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## The future of the car

Oliver S Kaiser, Heinz Eickenbusch, Vera Grimm, Axel Zweck

Zukünftige Technologien Consulting



On behalf of the

VDI



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Cover illustration: The *space up!* is one vision of the car of the future from Volkswagen. The interior design is made possible by locating the engine at the rear. There is also a version of this prototype with electric propulsion and on-board fuel cells for generating power (Source: Volkswagen AG).

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## SUMMARY AND OUTLOOK

The car of the future will be economical in its use of available resources. It will be designed to have as little impact on the environment as possible. It will also be safer, as it will incorporate a level of artificial intelligence that enables it to compensate for driver error. The car of the future will be networked with other vehicles in the vicinity, and this will extend its range of perception far beyond that of its own on-board sensors.

By 2020, the introduction of completely new technology, and the further development of that which is already tried and tested, will make the car into far more than just a means of getting from A to B. The motor car is, and will remain, a product with an emotional appeal, the character and design of which must accord with the lifestyle of the user. However, this does not mean that it makes sense, for example, to explicitly label a car that is especially suitable for older drivers as 'OAP-friendly'. Accordingly, the car of the future will not be able to sell itself purely by virtue of its many innovative features or by how environmentally friendly it is – it will be the complete package that counts.

### *Engine and drive technology*

Drive technology will be the decisive factor in bringing about significant changes in the future of the car. The ongoing development of the internal combustion engine has been steady rather than spectacular, but the potential is there for lower fuel consumption and for making it more environmentally friendly in the foreseeable future. Refinements in fuel injection technology are raising engine efficiency and reducing harmful emissions. There are also indications that the classic petrol engine can be married to the more positive characteristics of the diesel engine.

Both petrol and diesel will have to be replaced by alternative fuels, if only because our reserves of oil are finite. For that reason, the blending of biofuels with oil-based fuels in the European Union is set to increase from the current 5% level to 20% by 2020. The task of research today is to discover how we can produce biofuels in the quantity needed and what precise effect these have on the combustion process.

The efficient use of given energy resources must not be left to the traditional combustion engine alone. Electric drive motors are being introduced in cars, initially to supplement the internal combustion engine in so-called hybrid cars, and in due course, as stand-alone propulsion units in 'zero-emissions vehicles', which emit no harmful substances during on-road use. Electric motors have the additional advantage of generating a high level of torque from a standing start, so that handling during acceleration does not give the impression of driving some sort of 'ecomobile' where compromises have been made on performance. The electric motor, which also acts as an electrical generator, regains some of its ki-

netic energy during braking, and this increases its efficiency, particularly under urban driving conditions.

The electric drive system stands or falls by the issue of how it manages to store energy. In this regard, durable and powerful rechargeable batteries of a high capacity are indispensable. One promising candidate is the lithium-ion battery, but its energy density and operational safety will have to be significantly improved before it can be used successfully in the motor car. A flexible ceramic separator for lithium-ion batteries developed in Germany promises further possibilities in the future.

Another means of propulsion holding out prospects for the long term is the use of hydrogen to generate electric power in on-board fuel cells. Therefore the 'hydrogen car' is really also an electric car – although there is also the possibility of using hydrogen directly as a fuel for the internal combustion engine. Apart from pure water, the fuel-cell car emits virtually no harmful substances at all and is frequently seen as the 'Holy Grail' of automotive development. There is still a long way to go, as fuel-cell technology falls far short of being suitable for daily use and is not cost-effective in the medium term, even in large-scale production. Moreover, a suitable hydrogen distribution infrastructure with extensive coverage would have to be set up, something that is unlikely to happen until such time as it becomes apparent that fossil fuel reserves are close to running out. In any case, hydrogen itself is a fuel which has first to be extracted from other forms of energy.

Since electrical power is already extensively available from every mains socket, a high-quality battery is already a good alternative to hydrogen as a means of storing energy. So-called supercapacitors carried on board can supplement the battery, as they store and discharge electrical power very quickly. But supercapacitors too require considerable further research and development.

#### *The mechanics of the motor car*

Modern combustion engines are gradually becoming more efficient, a fact that we might expect to see signs of in falling fuel consumption. With few exceptions, however, vehicles are getting heavier, which in turn calls for increased engine performance. This increase in weight is mainly due to increasingly complex specifications and more stringent safety requirements. Mechanical components are required to compensate for this. Above all, the requirements of passive safety need to be met through improved lightweight construction in the area of bodywork, i.e. a 'weight-neutral' solution. Lightweight materials such as aluminium, magnesium and fibre-reinforced plastic (FRP) can help to reduce the mass of the vehicle. Even steel has potential here – for example through the recent development of 'Twinning-Induced Plasticity (TWIP) Steel', which absorbs the deforming energy of a collision.

In the future, ‘by-wire’ technology will transform chassis construction. Full electrical control of steering and braking will reduce the proportion of mechanical and hydraulic components. The advent of the all-electric car will also drive forward the reduction in the use of hydraulics. But at the same time, there will be a need to design and approve for general use redundant systems that are effective under all operating conditions.

### *Electronics*

Vehicle electronics are increasingly setting the pace as regards new technological development. The sophisticated use of electromechanical actuators for valve control will make it possible to produce a cam-free engine. New driver assistance systems have been introduced using high-performance electronics complemented by appropriate sensors. Active safety systems can already correct driver error to prevent accidents. Laser scanners and cameras survey the area around the car to give warning of potential collision during a lane change manoeuvre. In the future, on-board cameras with three-dimensional imaging will even keep an eye on traffic emerging from side roads and at junctions. They will be able, for example, to alert drivers in real time to approaching cyclists who would otherwise be out of the range of vision.

We can expect to see driver assistance systems playing a much greater role in steering and braking. The long-term aim is the autonomous car, in which the driver can concern himself during the journey with activities other than controlling the vehicle. However, before this vision can become a reality, complex questions of driver psychology need to be addressed – such as how he will react to being ‘nannied’ – and various legal questions must also be clarified, including who bears responsibility if the technical systems make a wrong decision?

Currently, a driver observes only the immediate surroundings of the vehicle. Night vision equipment and the laser scanners and cameras mentioned above can support him in this. Vehicle telematics such as traffic alerts on the radio and warnings of traffic jams broadcast on data channels and evaluated by satellite navigation systems extend our perception of what is happening on motorways and major roads over a wider surrounding area. Still missing, however, is an information source about traffic events in the immediate vicinity and in every street. This is where car-to-car communication comes into its own, broadcasting information gathered by individual vehicles to other vehicles in the immediate vicinity over the radio without having to go through a central agency such as a traffic management centre. In this way, warnings about unexpected black ice a few hundred metres ahead or a traffic jam over the brow of a hill or around a corner can be transmitted to other road users. In respect to networked car-to-car communication, though, we have to ask ourselves the fundamental question whether it would not be possible to achieve precisely the same positive effect by consistently adapting our driving to the

road conditions. Nonetheless, it is easier to influence this technical development than the driving habits of the all too human road user.

### *Conclusion*

There will not be a single 'car of the future'. Already, the designs emerging from the drawing boards of the various car manufacturers range across a broad spectrum, from mini models which, by their very nature, are environmentally friendly, up to luxury limousines with fuel consumption comparable to that of the current mid-range car. Development proceeds slowly, notably in the field of fuel consumption, since other factors offset progress in engine technology. As both German and European manufacturers have been unable to live up to their voluntary undertakings to reduce fuel consumption over the last ten years, the European Union plans to make the target figure they laid down compulsory by 2015.

Parallel to all of these ongoing improvements are a number of other innovations that are not only taking hold in vehicle technology but also require a change in mindset. The European automobile industry is not overly fond of the hybrid car but is nonetheless pursuing this goal assiduously. The next step is the introduction of fuel cells in place of the combustion engine, but this would involve the construction of a hydrogen distribution network. Before this can happen, there will have to be a fundamental change in the general situation – for example, in the price and availability of crude oil and biofuels.

If significant advances can be made over the next few years in battery technology, it may be possible to bypass the costly concepts of both the full hybrid and the fuel-cell powered car. In their place, there could be cars which run entirely on electricity, with batteries that are charged by plugging into a mains socket, or possibly while the vehicle is on the road by means of an on-board combustion engine running at a constant speed consistent with optimum efficiency. Whether established vehicle manufacturers will be prepared to change their way of thinking and follow this line of development remains to be seen. It would be an attractive option, given the political will to crack down on vehicle CO<sub>2</sub> emission levels. Having its own electric-powered models significantly reduces a manufacturer's average emission figures for its entire production range.

So in the next few years, we may well see the future of the motor car being significantly influenced by factors which have nothing to do with traditional automobile technology. Steady improvements in current technology and an openness to new ideas will be the key to securing our future mobility.

## 1 INTRODUCTION

‘The future of the car’ is a public status report from the Association of German Engineers (VDI), describing current trends over the next ten to fifteen years together with their various implications. The term ‘car’ is to be understood as meaning vehicles in general. Beyond the remit of this report are any wider policy considerations such as the role of the car within the relevant infrastructure, e.g. increasing traffic efficiency through the use of telematic systems or the relationship between private and public transport. Car manufacturing and engineering will also not be addressed.

Status report showing current trends in automobile technology

The automobile industry is reliant on society’s need for transport and mobility and road use is the basis of its existence. Every seventh job in Germany is directly or indirectly dependent on the car. In addition, the automobile sector is still seen today, as it has in the past, as the leading dynamic force for technological progress in Germany – German automobile technology takes its place amongst the best in the world. Free-flowing traffic is also a fundamental requirement for the functioning of the economy and of society, as it guarantees the mobility these require. The volume of movements by individual carriers is closely linked to the growth of the national product. A smoothly functioning traffic system and an efficient transport distribution network provide the basis for the success of the third-largest sector in the German economy: logistics. Employing 2.6 million people and generating an overall turnover of more than 150 billion euros, it represents about 7% of gross domestic product. In the future, an annual growth rate of up to 6% is expected in the turnover of the sector overall. Against the background of Germany’s growing importance as a transit country, it will be even more important in the future to improve the competitiveness of the German vehicle and transport industry, to reduce the impact of traffic and to ensure safe and reliable transport options for the whole population.

The automobile industry and the economy are closely linked

The United Nations estimates that world-wide vehicle ownership is set to double by 2030, from the current figure of 750 million to around 1.5 billion private and commercial vehicles. The driving force behind this development is the sharply increasing demand for cars in the rapidly expanding markets of China, India, Korea, Brazil and Russia. The increasing standard of living of the populations of these regions will lead to a greater desire for enhanced personal mobility and this in turn will lead to increased car sales and to more frequent usage. [Duy 04]

Car ownership is set to double

The car impacts on the environment and needs to adapt

Over and above this, there are an increasing number of socio-political demands being made on the transport sector, including environmental sustainability, the conservation of energy and natural resources, health and safety requirements and recyclability. Through the use of new technology, average CO<sub>2</sub> emissions from new vehicles produced in Europe should be reduced from the current 160 grams to 125 grams of carbon dioxide per kilometre by 2015. Biofuels will play a part in this, as their share of total fuel consumption in transportation is set to increase to 20% by 2020. [Hön 08]

Safety requirements may be counterproductive in terms of fuel economy

In developing an innovative vehicle that is fit for the future, it is necessary to take a holistic approach in order to reconcile various conflicting criteria that are in a complex relationship with each other. The ideal design will offer maximum levels of safety, comfort and quality together with minimum vehicle weight, noise and exhaust emissions, whilst not making any compromise on performance. For this reason, improvements aimed at any one of these criteria within the overall package will always be dependent on developments in several interrelated vehicle components.

The car of the future will be part of an intelligent, self-organising traffic system and thus itself be an active element in traffic management. In the future, cars will be able to communicate with each other and interact with transport infrastructure. This will not only bring about improved road safety but also open up new possibilities for improving traffic flows and optimising the use of scarce infrastructure. Safety technology in the car of the future will contribute to the realisation of 'Vision Zero'. This is the name given to a campaign aimed at the complete elimination of road fatalities. In Sweden, the Netherlands and Switzerland, there are already schemes dedicated to this ideal. In Germany, it has also won support from the national motoring organisation VCD. [VCD 06]

Technology must be useful and generate income

Despite all the enthusiasm for innovative vehicles, we should not lose sight of the fact that these innovations still need to find willing buyers, which means that they must actually match up to the expectations of the general public and not merely be designed for their own sake. 'Technically feasible' is by no means the same as 'commercially viable'. Particularly during a period of economic uncertainty, when prices are rising on the forecourt and at the filling station, the customer wants value for money and to weigh up the 'Total Cost of Ownership' factor.

For the car manufacturers and retailers too, innovations can cut both ways: one fifth of the research and development budget goes into new features that are included solely for the purpose of complying with legal requirements, with a further fifth being swallowed up by getting series production up and running. Forty percent of the budget will be effectively wasted because the development never makes it to the production line, or else there is insufficient public demand. This means that only 20% of investment goes into innovations that are profitable over the long

term. These are innovations that perform a sensible function, meet with a high level of customer acceptance, fulfil legal requirements and can be produced at reasonable cost. [Dan 07]

Our report goes on in the following chapter to outline technological developments and trends in essential vehicle components. Some of the components presented here have already been incorporated in certain high-end models from where in due course they will filter down to influence and penetrate the mass market. The majority of these components are still at the development stage and have not even left the research laboratories yet.

Technological developments in individual components

Chapter 3 demonstrates two different approaches to designing the car of the future. In the chapter headed 'Low-cost cars' we look at the vehicles that are set to dominate the market in the emerging economies of the world. Before that, however, we focus on the high-tech approach which involves incorporating the maximum number of new features in a single model. Designers are increasing their options by employing leading-edge technologies that make it possible to change the use of the available space. The consequence is that many concept cars have a strikingly futuristic look.

