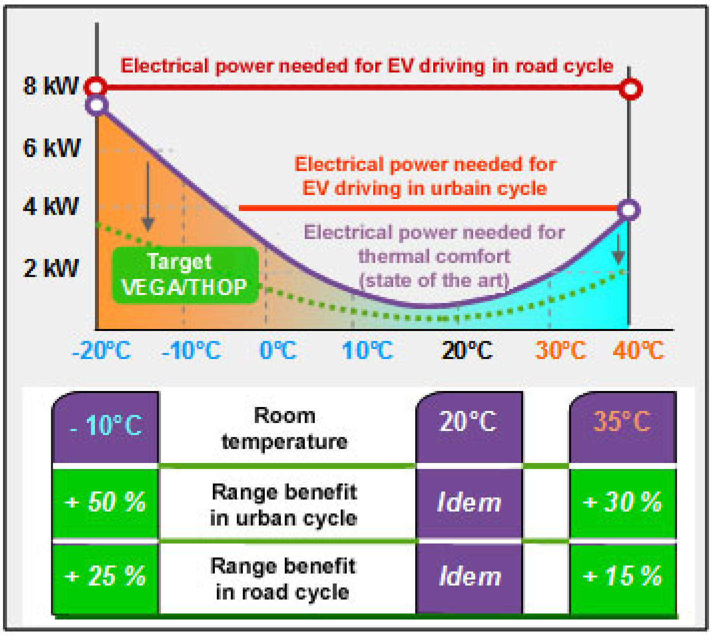
Production of over 10,000 electric cars

With over 10,000 vehicles equipped between 1995 and 2005, Valeo is the world's largest supplier of electric powertrains. Citroën AX, Saxo and Berlingo, Peugeot 106 and Partner, and Renault Kangoo vehicles driven by electric powertrains developed by Valeo have already covered more than one billion kilometers.

7.3 The VEGA/THOP project

The purpose of the VEGA/THOP(*) project is to build electric demonstrator vehicles with batteries and thermal management of the cabin that are optimized using new solutions. These solutions will improve the range of electric or hybrid vehicles, especially at extreme outdoor temperatures, not by optimizing the efficiency of the electric motors or the weight of the vehicles, but by proposing innovative heat control systems and by rethinking the thermal control of the passenger compartment. Under certain conditions, the heating and air conditioning functions can reduce the range of an electric vehicle by more than 50%. The aim is to develop a flexible source of heating and cooling for a better thermal control of the batteries.

The plan has been approved by the steering committee of the research demonstrator fund at the Agency for the Environment and Energy Management (ADEME). The plan consists in investigating solutions suited to the architectures of electric cars and converting two demonstration Renault Megane vehicles by 2011.



VEGA/THOP brings together Valeo, Renault, Saint Gobain, Hutchinson and two laboratories: the CETHIL-INSA in Lyon, which specializes in the analysis of thermal transfers, and the LINC, or Imaging and Cognitive Neuroscience Laboratory, which will look into a new approach to demands and expectations for temperature control in a vehicle.

(*) : VEGA/THOP: (long-range electric vehicle/system for the optimized thermal control of the cabin and the powertrain).

7.4 Thermal control of motors in hybrid vehicles

With the addition of another motor, the cooling system of hybrid vehicles (parallel, series or rechargeable) becomes more complex than in a conventional vehicle driven only by an internal combustion engine. The optimization of the cooling system is a key factor in extending the operating range of the electric powertrain, because the electric components need a stable temperature if they are to work efficiently and for a long time.

With a standard cooling architecture, it is necessary to add a dedicated circuit to cool the DC/DC converter and the electric motor, including a radiator, a water pump, an electric fan and valves. Thanks to its UltimateCooling™ architecture, Valeo has developed a plug-and-play approach that allows new parts requiring cooling to be added without making any changes to the architecture in the motor compartment.