Vehicle designs for high-tech, low-cost cars





## 2 TECHNOLOGICAL DEVELOPMENTS AND TRENDS

One of the challenges facing those designing the car of the future is the development of environmentally friendly vehicle technologies. These include lightweight construction, new drive concepts such as hybrid drives and fuel cells and alternative fuels such as hydrogen and biogenic fuels. One further focus is on the development of innovative driver assistance systems that are intended to make driving more comfortable and, above all, safer.

Environmental compatibility as the main challenge

### 2.1 Bodywork

Over the past 15 years, the weight of the average family car has increased by around 30%. An analysis of new vehicle registrations in Austria shows that, in the years from 2000 to 2005 alone, the weight of the average vehicle increased by 11%. Despite weight savings in engine blocks and bodywork made of light alloys, modern cars are getting heavier and heavier. This is happening because of the addition of new electronic components, above all in safety technology (for example ABS, ESP, seat belt tensioners, active steering and four-wheel drive) and because of the increasing popularity of comfort features (air-conditioning, electric windows and seats). But the more a vehicle weighs, the more fuel it will consume and the more pollutants it will emit. As a rule of thumb, reducing the weight of a vehicle by 100kg will reduce fuel consumption by around 0.5 litres per 100 km. By 2010, it is intended that there should be a 17% reduction in vehicle weight, i.e. equivalent to an average 250kg per vehicle. [VDI 05]

The weight of vehicles has increased over the years

There is certainly a conflict between, on the one hand, the tendency to add on more and more safety and comfort features, all of which make the vehicle heavier, and on the other, the general need to shed weight. This dichotomy can, however, be resolved by the use of weight-saving materials in conjunction with customised construction and manufacturing technologies on the assembly line. The choice of material depends very much on properties that are in part complementary, such as weight, stiffness and ductility, failure limits, manufacturing and processing characteristics, availability, whether it can be recycled and above all on price.

Savings in weight through new materials and construction techniques

New joining techniques in automobile construction are supplementing classic (laser) welding processes and making the joining together of diverse materials possible. Modern gluing technologies are being developed for steel, aluminium, magnesium, glass, plastics and bonded fibre materials as well as hybrid materials, thus increasing the torsional rigidity of the bodywork, reducing vibration and protecting from corrosion.

Aluminium, magnesium, bonded fibre materials

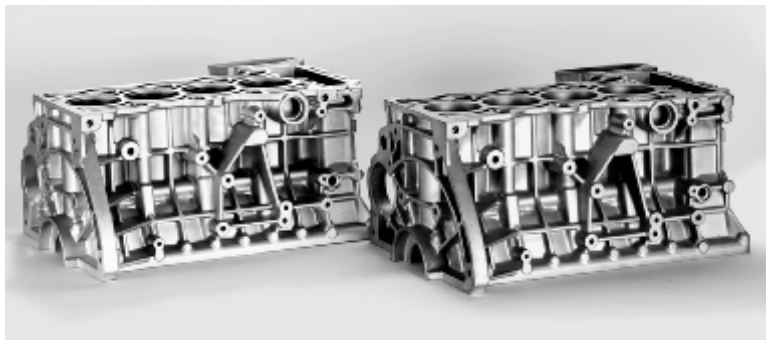
### 2.1.1 Lightweight construction

Lightweight construction materials such as aluminium, magnesium and bonded fibre materials should help to reduce weight and allow shorter manufacturing times, without compromising safety, comfort or reliability. Successful lightweight construction ideas are based on specific expertise in many areas of materials technology and engineering science and on 'systemic' thinking. Robust processes in lightweight construction go hand in hand with applied research into materials, configuration, process development and qualification of procedures, and with associated modelling and simulation.

The multi-material construction method is seen as key to super lightweight construction. For each individual element in the construction of the vehicle, those materials are chosen which best meet the requirements with a minimum amount of weight. For small series production vehicles, the multi-material approach is already a reality; as regards volume and medium series production, though, there have as yet been only a few hesitant steps towards such a systematic combination of diverse materials in structural bodywork. The task of developing a multi-material construction method that can also be applied cost-effectively to high-volume cars is being researched at present in various development projects. [Sah 06]

Aluminium is the classic material for lightweight construction

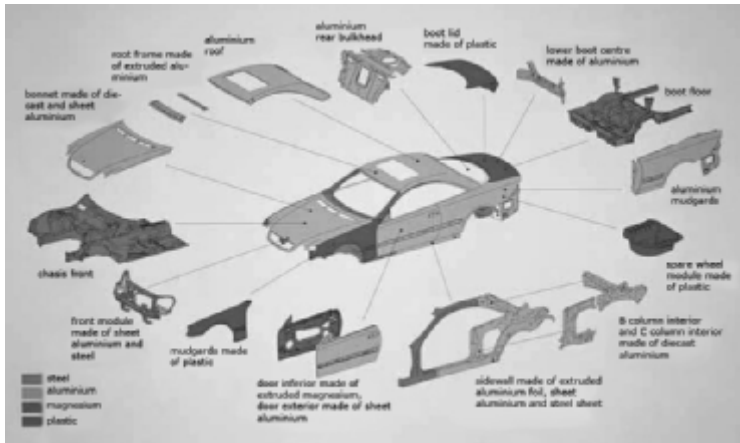
In the past, manufacturers have primarily pinned their hopes on the light metal aluminium, as this substance has a low mass and does not rust. In the year 2000, around 100kg of aluminium were used in the manufacture of the average car, according to figures from the European Aluminium Association. This rose to 132kg in 2005. The fact that aluminium is being used more and more in vehicle construction can also be attributed to laser technology. Some years ago, processes were developed that make possible the welding of aluminium components by laser. [EAA 07]



**Illustration 1:** Crankcase made from magnesium (on the right), up to 25% lighter than a comparable aluminium crankcase (on the left) (Source: BMW Group)

Magnesium is even lighter than aluminium. This substance has a density of only 1.8 g/cm<sup>3</sup>. By comparison, aluminium weighs 2.7 g/cm<sup>3</sup> and steel just under 8 g/cm<sup>3</sup>. Magnesium is available in almost limitless quantities and it can be easily processed and recycled. For these reasons, this light metal is becoming a favourite amongst lightweight construction materials. In the new Golf, the gearbox housing is made from magnesium and weighs around 25% less than the aluminium version, which was already lightweight. Magnesium is also to be found in the rear hatch of the VW Lupo, in the dashboard mounts of the Opel Vectra and in the housing of a seven-speed automatic gearbox developed by Mercedes-Benz. In the Pasat, 14kg of the light metal are already used as standard. And yet, no matter how great the advantages of magnesium may be, it still has disadvantages. Research and industry will both own up to gaps in their knowledge. Under what forces and in which places do magnesium components fail in an accident? How can magnesium be joined without flaws? How can it be protected from corrosion?

Magnesium lighter than aluminium



**Illustration 2:** Mercedes-Benz CL hybrid construction method: aluminium, magnesium, plastic and steel combined (Source: Daimler)

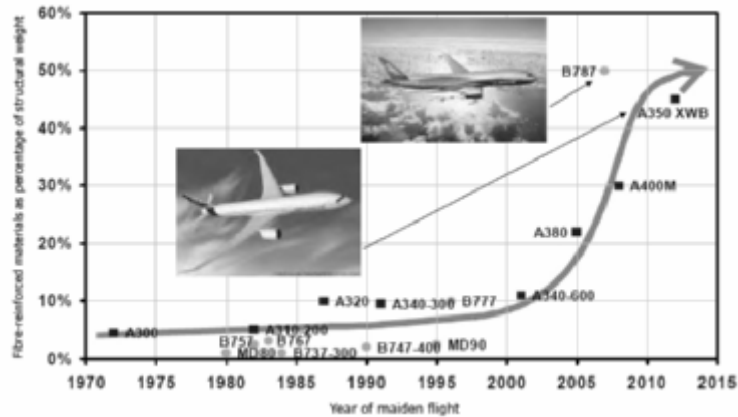
Magnesium is also suitable for the injection moulding process known as thixomoulding for manufacturing high-precision components with a wall thickness of 0.5mm. This has not been possible up to now with conventional injection moulding techniques. For thixomoulding, the magnesium is heated to a temperature of around 100 degrees Celsius below its melting point of 650 degrees. It changes to a 'thixotropic' state in which, subjected to sheering forces, the viscosity of the material is lowered. Just like a form of dough, the metal can then be very precisely shaped using relatively little pressure. At the present time, however, it is only possible to handle masses of up to 3kg at a time. Machines able to process up to 6kg of material are only just beginning to come onto the market. Because of the lower temperatures applied, the finished item shrinks less and is also less porous. Magnesium thixomoulding is also more environmen-

Thixomoulding makes the injection moulding of high-precision components possible

Fibre-reinforced  
plastics in aircraft  
construction

tally friendly than injection moulding because it requires less heat energy input. Thixomoulding is not yet used for working aluminium because in its liquid state this metal behaves more aggressively than magnesium and can therefore only be worked with expensive ceramic tools. [Tec 07]

Fibre-reinforced materials such as fibre-reinforced plastics can also contribute to lightweight construction. The original field of application for fibre-reinforced materials is mainly in the aerospace industry. Current examples of use in aircraft construction are the Airbus A380, which consists of around 35% of these lightweight construction materials, and the new long-haul aeroplane, the Boeing 787 Dreamliner, with up to 50% fibre-reinforced materials. The replacement of the conventional aluminium in the fuselage and wings reduces weight and gives a fuel saving in the order of 20% in the case of the Boeing 787.



**Illustration 3:** Example of the application of fibre-reinforced materials in aircraft construction (Source: DLR Center of Excellence Composite Structures)

New manufacturing  
processes bring fi-  
bre-reinforced plas-  
tics into the automo-  
bile

However, fibre-reinforced plastics are rarely to be found in the mass production of cars, as the manufacture of this material is very complex and expensive. But new production processes are now making the material more attractive for use in compact and medium-sized vehicles too. In a pilot project for the BMW 3 series, a bracket was ‘tailor made’ from a Long Fibre Thermoplastic (LFT) compound. This hidden component carries the headlights, the bonnet locking mechanism and the fan shroud. It is 30% lighter than its counterpart in aluminium. [FhG 07]

More components made from fibre-reinforced materials are being developed for future generations of vehicles. Carbon-fibre reinforced plastic is already used in the BMW M3 CSL. Here, this material dramatically reduces the sports car’s weight – the M3 CSL weighs in at 1,385kg, a good 110 kilograms less than its series-production equivalent. [Ros 03]

BASF is already working on the production of bodywork parts made completely of plastic, which no longer need painting. Coated or pigmented plastic films ensure that the plastic body parts are indistinguishable from steel panels. Take the Smart car, for example. Its roof is the first large exterior body part in which glass and plastic appear to merge into each other. Its plastic roof is half the weight of a comparable steel panel. [BAS 02]

Plastic bodywork parts are transparent or give the effect of being painted

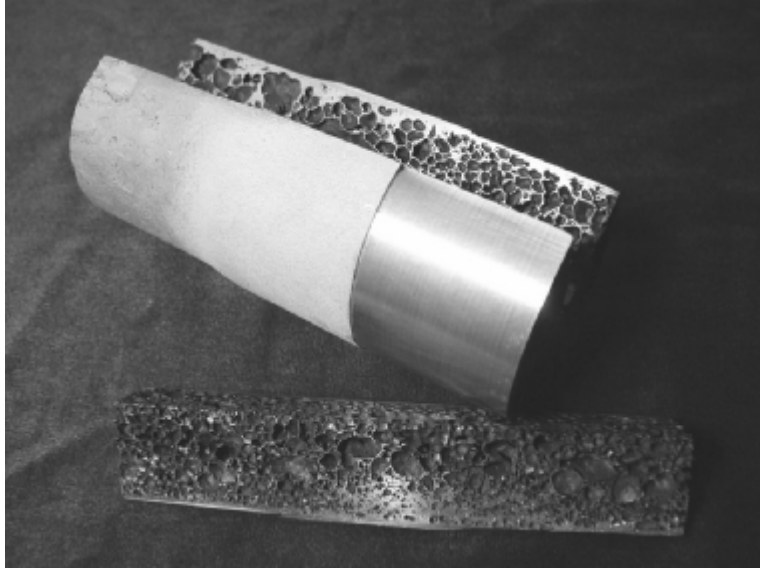


**Illustration 4:** The homogeneous, high-quality appearance of the roof module on the Smart is made possible by using multilayered plastic films (Source: BASF)

Studies assume that in 2010 every car will have a plastics content of 19% to 20%. Today, the figure already hovers around the 13% mark. [Nie 06]

One further option for lightweight construction is metal foam. Researchers at the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research in Bremen have discovered a process whereby a porous and yet hard foam structure can be made from metal powders. A kind of 'metal yeast', a special compound of metal and hydrogen, is critical for this procedure. It ensures that, when baked in an oven, the powder will swell like foam. The foaming agent must first be mixed with the metal powder and compacted in a press. The size and number of the pores will vary according to the amount of foaming agent used and the length of time of the reaction. In an extreme case, the structure consists of 90% air and 10% metal, e.g. aluminium. A ready-made lump of this material is lighter than water and can be sawn like wood. And just as easily, you can drive a nail into it. These metal foams can be used, for example, to save weight, whilst giving rigidity to structures used in automobile construction. One welcome side-effect is that, as a result of its cavities, cellular aluminium has very good insulation characteristics. Its sound-deadening qualities are five to eight times that of normal aluminium or steel. [Bau 02]

Metal foams contain air cavities and are strong

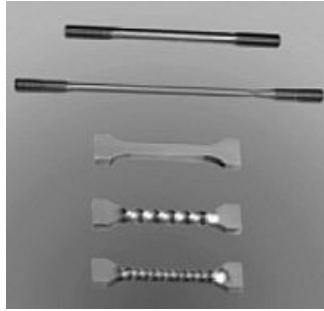


**Illustration 5:** Cylinders made of metal foam: uncoated, coated and mechanically finished (Source: Arbeitsgemeinschaft industrieller Forschungsvereinigungen 'Otto von Guericke' e.V., AiF)

### 2.1.2 Passive safety

The consequences of accidents can be mitigated by special steels

In Germany, there are more than 200,000 car accidents every year. Manufacturers are devoting technical resources to technologies aimed at affording better protection to drivers and passengers. Along with the construction design of the vehicle, the steel used for the bodywork also plays a central role. In an accident, enormous forces act on the car and its occupants. As the engine bay deforms, it absorbs a large part of the impact and thus protects the passengers in the passenger compartment. The bodywork must be able to deform and yet be rigid, two properties that are in fact mutually contradictory. Scientists at the Max Planck Institute for Iron Research in Düsseldorf have developed a new type of steel to serve both functions from a mixture of manganese, silicon, aluminium and iron. In a collision, this TWIP steel (Twinning Induced Plasticity) activates its expansion reserve and begins to deform. Each steel point deforms by a certain predefined amount only. It then stiffens again and distributes the remaining energy to the surrounding material. This spreads the energy over the entire surface of the metal. The impact forces are evenly distributed. In a few years, this new steel will be built into car wings and side doors. These are the areas most at risk of being hit in a collision. [MPG 07]



**Illustration 6:** TRIP/TWIP steel samples, drawn and twisted. The sample at the bottom was twisted three times around its own axis. (Source: weltderphysik.de)

Further examples of materials with ‘deformation intelligence’ are the TRIP (Transformation-induced Plasticity) steels developed some years ago, which become stiffer as the material deforms. Through the addition of alloys, energetically favoured crystal lattice structures are formed, which have an improved balance between stiffness and deformability. [Lan 07]

## 2.2 Engine and drive technology

Manufacturers and engineers are pursuing various avenues of research to come up with the drive technology of the future. Whilst the trend in Europe is towards clean diesel engines that bear relatively little resemblance to traditional diesel technology, developers in the USA and Asia already see the hydrogen solution as a realistic prospect for the near future. The ecological credentials of this form of energy are, however, still questionable, since in its role as energy transfer medium it is itself a great consumer of energy.

During a transitional period, internal combustion technology could be combined with electrical technology to make ‘hybrid’ engines. The first models employing this technology are already on the market.

The aim is to make the motor car more economical. Following the failure of the German and indeed the whole of the European automotive industry to adhere to its self-imposed obligations over the last ten years, the European Parliament in early 2008 argued in favour of a maximum permissible emission level of 125g CO<sub>2</sub> per kilometre with effect from 2015 instead of the 120g limit from 2012 proposed by the European Commission. [Web 08]

In 1998, European car manufacturers had agreed to target an average emission level of 140g CO<sub>2</sub> per kilometre by the end of 2008. By 2002, they had almost managed to achieve an average level of 160 grams but their efforts have stalled since then, mainly because of the increase in engine performance of European new models. [Ina 07]

Hybrid engines are a combination of internal combustion and electrical technology

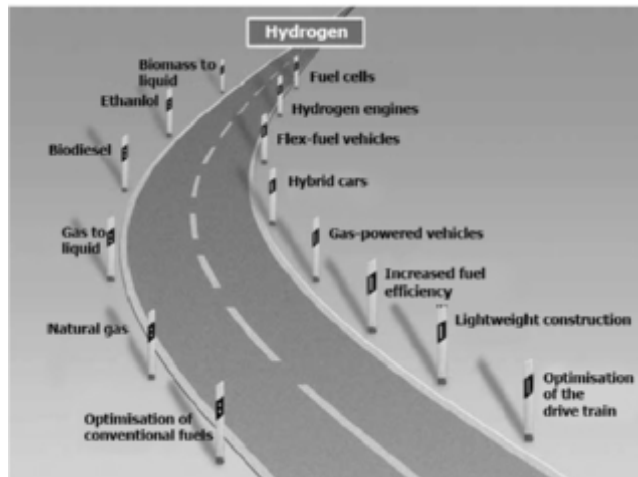
The carbon emissions of cars are subject to restrictions in Germany and throughout the rest of Europe

America cuts back on average consumption

National governments are also aiming to curb both consumption and CO<sub>2</sub> emissions. Since the beginning of 2008, purchasers of new vehicles in France have had to pay extra duty on cars that pump out more than 160 grams of CO<sub>2</sub> per kilometre. This has pushed up the prices of models such as the Porsche 911, BMW 740i, Audi Q7 and Mercedes S-Class 420 CDI by around 2,600 euros, according to calculations by specialist consultants B&D Forecast. There is, however, a strong possibility that the EU will overrule this French decision as anti-competitive. [Cro 07b]

In the USA, there are also moves to cut average consumption for new vehicles. By 2020, this is supposed to fall to 6.72 litres per 100km (35mpg). Up to now, the limit that applied was the one introduced in 1984 of 8.6 litres for saloon vehicles and 10.5 litres for off-road vehicles.

Individual states, including California, would even like to set a limit of 6.39 litres by 2016 to apply not just as an average across a manufacturer's annual range of models but to each individual vehicle. For the moment, however, this proposal has been overruled by Washington. [Gär 08]



**Illustration 7:** The roadmap in drive technology (Source: Verband der Automobil-industrie, 2006)

### 2.2.1 Internal combustion engine

The rationale behind the internal combustion engine at the heart of every motor vehicle is its convenient use of liquid fuel that is easy to handle and has a high energy density. In addition to these advantages, there is a national and international infrastructure already in place, so that distances of 500 to 1000 kilometres can easily be covered. We tend to take all of this for granted until we start to compare alternative fuels such as natural gas or alternative technologies such as electrically powered engines. In these alternative scenarios, refuelling opportunities are scarce and in-



involve circuitous journeys or recharging that lasts several hours and thus takes the vehicle off the road for an unacceptable length of time.

Internal combustion technology is already highly advanced, yet still capable of further development. One significant indicator is the way that the diesel engine has become increasingly economical to run over the past few years, though in the long term, the automotive industry is eyeing up the potential of the 'Diesotto': a petrol engine that combines the benefits of the low-emission petrol (Otto) engine with the fuel economy of diesel.

Diesel technology shows that the internal combustion engine still has plenty of potential

The performance of petrol engines has been enhanced by direct injection systems, such as the one first fitted in 2000 by VW to their Lupo FSI. They are a complex package in technical terms but nonetheless provide payback in the form of reduced fuel consumption on low throttle. Electromagnetically controlled fuel injectors have so far played a major role here. Combustion takes place either in the classic stoichiometric proportion – i.e. precisely the right quantity of air to burn the injected fuel – or in a lean burn process with surplus air so that all the fuel is burnt without residue. In the part-load operational range, lean burn allows increased efficiency with a corresponding reduction in fuel consumption, especially under routine operating conditions. However, it also presents two challenges: on the one hand, it is necessary to fit an additional NO<sub>x</sub> absorbing catalytic converter as the nitrogen oxides cannot be dealt with by the standard three-way catalytic converter; and on the other hand, the initial practice of wall-controlled injection did not really lead to the desired level of fuel economy because lean burn requires fuel stratified injection (FSI) for the air-fuel mix in the vicinity of the spark plug to be capable of ignition at all. Attention is now shifting towards spray-guided systems using ultra-fine atomisation, which, however, requires high pressures of around 200 bar. One such spray-guided system went into series production in 2006. However, this is based on complex and costly piezo technology. Researchers at Bosch and Siemens VDO are working to achieve high pressures with less complicated multi-hole fuel injectors. These would help direct fuel injection to make inroads into the mass market and to make engines more fuel economical on a broad front. [Bar 07]

Direct injection is taking on greater importance in petrol engines

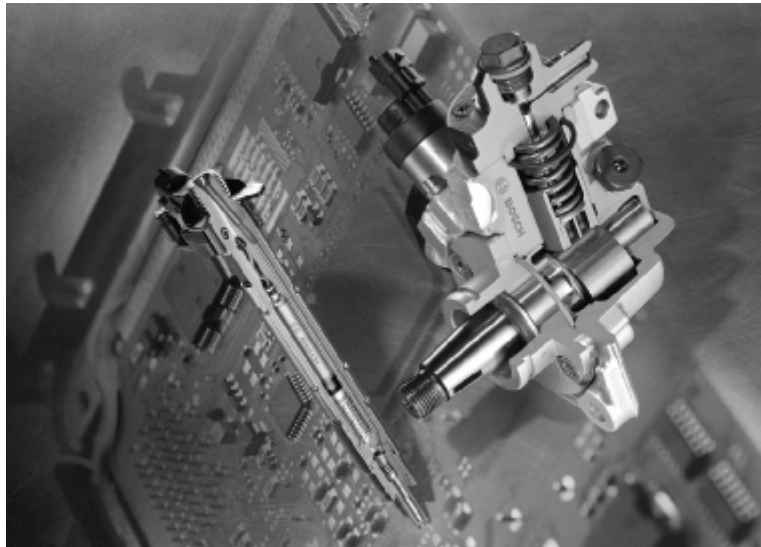
Direct injection is state-of-the-art with diesel engines: high injection pressures with correspondingly fine atomisation make for an efficient engine operating on lean burn – except when it is at full throttle. Here we are seeing a switch from pump-jet technology to 'common rail'. Whereas with common-rail injection the feedline shared by all the cylinders is at a pressure of around 1500 bar, with pump-jet technology it is only the jet for each cylinder which raises it above 2000 bar. A disadvantage of pump-jet injection is that it is mechanically driven by the camshaft. This means that the injection intervals are fixed, resulting in less efficient operation at low speeds and reduced throttle. For this reason, major supplier Bosch withdrew from further development of diesel engines with pump-

With common rail,  
diesel injection is  
100% electronically  
controlled

jet injection, and Volkswagen will discontinue production of cars fitted with this system in 2010. [Sch 07]

Already in series production since 1997, common rail continues to dominate the market – from the 0.8-litre 30kW diesel engine of the Smart to the 6-litre 370kW Audi Q7. The number of injections per cycle is electronically controlled, for example up to eight times at 2000 bar in the case of piezo injectors. Magnetic valves go up to 1800 bar. The injection pressure of common rail injection systems will be increased up to 2400 bar by the year 2011; there are even systems with a top pressure of 3000 bar at the development stage and, in the long term, these could make catalytic converters or particle filters superfluous. [Win 08]

It is only common-rail technology that will enable compliance with the strict exhaust emissions standards Euro 5 (from 2009) and Euro 6 (from 2014), as well as the American standard US07 Bin5. Together with the drastic reduction in the sulphur content of diesel fuel that has been in force in the USA since 2006, the diesel engine may at some future stage measure up to the petrol engine hybrid vehicles that are selling so well in the American market at the moment. Of the 16 million cars sold during 2006 in the USA, around 500,000 had diesel and 250,000 hybrid engines. [VDI 07b]



**Illustration 8:** The third generation common-rail system from Bosch with high-pressure pump, piezo injectors and controls (Source: Robert Bosch GmbH)

Along with injector technology, research is going on into lightweight materials such as ceramic valves and light alloys for engine manufacture with the aim of improving fuel economy. All-aluminium diesel engines are expensive to manufacture and are generally reserved for top-end models – with a few exceptions such as Honda's 2.2-litre CTDi engine for their Accord and Civic models. [Hon 05]

One further advance with the petrol engine has been the GCI (Gasoline Compression Ignition) process. Honda have already achieved ignition without spark plugs in a two-stroke motorbike engine; during the next few years, VW and Daimler would also like to extend this technology to the four-stroke engine. This involves the addition of up to 80% exhaust gases to the air intake. Once the level of compression necessary for self-ignition has been reached, the mixture ignites throughout the whole combustion chamber simultaneously. The high exhaust gas content acts as a brake on the explosive process and thus avoids the generation of nitrogen oxides. Volkswagen have called this engine technology the 'Combined Combustion System'; Mercedes have gone for the catchier name 'Diesotto'. In both cases, we are witnessing the triumph of electronics over mechanics: the camshaft which has traditionally operated the inlet and outlet valves in a purely mechanical fashion has given way to electromechanical actuators that control each valve individually. This builds on the concept of variable valve operation, first introduced by BMW under the patented name of 'Valvetronic', whereby the valve lift can be varied by means of an actuator. With this totally camshaft-free engine, it is possible to shut down cylinders temporarily and to hold them in reserve for bursts of full throttle. The Diesotto provides adequate torque from low fuel consumption and is not as expensive to manufacture as a diesel engine. Volkswagen are additionally optimising their 'Combined Combustion System' to operate on synthetic fuels. [Nie 01]

Petrol and diesel engine to be combined

These developments show that the internal combustion engine still has plenty of potential for powering the car of the future. However, the steady work being done here goes on outside the spotlight currently being shone on to the rising star of the automotive world – the hybrid engine.

### 2.2.2 Hybrid-electric powertrain

Together with the continual improvement of combustion engine technology, the use of hybrid drive vehicles can contribute greatly to a reduction in fuel consumption and CO<sub>2</sub> emissions. However, as regards driving performance and driving comfort, hybrid vehicles must have the same versatility and durability as conventional vehicles if they are to have a chance in the market place. The development of power train technologies for hybrid vehicles must address these criteria. The potential for innovation lies particularly in a significant reduction in fuel consumption, in

further applied research into key components and in the safe interaction of the drive system as a whole. In order to gain rapid acceptance, the research results must be shown to be in step with actual practice and vehicles developed that are suitable for everyday use.