UltimateCooling™ is based on the use of a single coolant fluid in two circuits at different temperatures. This system guarantees that every component is at its optimal working temperature with the lowest possible volume of coolant fluid. Adjusting the cooling system to the strict minimum reduces the consumption of electric power and CO_2 emissions. The two temperatures are provided by a single multi-temperature radiator that also reduces the dimensions of the front end of the vehicle.

For parallel or series hybrid vehicles, the ability to easily add components, such as the electric motor, the DC/DC converter or the battery charger, to the low temperature circuit using a simple system of valves means that a single cooling architecture can be used for combustion, hybrid and electric vehicles without making any changes.

The cooling system remains fully operational while the battery is being charged in order to protect both the charger and the battery. Valeo offers a wide range of battery thermal control technologies that are common to the hybrid and electric vehicles presented below.

Two European manufacturers have already opted for the UltimateCooling™ architecture to cool their future hybrid and electric vehicles.

7.5 Thermal control of electric vehicles

Electric vehicles have numerous requirements in terms of thermal control. Not only is it necessary to cool the electric motor and the electronics and to keep the occupants comfortable all year round, but the system also determines the range of the vehicle and the reliability and durability of the battery.

Valeo proposes a totally new architecture, made up of three circuits of fluids operating at different temperatures: a main coolant circuit that cools the drive train and heats the cabin, a refrigerant fluid circuit to cool the cabin and another coolant circuit for the thermal control of the battery. The global architecture optimizes energy flows to guarantee the reliability of the drive train components and to maximize the range.

7.5.1 Cooling the drive train and heating the cabin

A loop in the main circuit cools the drive train and heats the cabin. This hot loop uses equipment that has been tried and tested on internal combustion vehicles, but the front radiator has been adapted to the lower flow rates and internal operating temperatures. The fan positioned in front of this radiator starts up whenever necessary. This fan has been improved in comparison with the fans found in internal combustion engines for a longer service life, especially since it may be required to work while the battery is being charged. The reduced speed and specially adapted shape of the vanes mean that the fan is totally silent. It cannot be heard at all, which is a real advantage when charging at night.

Electric vehicles must provide the same levels of thermal comfort as conventional vehicles. But since the highly efficient electric motor only produces a little heat, it is necessary to find means of heating the passenger compartment that do not impact the range or the cost of the vehicle.

To do this, Valeo has developed a heat accumulator that produces and stores large quantities of heat when the vehicle is connected to the charging terminal. This accumulator is made up of a thermally insulated unit containing a special material capable of storing and dispensing heat through a water circuit connected to the vehicle's heating system. The complete system also includes a heating resistor and a water pump. The heat accumulator is designed for easy installation in the vehicle. The cabin is heated for a given length of time without discharging the battery. This system increases range by about 10% in urban driving at outdoor temperatures close to 0°C. Alternatively, and without affecting the range, automakers can also use this solution to limit the cost of the vehicle by reducing the number of battery modules.

Valeo has also developed a series of innovative solutions that are adapted to the vehicle's vocation and its characteristics, in order to limit the energy consumed by the heating function. These solutions offer a range of compromises between the quantity of energy to be recovered, complexity and the associated surcharges.

Conditions permitting, the drive train cooling circuit can input extra heat to the cabin heating circuit. It is also possible to recycle or recover part of the thermal energy available in the air in the cabin, rather than allowing it to escape outdoors. Valeo is also developing a number of heat pump architectures, which offer the benefit of using the energy in the ambient atmosphere.

7.5.2 Cabin air conditioning

The second thermal circuit is for the air conditioning system. The technology of the compressor has been optimized in order to better meet the specifications of electric and hybrid vehicles. Unlike conventional compressors, it is driven by a built-in electric motor. This option offers greater flexibility of installation in the engine compartment and allows the compressor to function when the motor is stopped, which is impossible with a conventional drive system.