In recent years, automobile manufacturers around the world have developed cars that get their energy from an electric motor with a battery as well as from an engine driven by petrol, diesel or natural gas. The latest models of these hybrid cars have vastly improved batteries and other features that put their predecessors in the shade. These latest hybrid cars could in future be the vehicle of choice for motorists, not just in Japan and America but worldwide.

Their main advantage is that they are environmentally friendly due to their low levels of carbon dioxide emissions. At the same time, the driver does not have to recharge the batteries himself by plugging into the mains, as is the case with traditional electric vehicles. The energy for the battery comes from an internal combustion engine and from the regenerative braking system. In 1997, Japan's biggest car manufacturer, the Toyota Motor Corporation, began to sell the first mass-produced hybrid car in Japan, the Toyota Prius, which since the year 2000 has also been marketed in Europe and North America. In 1999, the Honda Motor Corporation introduced the futuristic-looking two-seater Honda Insight. Subsequently, a hybrid version of the Civic was made available.

Together with its Lexus brand, Toyota sold a million hybrid drive units between 1997 and 2007, and Honda for their part over 100,000, mainly Honda Civic IMAs. [Kut 07]

By combining petrol and electric motor, the Toyota Prius achieves an official fuel consumption of 4.3 litres per 100km, a respectable figure for a medium-sized vehicle. Big savings in consumption are made above all in stop-go city traffic, as here the regenerative braking system and highly efficient drive combination really come into their own. In this full hybrid concept, the drive is either from the petrol engine or from the electric motor, the power trains being linked together by a differential planetary gearbox and by a complex drive management system. This means that, over short distances and at low speeds, drive is possible using just the electric motor.

Hybrid cars are already coming off the assembly line

A planetary gear links petrol engine and electric motor



**Illustration 9:** View inside a Toyota Prius: the electric motor is next to the combustion engine, the battery behind the back seat (Source: Toyota)

Electric motors work efficiently throughout the engine speed range and produce high torque on start-up. These factors are very much in their favour. In these respects, they are superior to the combustion engine. In addition, the electric motor works as a dynamo when braking or travelling downhill and charges the on-board battery so that the car does not need an external power source and the mechanical brake is largely redundant because of the electric brake. At present, only around half of the braking energy can be recovered, since the battery cannot store the energy thus generated quickly enough. Supercapacitors, which can be charged in seconds, can increase efficiency still further. The cylinder capacity of the petrol engine can be reduced, as its workload is shared with the electric motor (downsizing). Also, petrol engines in full hybrid vehicles can operate for the most part within an efficient range, as the engine's output is distributed either to the drive train or to the generator.

The weak points of the full hybrid concept – and this also applies to the wholly electric-powered car – are the increased vehicle weight caused by the electrical motor plus batteries and the higher production costs. The success of the Prius may also stem from the fact that Toyota essentially designed the vehicle afresh as a hybrid, and by giving it, for example, a good aerodynamic shape, they latched onto other potential savings in costs that are not part and parcel of the power train system. For the first time in a mass-production vehicle, the air conditioning has an electric compressor that will work even when the engine is switched off. In other words, the Prius went into production as a special car, easily distinguishable from all other conventionally powered models. Had it been unsuccessful it would have been consigned to the history books. All other motor manufacturers, however, are focusing on adapted models, which are already on the market and which are not distinguishable simply by look-

Electric motors produce high torque from a standing start

Braking energy is recovered

Various examples of  
hybrid technology on  
the road

ing at them. Consequently, their owners do not get the 'halo effect' from being an innovator or early adopter; a Swiss marketing study has indeed shown that Prius owners are less interested in the potential for fuel savings than in the unique, modern technology. It is barely possible for other manufacturers to reproduce this customer feeling. [ETH 05]

Whilst the full hybrid attracts the most attention, there are likewise diluted versions to be found on German roads. The production vehicle Honda Civic IMA is classified as a 'mild hybrid'. Its electric motor is placed as a starter motor coupled to the crankshaft between the engine and automatic gearbox. Here too, braking energy is recovered, but drive using the electric motor alone is not possible – it works in tandem with the engine.

Since 2007 BMW have been pursuing the concept of the 'micro hybrid' in the 1 series. An automatic start-stop function comes into play when the driver declutches and puts the car into neutral. As soon as the clutch pedal is operated, the engine starts immediately. Alternator and starter motor have been replaced with a special starter generator from Bosch. Fuel can be saved, especially in city traffic, by switching off the engine when the vehicle is stationary. The alternator charges the battery with energy from braking. In full hybrid vehicles, by the way, the engine is switched off as the brakes are applied.

Manufacturers in  
Europe and the USA  
are working together  
on hybrid vehicles

Whilst all varieties of hybrid drive are being manufactured in high volumes – and yet remain niche products – development continues with different emphases. European and American car manufacturers are working in collaboration to get their full and mild hybrid concept cars ready for volume production. Apart from the Japanese manufacturers, only Ford in America with its Ford Escape already have a hybrid vehicle in their line-up. Daimler, BMW and General Motors are working together, as are the suppliers ZF, and Continental. Bosch are doing research for VW, Audi and Porsche. The companies are trying to catch up and promote diesel drive combined with hybrid technology to satisfy the European market. The French PSA group would like to offer both the Citroen C4 as well as the Peugeot 308 as hybrid versions from 2010. Elsewhere, premium limousines such as the VW Touareg, Audi Q5, Mercedes GL, BMW X5 and Porsche Cayenne are also lined up for the "hybrid treatment". With these models, fuel consumption can be reduced from a high base level, a route previously taken only by Toyota with its premium brand Lexus.

Unnecessary up to  
now: mains power  
socket for hybrid car

Hybrid vehicles can seamlessly continue to use the existing infrastructure: they can use petrol or diesel and, contrary to initial stereotypes, do not need an external power source. And yet Toyota are planning to introduce, amongst other things, the next generation Prius as a 'plug-in hybrid' in 2010. Such plug-in hybrids continue to generate current from the engine and from regenerative braking, but as an option, they can be recharged from the mains as well, in order to be able to cover greater distances using just electrical power right from the outset. This is made pos-

sible by the development of new lithium-ion batteries which have a greater storage capacity. In the long term, it is even conceivable that plug-in hybrid cars could make sensible use of the nightly power station base load by tapping into inexpensive off-peak electricity. [Kut 08]

In order to control the ever-increasing performance on board a hybrid vehicle, silicon carbide high-performance switches are currently being developed. The silicon technology currently employed needs a separate cooling circuit for the power electronics because they are sensitive to high temperatures. Silicon carbide technology can reduce the weight of hybrid vehicles.

### 2.2.3 Electric powertrain

Besides hybrid technology, there has also been a renaissance of vehicles driven by electric power alone. This was already planned in the 90s, when zero-emissions regulations emerged in the American state of California. The need for such vehicles disappeared after the rules were relaxed. In the meantime, several electrically powered models are again being developed. The most prominent example is the roadster from Tesla Motors. With a top speed of 200km/h and an acceleration from 0 to 100km/h in 4 seconds plus a range of over 350km, this vehicle will not primarily appeal to buyers who have the environment at heart.

Electric car as environmentally sound roadster

The idea of using an electric powertrain especially for sports cars is obvious, as electric motors can develop maximum torque on start-up. Neither manual nor automatic transmission is needed. Moreover, wheel-mounted drive trains make possible four-wheel drive with variable transmission of power to each wheel. They are very efficient and take up little room.

More classic vehicle designs, such as the Chevrolet Volt from General Motors, are also to be offered with electric drive technology. In addition to the power socket connection, however, the Volt will have a small petrol engine on board, which can be used to recharge the lithium-ion battery during the journey. In this way, the petrol engine will always operate within its most efficient speed range. [Grü 07a]

Power supply network for electric cars in Israel

The former CEO of the software giant SAP, Shai Agassi, is starting an ambitious project. He would like to build up an extensive network of 500,000 charging stations in Israel and Denmark, with some offering a direct battery exchange service. In 2011, Renault and its Japanese subsidiary Nissan are to commence series production of electric cars. [Lam 08]



**Illustration 10:** Concept vehicle Chevrolet Volt: a one-litre three-cylinder turbo petrol engine turning at a constant speed produces current to recharge the batteries located in the transmission tunnel (Source: General Motors)

Petrol and diesel have a much higher energy density than batteries

Electric motors are ahead of combustion engines as they have inherently good tractive power even at low speeds. So they make a good addition to combustion engines, which always suffer from a lack of efficiency except when they are working at optimum engine speeds. This raises the question, why aren't there any all-electric powered vehicles on the market? The answer lies in the energy storage for the two different propulsion methods. With more than 10kWh/kg, the energy density of petrol and diesel is greater than the storage capacity of today's batteries by a factor of 50 and more. Lithium-ion batteries attain a respectable 0.2kWh/kg, which is nonetheless still modest by comparison. Although the efficiency of combustion engines is not even half that of electric motors, this by no means outweighs the 50-fold difference in energy density between liquid fuels and batteries. [Hon 06]



All types of rechargeable batteries are thus judged first and foremost by their energy density. Of secondary importance is the power density, which is critical for the car's actual performance characteristics. However, it is not possible to set both energy and performance density to their highest values simultaneously. The lithium-ion batteries already mentioned achieve a power density of 0.8kW/kg. Supercapacitors with a power density of 10kW/kg make an interesting addition, even though they have a modest energy density of less than 0.01kW/kg. Since supercapacitors, unlike batteries, can be charged and discharged within seconds, they complement sluggish electrochemical batteries well and are particularly suited to the short-term storage of recovered braking energy. [Sau 07]

Supercapacitors give up energy faster than batteries

In the future, lithium-ion batteries could replace the nickel metal hydride cells used up to now in hybrid and electric cars. They could even replace the lead acid accumulator battery, as they would be half the size and have a third of the weight whilst packing a comparable amount of energy. Further research into lithium-ion batteries has its prime focus on operating safety, increased energy and power density as well as improved durability. In 2006 and 2007, lithium-ion rechargeable batteries in laptops and mobile phones got a bad press, as they suffer damages by so-called "thermal runaway" when they were overcharged. The situation was not helped by the fact that the prescribed tolerances in the manufacture of the separators were also not adhered to. The consequence was a huge product recall campaign. Innovative separator membranes to keep the two electrodes apart to prevent short circuit, such as those developed by Evonik Degussa, can bring about advances here. The extent of the problem becomes apparent when you consider that the next-generation Toyota Prius will not come to market with lithium-ion rechargeable batteries but with well known nickel-metal hydride batteries of its predecessor. [Spi 07a]

Lithium-ion battery: the favourite still poses problems

Nanostructure materials have the potential to improve the electrical characteristics of lithium-ion cells: examples are nanophosphate, nanoporous carbon as electrode material and nanostructured solid electrolytes. Ceramic membranes improve the temperature stability of the whole system and thus avoid problems that might arise from overheating of the cells due to powerful currents.

There is a further alternative suitable for use in motor vehicles: the sodium-nickel-chloride high-temperature battery. This works at temperatures of around 300°C, the electrodes being in liquid form. This temperature is achieved through the reaction heat of the cells and can be maintained for several days in thermally insulated containers. If the battery subsequently becomes too cold, then it has to be 'reinitialised' by an external current source. It has the dual advantage that there is absolutely no memory effect, meaning that the battery can be charged and discharged as required in any operating condition, and that energy management is non-critical, since cells in series do not behave individually. In addition,

ZEBRA battery especially for cars

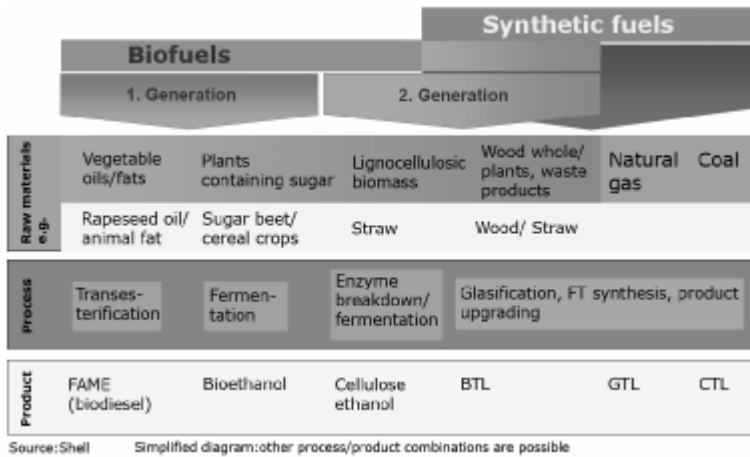
Supercapacitors complement sluggish batteries

the operating temperature of the module makes it independent from external climate conditions. This is why sodium-nickel-chloride high-temperature batteries are particularly attractive for electric vehicles, despite their only average energy density (0.15 kWh/kg) and performance density (0.25 kW/kg): In London, a hundred electrically driven Smart cars are using the so-called ZEBRA (Zero Emission Batteries Research Activity) battery, and thus avoiding the city congestion charge. [Grü 07b]

Supercapacitors or ‘supercaps’ are especially adept in the rapid buffering of energy stores in highly dynamic systems. They get their ultra-high capacity from a dielectric only several atoms thick and from an extensive electrode material – it is possible to have a specific surface of over 1000m<sup>2</sup> per gram of electrode material. Here the focus is on new materials such as carbon aerogels and ceramics sintered from nanopowders of the nitrides and carbides of transition metals. All the same, these new materials are still expensive and require processing stages that are not yet fully understood. However, since the correlation between pore size of the electrode surface, choice of electrolyte and electrical characteristics is now known, the development of supercapacitors with an even higher capacity and modest performance density cannot be too far away. [Sci 06]

#### 2.2.4 Fuels

Whilst it is true that hybrid and electric cars can reduce fuel consumption, the question arises whether there are alternatives to crude oil apart from just using electrical propulsion. The answer is yes, and these alternatives are already being widely used, yet they barely attract public attention. In Germany rapeseed methyl ester, known as biodiesel, is the most well known. Around 1,300 litres of biodiesel can be extracted from a hectare of rape seed. This is then mixed with normal diesel fuel in a proportion of up to six percent.



**Illustration 11:** Ingredients for the production of biofuels and synthetic fuels (Source: Shell)

Some filling stations are selling pure biodiesel, but then the motorist has to be sure that the manufacturer has cleared the model he is driving for use with biodiesel so that the seals and fuel injection systems do not suffer any damage. Pure biodiesel costs about twice as much to produce by comparison with diesel made from mineral oil, but is largely free from tax and so, in the final analysis, it is cheaper at the pump. In June 2006, the government decreed that the amount of tax payable on pure biodiesel should increase from 9 to 45 cents per litre during the period 2008-2012. Diesel fuel made from mineral oil is taxed at a rate of 47 cents per litre.

Pure biodiesel loses its tax advantages

Diesel fuel can, however, also be extracted from natural gas. The Fischer Tropsch Synthesis, invented in 1920s' Germany, makes 'gas to liquid' (GTL) possible. GTL fuel is free from sulphur and aromatic compounds. It can reduce the particle emissions of a current Euro 4 engine by a further 25%. Shell are adding five per cent GTL to their top-price premium diesel. [She 04]

Whilst the liquefaction of natural gas may be useful, it does not lead to an improvement in the carbon footprint. But liquid hydrocarbons can also be produced from biomass (BtL, biomass to liquid). In this process, it is not just the fruit or seeds that are utilised but the complete plant together with stem and stalk, meaning that a hectare of land can produce 4,000 litres of BtL diesel. Choren Industries based in Freiberg estimates that, by the end of the decade, production costs will be in the order of sixty cents per litre, meaning that BtL would be competitive with crude oil even when tax advantages are left out of the picture. The carbon footprint of biomass might not be neutral, since cultivation, fertilisation and transport of the biomass all produce CO<sub>2</sub> emissions, but the Carbon V Fischer Tropsch Synthesis process at Choren does enable the use of any type of organic material, from wood, old fat, used oil and sludge through to plastic waste.

Vegetable biomass is used in its entirety

Complete utilisation  
of vegetable biomass

And there are even environmentally friendly alternatives for petrol. At the top of the list is bioethanol, an alcohol fermented from cereals, sugar beet or sugar cane. In Brazil, it is added to the petrol used in standard vehicles in a proportion of up to 25%. In Germany, the proportion currently stands at up to six percent, the bioethanol being sourced from fermented corn, wheat or sugar beet. Just as with pure biodiesel, there are one or two special vehicles on the market equipped to use E85. This stands for 85% bioethanol and 15% petrol, the latter element compensating for the running characteristics of pure ethanol when the engine is cold. In contrast to biodiesel, fuel containing over 70% bioethanol will remain tax-exempt.

In 2006 and without so much as a by-your-leave, 6.3% biofuels were added to the petrol and diesel fuel sold at German filling stations. This percentage is expected to rise considerably over the coming years. An agreement to this effect was reached in November 2007 between the Federal Ministry of the Environment and Agriculture on the one hand and the car and petroleum industries on the other. The 'Biofuels Roadmap' envisages the addition of 20% biofuels by 2020 – the European Union recommendation for all EU states is 10%.

Proportion of bio-  
ethanol in petrol to  
rise to 10% by 2009

As a first step, the proportion of ethanol in petrol is set to rise to 10% by 2009. Although the biofuel content of diesel will be only 7%, the extra 3% will come from the addition of vegetable oil to the crude oil before the diesel production stage. [VDI 07a]

According to the Roadmap, the twenty-percent target in the second stage can only be achieved with second-generation biofuels, i.e. biomass to liquid (BtL). The only facility capable of this as yet is the Choren Industries pilot plant in Freiberg. The question of whether the addition of biofuels to petrol will remain problem-free for automotive technology (seals, petrol lines and aluminium engine parts) is yet to be answered. The petroleum industry plans to continue adding only 5% bioethanol to 'Super plus' grade fuel which owners of older cars will still be able to use – at a premium rate, of course. [Rot 08] How many vehicles will still need Super plus in 2009 is debatable – the figures vary wildly from around 375,000 to almost ten million. [Hal 08]

If fuel is being grown on the farm, then it is in competition with food. Initially, the idea was floated of using only fallow fields to grow plants for biofuels but it has since turned out to be the case that agriculture will give preference to renewable primary products. This has already led to massive increases in corn prices in Mexico, to take just one example. Second-generation BtL biofuels can help here. [Sam 07]

In Germany, liquid gas (Liquefied Petroleum Gas, LPG; also called Autogas) and natural gas (Compressed Natural Gas, CNG) are available from a relatively dense network of filling stations. Nitrogen oxide and particulate emissions are low, and there are a number of suitable car models available. Until the end of 2018 motorists can benefit from a reduced rate of tax. However, neither is a sustainable long-term option for the future, especially as their widespread distribution is dependent on favourable tax treatment, as experience in Austria has shown.

Liquid and natural gas at a reduced rate of tax until 2018

But even normal diesel fuel still has potential. By using a storage catalyst, the emissions of nitrogen oxide from diesel vehicles can be reduced to the same level as in petrol-driven cars. The storage catalyst is part of a modular system that, together with the classic diesel oxidation catalyst, reduces the emission of carbon monoxide and, with the help of a particle filter, the emission of soot particles. The storage catalyst is complemented by an SCR catalyst (Selective Catalytic Reduction), which breaks down more nitrogen oxides. The complete system is marketed by Daimler using the name Bluetec. It has been introduced first for the American market in the Mercedes-Benz E320 Bluetec. Since 2006, it has been possible to obtain sulphur-free diesel fuel, without which the storage catalyst would otherwise be damaged. From 2008 onwards, sulphur-free diesel should also be extensively available in EU countries, so that Bluetec vehicles can be sold in Europe as well. [Dai 07a]

Catalytic converter system for diesel vehicles

The efficiency of Bluetec can be improved further by injecting ammonia into the exhaust gas system before the SCR catalyst is reached. For this purpose, one twentieth of the amount of fuel to be used is in the form of an aqueous urea solution. This solution carries the trademark AdBlue and is sold at many filling stations, as diesel-powered commercial vehicles are increasingly using AdBlue to meet the Euro 5 Standard which comes into force in 2009.

Sulphur-free diesel fuel in the USA makes storage catalyst possible

Fuels / drive systems	Environmental pluses	Environmental minuses	Comments
Biofuels - Ethanol - Rapeseed oil / rapeseed methyl ester (RME)	Superior to diesel in terms of CO <sub>2</sub> ; biodegradability	Heavy toll on ground water and soil; also high demand made in terms of agricultural land; N <sub>2</sub> O emissions caused by use of fertilisers	No change in emissions from those of diesel; uneconomical; high level of agricultural subsidy and loss of revenue from mineral oil taxation
Natural gas - compressed (CNG) - liquefied (LNG)	Lowest emissions; 25% less CO <sub>2</sub> emissions per energy unit compared to petrol and diesel	Heavy fuel tanks increase vehicle weight	Infrastructure being put in place; reduced range; makes sense for fleet operators; all safety standards complied with
Liquefied petroleum gas (LPG)	Low emissions; 10-16% less CO <sub>2</sub> emission per energy unit than petrol or diesel	Heavy fuel tanks increase vehicle weight	Comparable with natural gas, with advantages in terms of filling stations, fuel tanks, range, handling; access to subterranean garages may be restricted
Hydrogen (H <sub>2</sub> )	No harmful emissions apart from NO <sub>x</sub> at place of combustion	Emissions when generated from fossil energy sources; production costs still high	Bulky fuel tanks; uneconomical; when sourced from solar energy, direct use would be preferable
Electricity	Almost no local emissions at place of use; low noise	Displacement of emissions to power station; battery issues (recycling, manufacture); very high vehicle weight	uneconomical; restricted scope for use (protected areas); no overall reduction in emissions
Fuel cells	Almost emission-free at place of use; catalysed use of fuel; high degree of efficiency; low temperatures	Additional losses when additional engine fitted; high demands made in terms of H <sub>2</sub> purity	Technical development still at early prototype stage; not expected to enter service for 10-20 years; preferable to use fuel cells for static power generation

**Illustration 12:** Alternative fuels and vehicle propulsion systems (Source: Federal Ministry for the Environment, Conservation and Reactor Safety)

### 2.2.5 Fuel cells

Hydrogen plays a key role in the quest for the so-called 'zero emissions' vehicle. Since the beginning of the 90s, intensive research has been carried out in this area in pursuit of two essentially different ideas: on the one hand, there is the vehicle powered by the direct combustion of hydrogen in a suitably adapted combustion engine. BMW are now the only company still pursuing this approach. The alternative technology is

aimed at an on-board system for generating electric current from hydrogen in fuel cells to drive an electric engine.

For automotive applications, PEM (Proton Exchange Membrane) fuel cells are the most suitable. They provide enough power for motor cars and also for buses. The chemical energy stored in hydrogen is converted with oxygen directly into electrical energy without going through the otherwise intermediate steps of heat and mechanical energy necessary in power stations. The eponymous protons permeate through a polymer membrane coated with a catalyst layer, so that the reaction of hydrogen and oxygen to make water is a completely electrochemical one. The working temperature is limited to 80°C, which calls for complex cooling systems. Thus, a fuel-cell-powered car needs around three times more radiator surface than a diesel car. The low working temperature is necessary because of the water molecules in the exchange membrane, which are necessary to transport protons. Volkswagen are working on a high-temperature PEM cell with an operating temperature of 160°C. Instead of water, phosphoric acid is used as an electrolyte. [Sch 06]

For all types of fuel cell, the challenge is now to find a cost-effective and plentiful catalyst material. Platinum has generally been the catalyst used up until now and is the biggest cost factor in fuel cells. Up to half a kilogram of platinum costing several thousand euros is needed for one test vehicle.

Volume production of fuel cells still remains expensive

The storage of hydrogen in the car takes place either under high pressure or in cryogenic liquid form or even as a metal hydride compound. This latter method is barely feasible at the moment due to the weight of the metal reservoir and the heat of absorption generated when filling up. More basic research is needed. The use of carbon nanotechnology affords good prospects. Also, the mass of the pressure tanks or cold tanks relative to the amount of energy transported is large, resulting in a corresponding loss in range. In addition, the liquefied hydrogen evaporates over time. In practice, pressure tank storage is manageable. Ford report that even in a crash or when shot at with a gun, there is no danger of an explosion

Hydrogen storage must be improved

There have already been an immense number of hydrogen-powered prototypes and limited production runs. Fuel-cell engines are undergoing intensive research. Daimler alone employ a research team of 500 and have invested well over a billion euros so far. The greatest advance has been in the fuel-cell engine for public transport buses, which have enough space for all the components and are regularly serviced by the bus companies. In several European cities, bus companies have a number of hydrogen-powered buses in their fleet. Their initial cost, which can be around six times higher, is usually funded by the EU, and they give valuable information about routine operation. [Wei 04]

Daimler and Honda  
announce limited pro-  
duction runs of fuel  
cell cars

Starting in 2010, Daimler intend to use the B Class as a prototype for fuel cells in a limited production run. The sandwich floor of both the B class and the A class is ideally suited to the integration of fuel cell technology. For the 'B class F Cell', 136hp (100kW), a top speed of 170km/h and a range of 400km are planned. The vehicle will start up even at a temperature of -15°C. [Dai 07c]

For summer 2008, Honda have announced an ambitious step: the 'FCX Clarity' with fuel-cell engine will be leased to a representative range of customers for a monthly fee of 600 US dollars in a limited production run. Honda do not use PEM fuel cells but a proprietary development. The FCX Clarity has been specially constructed around a fuel-cell engine. [Hon 07]



**Illustration 13:** Delivering liquid hydrogen to a filling station in Berlin (Source: BMW Group)

The fuel cell car is  
an electric car

Just like internal combustion engines, fuel cells have an optimum working capacity, which is basically at variance with the continual changes in load of a road-going vehicle. That is why the intermediate storage of electrical energy in batteries and supercapacitors is essential. The technologies needed for this are likewise being further developed with the introduction of hybrid vehicles, which have an electric motor in addition to the traditional internal combustion engine.

In the long term, it may be possible to mass manufacture a hydrogen-powered car which, as regards looks and functionality, does not differ greatly from the cars of today; one, however, that would use a fuel that was independent of oil and supplied via a completely new infrastructure.



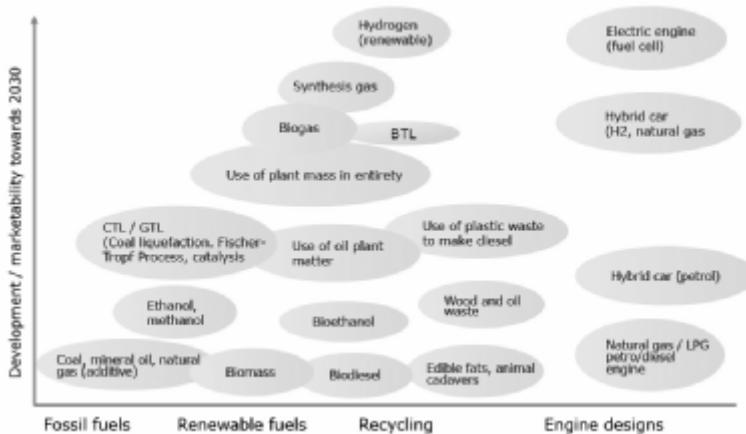
In an electrically powered car, the number of mechanical components would also be drastically reduced.