Since the interior of an electric vehicle is very quiet, the vibrations and noise produced by the compressor have been reduced to the strict minimum. The compact compressor is of the scroll type. This high-performance technology and the brushless electric drive motor help to cut consumption of electricity. Furthermore, the compressor is fitted with an oil separator that boosts the overall efficiency of the air conditioning system. Lastly, this system is compatible with the R1234yf refrigerant that complies with the new European regulations.

7.5.3 Thermal control of the battery

The thermal control of the lithium-ion battery is crucially important, because it determines the life time of the battery and its capacity to deliver and absorb energy. The operating temperature of the battery must remain at between 20°C and 30°C, irrespective of the ambient conditions and usage (loading, driving). This temperature must be guaranteed throughout the battery pack so that all the cells age in an even manner.

In the architecture developed by Valeo, it is the third circuit that thermally controls the battery by circulating water inside its casing. The energy required for heating purposes is taken from the main circuit of the drive train, while energy for cooling is taken from the air conditioning circuit.

Depending on the demands of the automakers and factors relating to performance, cost or standardization, Valeo also proposes alternative solutions, including cooling by air, direct cooling by refrigerant or reversible hot or cold conditioning by thermo-electricity.

In air cooling systems, a fan draws in the air from the cabin and spreads it uniformly across the battery pack via the ducts. For increased cooling, it is also possible to recover cool air from an evaporator used in the air conditioning system. As well as this cooling function, the air circuit also evacuates any toxic or inflammable gases released by the batteries. The fan is powered by a high-performance brushless motor, and its output can be varied through voltage control. This brushless technology eliminates any risk of sparks near the batteries. In order to reduce cabin temperature before starting up the vehicle, the fan can also "pre-cool" the cabin in hot weather, with low electricity consumption.

In direct cooling by refrigerant, which is even more innovative, an evaporator is built into the battery module and connected in parallel to the vehicle's conventional air conditioning circuit. This evaporator is made of coil-shaped aluminum tubes put in contact with the cells of the battery pack. This construction ensures direct heat exchange with the cells, and perfect regulation of the temperatures inside the pack.

Reversible hot or cold conditioning by thermo-electricity controls the temperature of the battery cells using a set of Peltier cells with two faces, one cold and the other hot. The difference in temperature is controlled by the voltage applied to the cells. By using the cold side or the hot side, it is possible to cool the batteries down or heat them up. One advantage of this system is that it is totally autonomous from the vehicle, apart from the electric connection. It is specially well suited to the automated replacement of batteries.

7.6 Energy-efficient lighting

Daytime lights, which are already compulsory in Scandinavia and Canada, will also become compulsory in Europe on all light vehicles in 2011. Daytime lights are an active safety measure that allows other vehicles to be seen more quickly and more clearly. Unlike night lights, daytime lights are switched on permanently, so it is very important to minimize their consumption and limit their impact on the vehicle's range. Valeo has developed a dedicated function that uses LEDs, or Light Emitting Diodes. The total electric power consumed by this function has been cut from 38 W with halogen bulbs, to just 10 W. Moreover, LED-based daytime lights do not require any maintenance for the vehicle’s entire life cycle and are perfectly suited to intensive use.

Low-beam lights, which consume 125 W with H4 halogen bulbs, consume just 40 W with LEDs, while producing the same quantity of light. New developments will also reduce consumption to just 30 W by 2015. In this case too, the LEDs last as long as the car, or four times longer than H4 halogen bulbs. Their whiter light is also easier on the eyes, because it is closer to natural daylight. In the future, it will be possible to momentarily reduce the intensity of the LEDs in certain cases, in very heavy traffic for example or when the vehicle is moving slowly, thereby cutting energy consumption even further. This is not possible with halogen bulbs, which produce a reddish light when their supply voltage is reduced.

With conventional bulbs, the night lighting system, weighted with the rate of use of each function (0% daytime lights, 5% indicators, 100% side lights, 30% brake lights, 80% low beam lights, 20% high-beam lights) consumes an average of 206 W. If all these functions use LEDs, they consume an average of just 41 W.