Taken over the whole energy chain, the efficiency of hydrogen is debatable. Yes, the conversion in the vehicle takes place relatively efficiently – at any rate, much more efficiently than in an internal combustion engine – but taken as a whole, the production of hydrogen by electrolysis or by the reforming of hydrocarbons represents a major negative on the balance sheet. Hydrogen is an energy medium that cannot be simply be ‘mined’ or ‘drilled for’. The crucial factor, therefore, is the choice of energy sources used to obtain the hydrogen.

An on-board PEM fuel cell with a special platinum ruthenium catalyst can convert methanol into electricity, which would make it possible to delay the construction of new infrastructure for hydrogen. Its power density may not be as great but liquid methanol is easier to manage and can in principle be extracted from any source of carbon (crude oil, natural gas, wood waste and biomass). [But 07]

Ultimately, after a careful consideration of the alternatives, the balance sheet for the whole of the hydrogen business could turn out to be positive. If there is no long-term alternative except to increase the efficiency of the traditional combustion engine, hydrogen could well become the energy transfer medium of the future. If, however, battery technology continues to make progress, the energy storage capacity of batteries could rival that of hydrogen tanks. Then the electrical energy of the car of the future would be stored electrochemically and hydrogen as an intermediate step could be dispensed with.

When weighing up the pros and cons, we need to take into account the source of the energy transfer medium hydrogen



**Illustration 14:** Development paths for new fuel concepts (Source: Energy Agency.NRW)

## 2.3 Chassis

One of the automotive industry's most ambitious aims is the introduction of steer-by-wire. By this is meant the idea of steering the car electrically without a mechanical steering column. Up until now, the steering column has more or less determined the position of engine and gearbox and increased the danger of injury for the driver in the event of a collision.

### 2.3.1 Steer-by-wire

An electrically aided mechatronic steering system will enable other automatic interventions by driver-assist systems such as ESP, as it is not just braking but also compensatory steering movements that contribute to vehicle stability. Lane-keeping assist systems draw the driver's attention by increasing steering wheel resistance or by gently vibrating the wheel. Likewise, parking aids can make good use of electrical steering.

Steer-by-wire systems that are purely electrical must not be allowed to fail, as the steering is almost more important for controlling the vehicle than the brake. Without brakes a driver can use the braking effect of the engine by changing down, can freewheel, can reduce kinetic energy by skimming along crash barriers or can drive around obstacles. If the steering should fail completely the only remaining option is to brake. So it is prescribed in law that steering assemblies may not have actuator components that are exclusively electrical or exclusively pneumatic. The car manufacturers must prove the safety of further systems before regulations and the present legal situation can be changed. This proof is not yet in evidence, as steer-by-wire calls for multiple redundant systems, ideally having their own power supply, all of which greatly increases the vehicle's mass. But there are compromises: BMW has added an integrated planetary gearbox to the mechanically operated steering column, which varies the given steering angle according to the driving situation and driving speed. Should this active steering assistance fail, then it would be like the failure of hydraulic power steering; the vehicle can still be steered. [Lem 05]

Steer-by-wire has to  
be configured with  
redundant systems



**Illustration 15:** Systems which are purely steer-by-wire or drive-by-wire are already in use in the construction of specialist vehicles for drivers with limited mobility. They are configured as redundant systems and have TÜV approval. The left hand steers a mini steering wheel and the right hand operates the throttle (Source: Paravan Ltd.)

A steering system using electronic data transfer does not give an authentic driving ‘feel’, however, as the steering wheel is not connected mechanically to the road. This has to be corrected by the use of a force-feedback system, which should convey the driving feel in real time. There are still challenges to be met before software-defined steering can be made not just safe but practicable.

In the years to come, there will be further scope for improvements in chassis technology. Comfort can be improved by systems which compensate for ruts and side winds. Fully automatic parking is also not beyond the bounds of possibility. But an active chassis will prove to be particularly comfortable during a journey: via actuators it adjusts the shock absorber characteristics to suit different road conditions and is regulated by sensors for speed, lateral acceleration and road condition. Within milliseconds, the optimum damping force is applied to each wheel.

New chassis technologies are improving comfort

The car’s cornering ability can be increased by the use of steerable rear wheels: the turning radius would be smaller and manoeuvrability in parking spots and multi-storey car parks improved. If, on the other hand, the rear wheels could steer in the same direction as the front wheels, then it would be possible to change direction more quickly in a hazardous situation. Continental Automotive Systems are working on such systems, but think it unlikely they will be introduced before 2020. [Wal 06]

### 2.3.2 Brakes

The electro-hydraulic  
brake already exists

Basic safety considerations have to be taken into account for brake-by-wire. Brake-by-wire using electro-hydraulic braking systems is a standard feature on some Mercedes-Benz models as well as on hybrid cars from Toyota and Ford. The position of the brake pedal is sensed electronically and the braking effort is distributed electro-hydraulically. The corresponding resistance at the brake pedal itself is simply simulated. Back-up in case of failure of the on-board electrical system is provided by supercapacitors. A conventional direct link between the main cylinder and the slave cylinders is in place should the regulating system fail.

All-electric braking  
is one for the future

Purely electromechanical systems in which the brake pads are applied to the discs by means of a motor or an actuator are of immediate interest for future applications. Many suppliers are working on this but, because of the high energy requirement, they are reliant on an electrical supply of 42 volts, which does not yet exist – at least not in a fail-safe form.

As an alternative, Continental (formerly Siemens VDO) are developing the Electronic Wedge Brake (EWB), which for the most part gets its contact pressure from the brake friction itself and can be run on 12 volts. Using this system, even on slippery roads the braking distance can be reduced by 15%. Series production is due to begin in 2010.



**Illustration 16:** An electronic wedge brake being tested (Source: Continental/Siemens VDO)

### 2.3.3 Wheels and tyres

The tyres transmit all the forces between vehicle and road. Despite their great importance for safety, far too little regard is paid to them. Although the on-board active safety systems register the number of revolutions made by the wheels and compute the vehicle's dynamics by means of the acceleration sensors, the condition of the tyres themselves and the quality of the contact between tyre and road surface are still the subject of research programmes such as the EU-sponsored APOLLO and FRICTION projects. The 'intelligent tyre' senses the movement of the sidewalls via an optical sensor in the rim and compares the tyre's deformation parameters with a mathematically simplified model of the tyre. This system enables tyre pressure and condition to be measured. How tyre wear and road condition can be gauged is currently the subject of research. [Wal 06]

Previously unavailable data about tyre condition is radioed to the instrument panel

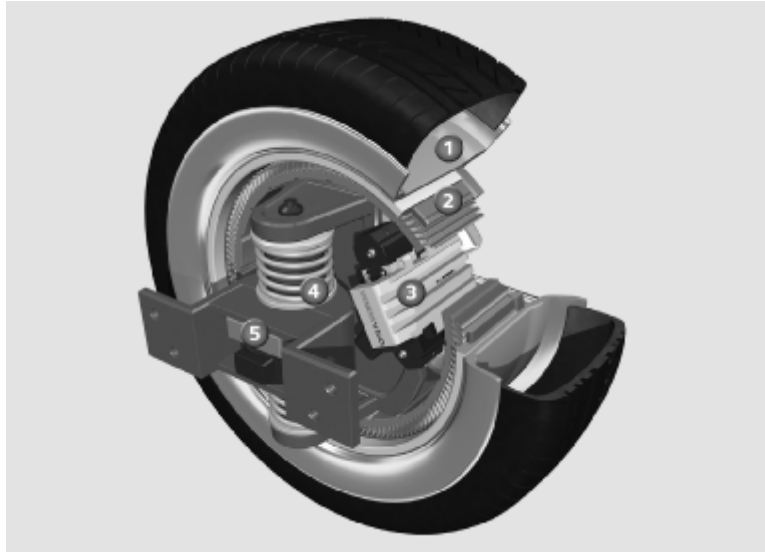
Tyre manufacturers Continental have given the traditional tyre pressure sensor new functions: a module weighing a mere 7 grams attached to the inside of the tyre transmits the current load on the wheel and static tyre data to the instrument panel. Not only can tyre pressures be checked, which can help with fuel economy, but unequal distribution of loads can also be detected immediately, an important factor in the case of vans and heavy goods vehicles.

In the future, the significance of car wheels could be very different to that of today. Continental (formerly Siemens VDO) are developing a wheel system called 'eCorner' which is intended to replace the drive, the classic hydraulic shock absorber suspension, mechanical steering and the hydraulic brake. It is being developed with electrically powered vehicles particularly in mind.

The integrated wheel combines several components in the smallest of spaces

The car is powered by electric motors in the hubs of the actual wheels. Keeping contact with the road will be tyres, in the interior of which sensors (Tire Guard) also monitor tyre pressure. However, the wheel of tomorrow will differ considerably from the wheel of today as regards the suspension: whereas at the moment, complex mechanical suspension is the norm using oil under pressure and springs to give a comfortable ride for the passengers and ensuring that the wheels always maintain safe contact with the ground, electronics are destined to play a much greater role in the future. Electric actuators will take over the task of maintaining permanent contact between wheel and carriageway. This new type of suspension will mean that hydraulic steering can be dispensed with – in future, each wheel will be individually steerable. When slowing down, the hub motor can also be used to assist braking through the generator effect. The electrical energy thus generated can be used to charge the vehicle's batteries to the point where the 'Electronic Wedge Brake' (EWB) acts as a supplement to the generator brake in decelerating each wheel individually. Thanks to its steerable wheels, the eCorner system makes it possible to park almost at right angles and, in a hazardous situa-

tion, the vehicle can more easily be stabilised by the use of electronic steering and by systematically accelerating individual wheels.



**Illustration 17:** The ‘eCorner’ vision: The rim remains (1). Underneath is the electric hub motor (2). The electronic wedge brake takes care of braking (3). Active damping (4) and electronic steering (5) replace the classic hydraulic systems. (Source: Continental)

The active chassis anticipates bumps in the road and adjusts the damping effect accordingly

Whilst the eCorner system is meant for drive-by-wire cars, expected to be on our roads in 15 years time, an interesting development in vibration dampers exists here and now. Shock absorbers filled with a magneto-rheological fluid make continuous and variable control of the shock absorber possible, as the shock absorber fluid reacts to a magnetic field. With its very quick response, the shock absorber can be set over a much wider range than is possible with a normal shock absorber system controlled by valves. If the car’s laser scanner now scans the road ahead, the vehicle body can be completely decoupled from the driving surface. Not only can the ‘active chassis’ be switched from sport to comfort mode as the driver requires, it can also adjust in advance to bumps in the road. A hitherto unimagined level of driver comfort is now achievable. [Dai 07b]

A low rolling resistance helps to save fuel

The tyre is especially important where fuel economy is concerned. A reduction in carbon dioxide emissions can be achieved not just by improving the internal combustion engine and adding biofuels but partly through tyres having a low rolling resistance. To this end, politicians are planning a classification system in which tyres, like fridges, are to be allocated to environmental categories. The tyre manufacturers are rather critical of a classification based simply on a tyre’s low rolling resistance

characteristics. Low rolling resistance is the result of the use of a particularly hard rubber compound which considerably impairs the handling and braking characteristics on wet roads. So in any classification, the tyre's wet braking capabilities and the amount of noise it generates must also be taken into account. The question of the extent to which tyre wear contributes to particulate emissions remains unanswered. [Sch 08a]

A newly developed high-performance rubber additive from the specialist chemical company Lanxess can considerably reduce the surface wear of car tyres. The nanoparticles are made up of the usual tyre raw materials and combine very well with silica, which is used instead of carbon to lower rolling resistance whilst improving wet weather performance. [Sch 08b]

## 2.4 Electronics

Electronics are taking up an ever-increasing share of automotive technology. In new vehicles, electronics account for 20% of the added value and the Association of Car Manufacturers (VDA) predicts that this will reach 35% by 2015. [VDA 06]

Navigation devices are the application currently enjoying the greatest growth. While more and more car drivers are purchasing fitted or removable satnavs, manufacturers are developing software that shows not just a view of a map but also 3D views of prominent buildings as an additional aid to navigation. If the accuracy of the Global Positioning System satellites for civilian purposes was better, then lane-level positional information could also be given. The plan is for the European civilian satellite navigation system GALILEO to give just such a precise level of information. After experiencing a number of political and commercial difficulties, however, it is not due to go into service until 2013 at the earliest. [EU 07]

As yet, the file formats used in today's satnav systems are not standardised: almost every model has its own data format, for which the raw data from the map suppliers must be specially converted. So at Volkswagen, a total of 200 different DVDs have to be generated for the yearly update of in-built satnav systems. Several car companies, equipment manufacturers and map suppliers have decided through the PSF initiative to introduce the 'Physical Storage Format' in order to standardise the storing of data.

European satellites  
permit lane-level  
navigation

2.4.1 Driver assistance systems

In a car, driver assistance systems make up the lion’s share of electronic components. Many are now standard equipment in almost all vehicles, such as the electronic stability programme (ESP) or anti-lock brakes (ABS). Both of these should ensure that the car can still be steered in exceptional circumstances by acting on the driving dynamics. Today, their use is beyond dispute.

Night vision systems already exist for top-of-the-range cars, which to a certain extent broaden the driver’s horizon. Even with high-performance xenon headlights, how far you can see is limited, because the cone of light has to be designed in such a way as not to dazzle oncoming drivers. Passive night vision systems use infrared beams, so that warmer objects such as people and animals can be detected on a monitor at a range of up to 300 metres. But illuminating the area in front of the vehicle at night using special infrared headlights is also possible. A camera behind the windscreen records the otherwise invisible scene and also shows up lane markings and traffic signs on a black-and-white monitor at distances of up to 150 metres. As the number of older drivers with night vision difficulties is increasing, this technology will be adopted in all classes of vehicles. Rear-view cameras are a simple, established technology. Frequently, poor rear vision is caused by the need to have an aerodynamic body shape. The ‘electronic eye’ compensates for this. [Cro 07a]

Night vision devices  
broaden the horizon

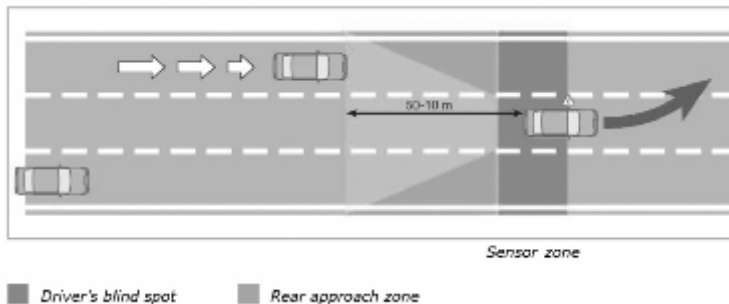


**Illustration 18:** Infrared night vision system (Source: Service Office FAS)



Last year there were more than 2.5 million accidents on German roads resulting in just under 460,000 injuries and more than 6,500 fatalities. Most accidents happen because the driver is inattentive, distracted or is unequal to the demands made by a particular situation. Here, predictive and proactive safety systems come into play and correct the driver as necessary. Laser scanners, cameras and associated on-board computers detect the position of the car on the road. These information sources make it possible to design equipment to provide lane change assistance and also to warn of an unintentional lane change: in the first system, the driver is warned of a vehicle approaching from behind which could otherwise be in his blind spot when he is intending to change lane. In the second system, the vehicle detects if an inattentive driver is straying from his lane and gives a warning by, for example, vibrating the seat. These systems are already available in top-of-the-range models from Mercedes-Benz, Audi and Volvo. Electronic assistance in observing traffic emerging from side roads is still at an early stage of development: for example, cameras with three-dimensional vision that can detect cyclists approaching at speed from the side. As almost a third of accidents happen at cross-roads and junctions, electronic monitoring has the potential to be very helpful indeed. The problem is how to generate the three-dimensional image: at least two conventional cameras are needed to produce the images which then require complex processing. Alternatively, a new type of micro-integrated, real-time 3D camera can be used, which takes into account the depth of field.

Assistance systems actively correct inattentive drivers



**Illustration 19:** The lane change assistant keeps track of vehicles in close proximity to the rear (Source: Service Office FAS)

In an imminent accident situation, the proactive safety systems can be linked to the passive systems. By this means, the air suspension chassis is stiffened, making the handling more stable. The steering is reconfigured and becomes more responsive. The brakes are put on red alert and, as a precaution, braking pressure is increased should an emergency stop be necessary. The seat belt tension is increased slightly and the electrically operated seats automatically move to the best position in relation to the airbags. Side windows and sun roof close, so that no foreign objects can get into the car. If there is no accident, then all these measures can be

Should an accident be imminent, precautionary measures are taken

reversed. In the case of an actual accident, the passive safety systems are now in a high state of readiness.

A cruise control device holds the selected speed automatically, but only when integrated with distance control does it become the first driver assistance system with integrated environment sensors. By means of radar or infrared cameras, this system monitors the traffic in front and automatically brakes the vehicle should the distance to the vehicles in front become too small. The driver may also receive an additional warning, as the delay for this automatic system is limited by law to 40% of the maximum possible.

A system developed by Nissan is 'proactive' in quite a different way. Before the vehicle is started, sweat is measured by a sensor on the gear stick to assess the driver's blood alcohol level. Should the level prove too high then the vehicle will not start. As it would be difficult to sell a private motor car with such a safety device, Nissan is aiming the product at professional drivers such as taxi drivers and freight carriers.



**Illustration 20:** The assistant for traffic from side roads uses a head-up display on the windscreen to warn of moving objects outside the driver's direct field of vision (Source: BMW Group)

Information systems such as navigation aids have become widespread in their use. The market for navigation systems is booming and the continual improvement of the hardware means that the whole of the Central European road network, plus additional information, will fit on a single memory card. Greater mobile processing power and memory capacity will soon make possible not just a bird's eye view of three-dimensional maps but also the visual representation of the facades of prominent buildings. In this way, far less is left to the driver's imagination and orientation becomes even easier.

In the future, two improvements will have a profound effect on satnavs: at the moment, the geographical map data is usually more than six months old before it reaches the customer in the form of a CD-ROM, DVD or memory card. Maps stored on a central server and routing transmitted online (such as is already used today to provide navigation information for mobile phones) could considerably enhance topical accuracy. Much depends on setting a reasonable price for the data transfer included in the purchase price of the device or calculated individually for each route provided. When the new European satellite navigation system Galileo makes possible even more accurate positioning, then accurate lane-level directions could be given even in the city. Galileo will commence commercial operations in the next decade and, in conjunction with the present Global Positioning System GPS, will permit reliable positioning down to the nearest centimetre.

Even today, satnavs frequently give the maximum speed permissible as additional information, with the danger that this information is no longer current. This could apply even with the online transfer of data. It would be a good idea to superimpose the relevant road signs for the driver after a camera has scanned the vicinity for them. Together with the night vision device already mentioned, order can thus be imposed on otherwise confusing situations.

The 3D view from satnav systems also shows buildings and their facades.

Map data can be combined with local information from vehicle cameras



**Illustration 21:** Local 'car to car' communication  
(Source: CAR 2 CAR Communication Consortium)

Cars communicate  
with one another  
about the traffic  
situation

One interesting alternative to getting information by satellite from space or from a central data bank could involve the vehicles themselves communicating with one another. Using 'car to car' communication, vehicles can relay the current situation to others in the neighbourhood. For example, this might be information about the sudden appearance of black ice or traffic congestion over the brow of a hill or around a bend. Radio technology to transfer data such as WLAN is one option, but it is conceivable that optical impulses in headlamps or tail lights could also be used. Data could be transmitted using LEDs which can be quickly modulated in a way that is imperceptible to humans. With such a range of possible options, standardisation and a certain proliferation of suitably equipped vehicles would of course be necessary to sustain the system. Fiat, Volkswagen, Daimler, Renault and Audi are therefore working together in the CAR 2 CAR consortium to develop this 'Network on Wheels'. [Sti 07]

The transfer of data from vehicle to vehicle in network-enabled traffic presents not only technical challenges – such as countering interference – but also psychological hurdles. In order that the whole system can function, many road users must be actively involved. Most road users will not mind supplying information, but they will be less happy to divulge 'inconvenient' data such as their actual current speed. Should this be higher than is allowed, then their misdemeanour will be apparent to everyone. The authorities could also be interested in such data. [Set 07]

Many driver assistance systems such as satnavs, telephones, infotainment systems and air conditioners have to be manually operated by the driver. Voice recognition systems are set to remedy this situation. They are now speaker independent and will work without previous 'training'. It is already possible to operate them using simple commands or by uttering place names, but in the future, the driver will be able to interact with the assistance system using whole sentences.

Voice recognition  
makes things easier

Sometimes speech is no longer possible: in the event of an accident, 'eCall' will automatically summon assistance and, at the same time, communicate the vehicle's position as indicated by GPS or Galileo to an emergency call centre. In the medium term, this EU-initiated project envisages the provision of this system by law in all new cars.

Automatic call for  
help after an acci-  
dent

In the long term, researchers not only have a multitude of assistance systems in mind but are already working on the completely autonomous motor car. Just as on a train or bus, the driver can then occupy himself with other things during the journey. Several video cameras and 360° laser scanners will capture the vehicle's surroundings. Powerful computers will calculate in real time what action to take. As the driver is no longer able to make mistakes, the number of accidents should fall significantly. Before we get to this stage, however, the legal position must be clarified. To what extent is the passive driver or the manufacturer responsible for any wrong decisions taken by the autonomous motor car? [Kür 07]

Through the use of autonomous cars, traffic density can be increased and better use made of the available road space. Conversely, findings gained from the development of robot vehicles will also filter into the design of discrete driver assistance systems that will come onto the market over the next few years. In an ambitious timeframe, General Motors have announced plans for series production of the autonomous motor car in the year 2018. [Spi 08]

Autonomous cars  
manage without driv-  
ers

An idea of the capabilities of the completely autonomous car can be gained from several competitions organised by the research department of the American Ministry for Defence. In 2004, none of the vehicles reached the 240km-distant destination in the desert, but one of them did cover the first 12 kilometres. The following year, 22 of the 23 cars taking part managed the first dozen kilometres and five even reached the distant destination after around seven hours driving. In November 2007 the route led 96 kilometres through a disused military base. This time, the test vehicles encountered 50 manned cars in a city-like environment with simulated traffic conditions and had to obey the traffic regulations. Despite all this, six of the eleven cars in the final reached the destination without stopping for too long and without crashing. Unfortunately, neither of the two German teams made it. Like the US team that came second, they were using converted VW Passats.

### 2.4.2 Displays and lighting

In recent years, display instruments have become increasingly important. The amount of information reaching the driver has increased enormously, from satnavs, from signals emitted by new types of status sensors, and from components which have become more and more complex such as air conditioning systems offering a variety of settings. One basic problem remains: in order to take in information from the dashboard, the driver must briefly look away from the road.

Eyes on the road  
rather than the  
dashboard

One possible strategy to combat this is the ‘head-up’ display which projects information onto the windscreen, making it appear to hover one or two metres away over the car’s bonnet in the driver’s field of vision. For this purpose, the display image is projected onto a so-called ‘combiner’; usually this is just the windscreen with the help of optical and mirror systems. The curvature of the windscreen is corrected optically by the clever use of concave mirrors. Not only is the eye now no longer distracted to another spot away from the carriageway, it does not have to refocus, as the information appears on the windscreen in the virtual distance.

Of course, only information relevant to the journey or warnings should be superimposed, in order not to confuse the driver. Most of the displays will remain on the dashboard or on the centre console. Here too, the question arises of attention economy. As the driver’s field of vision is limited when looking quickly at something, then symbols have to be colour coded accordingly: a blue engine temperature light indicates normal whereas red indicates overheating. A colour code rather than a shape is more easily taken in out of the corner of one’s eye. Coloured LCD displays serve this purpose adequately and are being used more and more in automobiles. This process is slow, however, as the requirements in a car are essentially greater than applications in computers; for example, as regards temperature stability and clearness of display in bright ambient light.

Flexible displays are  
conducive to good  
design

Flexible plastic displays that don’t need a rigid glass cover are also attracting the interest of car manufacturers. With their unconstrained geometric shape and multiple colours they could open up new design options. So far, however, plastic films have relatively low durability, so further research is necessary. It is hoped that flexible displays will succeed in breaking through into devices for the mass market, that the manufacturing costs will fall and their use in the automobile will as a result become more attractive to manufacturers, but as yet the real ‘killer application’ is still being sought. It is conceivable that there will eventually be seat covers that change colour at the press of a button. And the same technology could also be used to cover the whole of the roof lining with an array of LEDs to provide the interior lighting. [Fih 07]

The classic display instrument is not obsolete yet. Progress is also to be expected in other areas: a monitor placed in the middle of the dashboard

can display two different images depending on the angle it is viewed from. A fine aperture mask makes this possible, showing the driver the satnav map and the passenger a feature film.

With the help of modern displays, an improved operating concept is feasible. In the centre console at the moment are the classic haptic pushbuttons and rotary controls, with LCD displays using software-defined function buttons at the side, as well as a button that can be turned or pressed, such as the one introduced by BMW for the multifunctional control of its iDrive. Completing the picture is the touchscreen, which could function equally well with hand movements instead of actual finger pressure. The Canadian company Digital Dash Ltd based in Montreal is researching a combination of display and controls: captions and status displays are back-projected onto the control surface with its non-virtual yet passive buttons and rotary knobs; adjustments to the controls are detected optically by camera-like sensors from the rear, so that the position of knobs and rotary controls can be detected without contact and without further electrical connections.

Virtual human-machine interface

Progress in the area of lighting is visible in the truest sense of the word. Gas discharge bulbs instead of filament bulbs, improved reflector technology, which makes possible a precise and dazzle-free lighting profile, adaptive cornering lights; all of these are becoming established. Indicator, stop and tail lights using LEDs are also becoming more and more prevalent. The use of LEDs in modern motor cars offers many advantages: they are economical as regards energy consumption, switch on very quickly – thus showing the following driver without any delay that the brakes have been applied – and they are low maintenance. They last much longer than traditional filament bulbs, simply because they are resistant to shocks.

LEDs are available in the colours red, yellow and green and are therefore highly suitable for use in traffic lights, as car indicator lights and stop lights. The big challenge is to design front headlights consisting of white LEDs. White LEDs have now reached the point where they are not just suitable for indicating and as background lighting for displays but can also actively illuminate bigger surface areas. They do not yet have the light intensity necessary for main beam headlights.

LEDs replace incandescent bulbs



**Illustration 22:** The first LED-only headlamp with 54 LEDs in the Audi R8 (Source: Audi)

The light intensity is, however, sufficient for parking lights, daytime running lights and dipped beam. The one exception so far has been the special equipment fitted to the Audi R8, where LEDs are used for all the front light functions. In one single headlight, a total of 54 LEDs are employed. Two small fans transfer the heat produced by the resulting high current to the front cover glass, which in winter is then immediately defrosted. Designers like to arrange these almost punctiform sources of light in circular, belt-shaped or other types of array to give models their own unique, luminous livery. Furthermore, the light produced by the white LEDs, which has a daylight quality, produces more contrast for the driver.