7.7 Smart keys

Electric cars can communicate with their key in order to inform the owner of its current charge status: is the car connected to the terminal, is the battery charged, what is the estimated range at the moment and after a given charging time? Owners can then organize their journeys and check that the battery is properly charged.

Valeo’s Smart Car Key is fitted with a color screen, whose dimensions can be modulated to meet the constructor's demands. Communications between the car and the owner can be enhanced by a beeper or a buzzer. The Smart Car Key uses a two-way radio frequency that is higher than that of existing remote controls. Depending on the environment, the range can reach 500 meters, which is far enough to communicate with the car from home or the office.

Another very useful function of this key is the possibility to control the temperature in the car before setting off on a journey. Since the heating and air conditioning functions consume a lot of energy, it is preferable to use the power from the charging terminal whenever possible, rather than consuming the battery's power. The Smart Car Key can be used to remotely control the temperature inside the vehicle before setting off and to view the current temperature. Occupants will be comfortable from the moment they set off, without impacting the range of the car.

The Smart Car Key can provide a host of other useful information, depending on the automaker’s specific demands. It can be used to view the position of the windows, the tire pressure or the mileage remaining before the next service. The Smart Car Key also offers another useful service, since it doubles up as a USB key that can be used to copy music or video files from a PC.

7.8 Driving aids and safety functions

The specifics of electric vehicles have shown that new functions need to be developed, in particular in the fields of driving aids and active safety. Today, Valeo proposes a range of solutions based on ultrasound and camera technologies, which have already been tried and tested.

7.8.1 Quiet pedestrian warning system

Silence is one of the qualities of electric cars that is often highlighted. At speeds of less than 50 kph, the electric motor is just about the only source of noise, and it is much quieter than an internal combustion engine. While this quality may be appreciated, especially in built-up areas, it can pose a problem when it comes to the safety of pedestrians, who often cross the road without looking carefully and simply listen out for the sound of an engine. The smart solution developed by Valeo consists of a pedestrian detection system that automatically sends a sound warning in the direction where the pedestrians are located. This concept offers the advantage of warning any pedestrians who are in the vehicle’s path, without making any needless noise. The detection system comprises a forward-looking camera positioned behind the windscreen and ultrasound detectors. The camera detects the pedestrian(s), the ultrasound sensors confirm their presence and the software determines their position in relation to the vehicle’s trajectory.

7.8.2 Easy docking for automatic connection

Automatic connection is a concept that allows the battery to be charged without taking a cable and connecting it to an electric terminal. The operation is performed by an automatic arm that connects the charging terminal to the vehicle. But this system requires the vehicle to be precisely positioned in front of the arm. The docking maneuver can only be made by combining the data from the front camera and the ultrasound sensors that are used by the forward parking aid system. As the vehicle approaches, the camera scans the surroundings and the target, then the ultrasound sensors provide the precision needed to position the connector in front of the arm.

7.8.3 Reducing consumption by taking account of traffic flows

The consumption of an electric or internal combustion vehicle increases sharply when the vehicle brakes sharply. Using Valeo's front camera, a programme can be used to cut consumption by adapting the vehicle's speed to the speed of the traffic flow. This camera takes account of the speed of the vehicle in front and the presence of traffic lights in order to instruct the driver to release the accelerator immediately, as soon as the system detects that it will soon be necessary to apply the brakes.

7.8.4 Numerous new driving aids

The vehicle is already fitted with 12 ultrasound sensors – four at the front, four at the rear and one on each corner – meaning that it can be enhanced with a range of new functions. Ultra Park Assist provides semi-automatic aid when parking in a parallel, oblique or perpendicular position, and when maneuvering to leave a parking spot. In addition to the functions already mentioned, the front camera adds automatic switching between high- and low-beam headlights, BeamAtic® Premium (maximum high-beam lights without dazzling), reading speed limit signs and accidental lane change warning. A second camera positioned behind the rear window works with the rear ultrasound sensors to detect pedestrians when reversing.

8 Vehicles available

Electric propulsion can address the needs of a broad range of means of transport: bicycles, tricycles, motorbikes, basic compact cars, conventional or sports cars, LCVs, trucks, buses and even aircraft.

The tables below contain some of the electric vehicles capable of reaching at least 100 kph. The models are classified by their planned launch date (sometimes in limited initial volumes).

8.1 Battery electric vehicles (BEV)

Make and model	Length x Width (m)	Number of seats	Batteries	Motor	Range (Standard)	Performance	Expected launch date
Fiat Fiorino Micro-Vett	3.96 x 1.72	5	Lithium-ion	30 kW	100 km in urban cycles	100 kph 0-50 kph in 7 s.	Available
Fiat Fiorino Micro-Vett	4.25 x 1.72	5	Lithium-ion	30 kW	70 to 156 km	100 to 120 kph	Available
Phoenix Motorcars SUT	4.97 x 1.90	4	Lithium-titanium	98 kW	160 km	150 kph	Available
Venturi Fetish	2.89 x 1.88	2	Lithium-ion	180 kW	250 km	160 kph 0-100 kph in less than 5 s.	Available
TH!NK city	3.14 x 1.66	2	Lithium-ion or sodium	30 kW	180 km (ECE-R101)	100 kph 0-80 kph in 16.0 s.	Available
Tesla Motors Roadster	3.95 x 1.87	2	Lithium-ion	215 kW	340 km (NEDC)	212 kph 0-100 kph in 3.9 s.	Available
Subaru Stella	3.40 x 1.48	4	Lithium-ion	47 kW	80 km (10-15 Japan)	100 kph	Available in Japan
Toyota iQ (FT-EV)	2.99 x 1.68	3 (+1)	Lithium-ion	45 kW	80 km (10-15 Japan)	110 kph	Available in Japan
Mitsubishi i-Miev	3.40 x 1.48	4	Lithium-ion	47 kW	160 km (10-15 Japan)	130 kph	End of 2010
Peugeot Ion	3.47 x 1.48	4	Lithium - ion	47 kW	150 km (NEDC)	130 km/h 0-100 km/h in 15.9 s.	End of 2010
Citroën C-Zero	3.48 x 1.48	4	Lithium - ion	47 kW	130 km (NEDC)	130 km/h 0-100 km/h approx.. 15 s.	End of 2010
Nissan Leaf	4.45 x 1.77	5	Lithium-ion	90 kW	160 km (US-LA 4)	140 kph	End of 2010
Bolloré Bluecar	3.65 x 1.72	4	Lithium polymer metal	50 kW	250 km	130 kph 0-100 kph in 10 s.	End of 2010

Make and model	Length x Width (m)	Number of seats	Batteries	Motor	Range	Performance	Expected launch date
Renault Kangoo Express Z.E.	4.21 x 1.83	2	Lithium-ion	44 kW	160 km (NEDC)	130 kph	2011
Renault Fluence Z.E.	6.75 x 1.81	5	Lithium-ion	70 kW	160 km (NEDC)	135 kph	2011
BYD e6	4.56 x 1.82	5	Lithium iron phosphate	200 kW	400 km	140 kph 0-100 kph in 10 s.	2011 in the USA
Hyundai BlueOn	3.57 x 1.60	4	Lithium-ion polymer	61 kW	140 km (NEDC)	130 kph 0-100 km/h in 13.1 s.	2012
Smart Electric	2.69 x 1.56	2	Lithium-ion	30 kW	135 km (NEDC)	100 kph	2012 (Fleet in tests since 2010)
Mini E	3.70 x 1.68	2	Lithium-ion	150 kW	167 km (NEDC)	152 kph 0-100 km in 8.5 s.	Fleet in customer tests
BMW MegaCity	NC	4	Lithium-ion	100 kW	NC	150 kph	2013

Examples of other projects: Ford Focus (2012), Honda (2012), Porsche Boxster, Volkswagen Up!, Golf and Jetta (2013).

8.2 Range extender battery electric vehicles (REBEV)

Make and model	Length x Width (m)	Number of seats	Batteries	Electric motor	Range	Performance	Launch date
Audi A1 e-tron	NC	4	Lithium-ion	75 kW	50 km elect plus Wankel engine	130 kph	NC
Fisker Karma	4.99 x 1.98	4	Lithium-ion	300 kW (2 motors)	80 km (electric)	200 kph 0-100 kph in 5.8 s.	2010
Chevrolet Volt (2)	4.40 x 1.80	4	Lithium-ion	111 kW	60 km (electric) More than 500 km (combustion+electric) (1)	161 kph 0-100 kph in 9 s.	End of 2010
Volvo ReCharge Concept	4.25 x 1.78	4	Lithium-polymer	In the 4 wheels	100 km (electric)	160 kph 0-100 kph in 9 s.	2011 ?
Mercedes BlueZERO E-CELL PLUS	4.22 x 1.78	5	Lithium-ion	70 kW Peaks of 100 kW	50 km (electric) 600 km (combustion+electric)	150 kph 0-100 kph in less than 11 s.	NC
Chrysler 200C EV	4.88 x 1.87	4	Lithium-ion	200 kW	64 km (electric) 644 km (combustion+electric)	193 kph 0-100 kph in 7 s.	NC
BMW MegaCity	NC	4	Lithium-ion	100 kW	NC	150 kph	2013

(1) : according to internal GM cycle, NC: non communicated, (2): plus the Opel Ampera and Cadillac Converj with similar drive and recharging systems.

8.3 Rechargeable hybrid vehicles (PHEV)

Few rechargeable hybrid vehicles have been officially announced, but most automakers who already sell, or will soon launch, hybrid vehicles, have announced the development of a rechargeable hybrid. In more concrete terms, Toyota is currently testing different plug-in configurations of the Prius in several major cities, especially in terms of range (battery type and capacity). PSA Peugeot Citroën has also announced that its Hybrid4 (diesel/electric) architecture will feature a recharge mode by 2012.

All hybrids can potentially be converted into rechargeable versions. Range in electric mode will be close to that of REBEV electric vehicles.

9 Conclusion

Allowing only ZEV into our major cities by 2025 would address many of the problems that our society currently faces. The technical maturity of electric vehicles and rechargeable hybrids and the outlook for their future development mean that this goal can be achieved. But many obstacles must be overcome before a significant number of ZEV are on the road.

As we have already demonstrated, the challenge facing the electric vehicle or the rechargeable hybrid is essentially an economic one. The technical development of these vehicles is necessary in order to propose a product with a total cost of ownership equivalent to that of an internal combustion vehicle without any financial incentives. The rapid development of this market will comprise the following phases:

From 2010-2011, a first generation of vehicles intended mainly for fleets operated by companies and public authorities, public transport, taxis, and rental and car-sharing schemes will be marketed. The investment in the necessary infrastructure will be limited. This first step should create demand from the general public.

In 2014-2015, a second generation of electric vehicles or rechargeable hybrids for consumers will be available. Its success will be determined by its competitive appeal compared with internal combustion vehicles and the deployment of a denser infrastructure that includes show-charge terminals at home and at the workplace, quick-recharge terminals and battery replacement stations.

The simultaneous development of two generations of vehicles is necessary, because governments will not be able to pay the incentives to buy if the market takes off, and because around ten years are necessary before polluting vehicles can be banned from city centers.

Faced with the technological lead taken by the Japanese and the ambitions of the United States and China, the European automotive industry needs to react quickly.

“ZEV obligatory in major cities by 2025”

This goal is feasible: in order to reach it, every single player must be mobilized in order to overcome the existing obstacles and it will only be reached on time with strong political will.