LEDs are especially suited to giving precise illumination. Thus, by switching on a special LED in front of certain optical reflectors it would be possible to have a cornering light operated exclusively by electricity without the use of any mechanical device. In the long term, LEDs will take over from halogen and xenon lights. Arrays containing several LEDs serving a particular function can be kept flat and this makes new designs possible.

### 2.4.3 Software and networking

The wide variety of electrical and electronic components in a vehicle is operated by control devices, which also have to communicate with one another. For example, road speed is evaluated by the electronic stability programme, by the cruise control and by the device for adjusting radio volume. These associated systems have to be physically linked and communicate with each other via a standardised protocol.



The motor manufacturers themselves develop the software for control devices, which is why new components from suppliers have to be adapted to the manufacturer's own standards. In order to simplify this complex process, the 'Automotive Open System Architecture' (Autosar) standard for adapting interfaces has been in place since 2003. Over a hundred companies have joined the consortium in an effort to reduce complexity and costs through the efficient harmonisation of motor vehicle software. The VW Passat already has a control device that conforms to Autosar standards. Some time between 2012 and 2014, the first wiring looms based completely on Autosar should come into production. [VDI 07c]

Vehicle software communicates via new interfaces

German, French and American companies are part of the Autosar initiative plus Toyota as well. In Japan, they are also working on an automotive operating system of their own called JasPar (Japan Automotive Software Platform Architecture). During 2008, the Japanese Ministry for Trade and Industry will be supporting a joint venture between leading car manufacturers and suppliers as well as electronics companies to the tune of 6 million euros. [Hei 07]

The way control devices, sensors and on board electronics communicate with one another is dependent on the so-called data bus. Until now, CAN (Controller Area Network), LIN (Local Interconnect Network) and MOST (Media Oriented System Transport) have been in use. Each of these bus systems fulfils special criteria as regards transfer rates, real-time capability and suitability for various applications. The growing length of wiring needed for data transfer – in the BMW 3 series around 1,800 metres and weighing in at 30kg – as well as the integration of the various bus systems with one another, creates a problem which it is hoped that the Flexray data bus can solve in the future. In the long term, Flexray should take over the tasks performed by other bus systems and provide a secure connection for demanding applications such as steer-by-wire. This data bus made its series production debut in 2006 in the active chassis damping of the BMW X5.

Data cabling is being standardised and made lighter

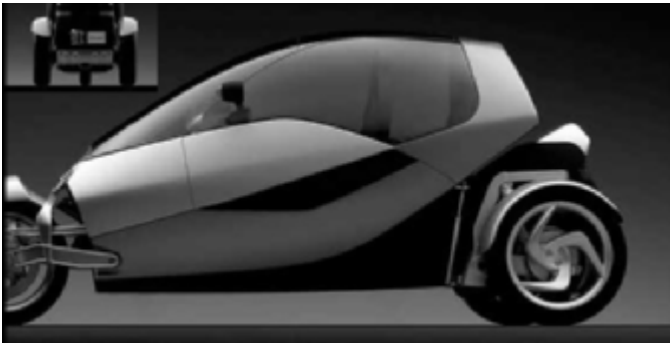
Towards the end of 2007, BMW Forschung und Technik GmbH put forward another proposal for substantially reducing the length of wiring looms, which is rapidly getting out of hand: Internet Protocol (IP) should be used to integrate all communication functions and be combined with the world standards Ethernet and WLAN. There would then be at most five cables to give a safe, expandable, vehicle electrical system, operated by five control devices for chassis, engine, infotainment, comfort and driver assistance. Internet Protocol would make it easier for the service workshop to integrate new control devices and add end user devices with Internet access. [VDI 07d]

Internet Protocol under the bonnet



### 3 CONCEPT CARS

Concept cars that could become a reality hog the limelight, especially at motor shows. By using what are in some cases mock-up vehicles, designers and strategists can gauge the first reactions of experts, journalists and the public to what the automobile of the future might be like. This is not just the case with technically advanced, top-end vehicles ('high-tech cars') but also with less expensive, more modestly appointed ones ('low-cost cars').

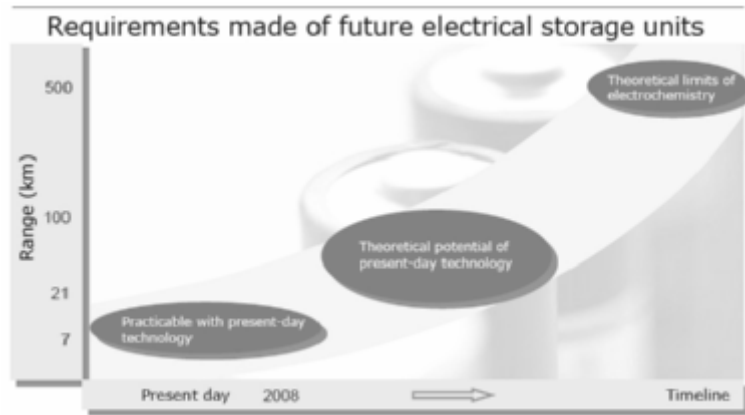


**Illustration 23:** Vehicle study: 'Clever'. The Clever is small, light and economical – and yet it is not simply a 'green' vehicle. In order to enhance its market appeal, its designers have attached great importance to its design (Source: Innovate! 2/06)

#### 3.1 High-tech cars

From today's perspective, new concept vehicles of the future will be based on the internal combustion engine and the electric drive or on a combination of both, giving hybrid propulsion. After a development history stretching back 100 years, the internal combustion engine is by far the most highly developed of all industrial products. And yet, developers can see room for further – even considerable – improvement. Whilst the degree of efficiency under full load is already very good, it tails off noticeably under part load – in the petrol engine more so than in the diesel. On the other hand, the electric motor boasts a high degree of efficiency, even under part load. However, when compared to the combustion engine, the electric motor is by no means ready yet for continuous operation in a marketable vehicle. With the battery technology available today, ranges of up to 100 km are theoretically feasible. This would be sufficient for limited use only, for example in city traffic. Using new battery designs, it is hoped to achieve ranges of up to 500km in the near future.

The internal combustion engine is continually being improved



**Illustration 24:** Future development potential of electric motors (Source: VW Research Department)

Against this background, car manufacturers are working on various design studies to make vehicles more efficient in terms of technology and costs.

Hybrid cars - not just from Japan

There is a wide range of hybrid vehicles. Toyota have had their Prius and Honda their Civic IMA on the German market for years and now, after some initial hesitation, European manufacturers are keen to offer hybrid cars as well. Which of the concept cars will reach the customer first will not be apparent until 2009 at the earliest.

Electric car with range extender

Whilst for some, a car with hybrid propulsion still seems to be a somewhat novel idea, others are looking further into the future. With its 'E Flex System', Opel (General Motors) are producing a variable drive system for fully electric-powered vehicles, which can be recharged from a mains socket. A 'Range Extender' consisting of a supplementary three-cylinder one-litre petrol engine turning at a constant speed to charge the batteries during the journey and extend the range is just one of the variants on offer. The battery system itself is the key factor here – General Motors are betting on lithium-ion batteries and have contracted the German supplier Continental Automotive Systems as well as Compact Power Inc in America to carry out further development. In addition, GM are still working on a fuel cell version.

Lightweight car, small engine.

Without an electric motor and with a combustion engine of just 15kW, Loremo AG are launching their new model of the same name. Loremo stands for 'low resistance mobile', which explains the low-output engine. The car weighs in at less than 600kg and the drag coefficient is just 0.2. The Loremo can reach a top speed of 160km/h and can accelerate from 0 to 100km/h in 16 seconds, i.e. the same performance as a typical compact car. According to its specification, the consumption of this two-cylinder turbo diesel is less than 2 litres per 100km. The front opens up to provide

access for both driver and front-seat passenger. There is room for two adults and there are two rear-facing seats for children or luggage. At the heart of the bodywork is a steel shell weighing 95 kilograms. The rest of the bodywork is made of lightweight plastics. The engine block is behind the driver's seat, giving perfect 50:50 weight distribution. A roadworthy prototype will be ready in 2008. The final purchase price of the first batch should be around 15,000 euros. [Lor 08]



**Illustration 25:** The 'Low Resistant Mobile' with open front door and rear hatch  
(Source: Loremo Plc.)

In 2007 Volkswagen presented a whole new model range called 'Up!'. The basic form of the Up! is a car for four, just 3.45 metres in length, so significantly shorter than the Fox at 3.83 metres and the Polo at 3.92 metres. An integral part of the design is the rear engine, which lies flat so that there is luggage space at both front and rear. In addition, the seats for the three passengers can be removed. Two displays inform the driver about the status of all operating systems.

Model range  
VW Up!

The four-door VW 'space up!' completes the 'New Small Family'. As a single-seater, within its length of 3.68 metres – still shorter than a VW Fox – it has a load capacity of more than 1,000 litres. The front passenger seat can also be turned to face the rear. Like all the seats, it is designed to be very low, yet with its air cushioning, it can adjust itself to the person using it. Petrol, diesel or electric propulsion are all possible. The last of these three is to be found in the 'space up! blue' model, which has a 45kW electric motor and can reach 100km/h in 13.7 seconds with a top speed of 120kph. It derives its power from a lithium ion battery under the front seats and a range of around 100km should be possible using just the battery. A fuel cell with on-board hydrogen tanks increases the range to around 300 kilometres. In addition, the battery can be charged by a solar cell module on the roof or from an electric socket. Cell and tanks are arranged in such a way that the amount of space available inside the 'space up!' is not affected. [Reu 07]

Modular Volkswagen



**Illustration 26:** The 'space! up' from Volkswagen (Source: Volkswagen AG)

The Toyota design study 'iQ' has come up with the smallest four-seater car in the world. With its length of just 2.98 metres, it is shorter than the VW space up! and is 28 centimetres longer than the two seater Smart.

The F700 limousine from Mercedes is likewise a four-seater with a passenger seat that swivels. The rear doors open in the opposite direction. The Mercedes, however, has an overall length of more than five metres. The 1.8 litre engine produces 175kW of power and delivers 400Nm of torque. The engine is a 'Diesotto', a twin turbo four-cylinder, in which the mixture is directly injected and combusted using so-called 'controlled auto ignition'. The F700 will do 0 to 100km/h in just 7.5 seconds, have a fuel consumption of only 5.3 litres and CO<sub>2</sub> emissions of less than 130 grams per 100 kilometres.

New technologies are used in all the designs. Examples include new materials such as lightweight construction materials, nanomaterials, micro-system technologies as well as optical technologies.





Because of their effects and functionalities, nanotechnologies can be employed in almost all areas and together with all other technologies. Because of their versatility in application, nanotechnologies are important across many sectors of the automobile construction industry. This can be seen in the 'NanoMobil', a flagship innovation from the German Ministry for Education and Research. This is an in-depth case study of how nanotechnologies can be applied in automotive construction. For example, glue is being used more and more frequently as a method of joining,

Mercedes with  
'Diesotto' engine

Nanotechnologies in  
the motor car

especially in lightweight construction applications. However, the same glues utilised in factory production cannot be used for repairs and the joints cannot easily be separated in the garage workshop. Likewise, it is not possible to inspect the glued joint without damaging it. This is where glues filled with nanoparticles come into their own as they can be excited by external electromagnetic force. The glue layer becomes warm, leading either to easier separation or to accelerated hardening.

The range of applications for nanotechnologies is broad: in fuel cell technology, in storing hydrogen, for easy-to-clean paintwork and glass surfaces, for textiles that can change colour, for cleaning the air in air conditioners and for tyres with low rolling resistance. The following table shows the range of possibilities.

		Existing uses						Possible future uses	
Use	Functionalities	Outer skin	Bodywork	Interior	Suspension and tyres	Electrics and electronics	Engine and drive system		
									
Mechanical functionality	Rigidity, friction, tribological properties, tensile strength	Nano-clear paintwork Polymer paneling	Nanosteel		Carbon Black in tyres		Low friction engine components		
Geometric effects	High surface-to-volume ratio, pore size		Chameleon effect	Nanofilters Chameleon effect		Supercaps Fuel cells			
Electronic / magnetic functionality	Scale-dependent electrical and magnetic properties		On-command adhesion		Elastic materials (rheology)	GMR sensors Solar cells	Piezoejectors		
Optical functionality	Colour, fluorescence, transparency	Ultra-thin coating Electro-chrome coating		Anti-reflective coatings					
Chemical functionality	Reactivity, selectivity, surface properties	Maintenance and sealing systems	Reshaping highly rigid steels Anti-corrosion	Anti-dirt protection Interior air-freshener			Catalytic converters Fuel additives		

**Illustration 27:** Uses for nanotechnologies in the motor car (Source: Nanotechnologies in the Motor Car, Ministry for Trade, Transport and Development of the State of Hessen)

One important design initiative is, however, the 'LiBaMobil' joint project – new lithium-ion batteries for automobile applications offering increased performance and safety through nanotechnology. At the moment, the weak point of every hybrid or electric car is the storage of electricity in the on-board, rechargeable batteries. The energy and also the power density must be significantly increased, whilst at the same time ensuring that safety considerations are not overlooked. LiBaMobil is focusing on both these aspects: an improved, safe ceramic membrane and a high-capacity anode made of carbon/nanosilica composites.

Improved batteries thanks to nanotechnology

Interaction of various driver assistance components

In their research project known as AUTOSAFE, Siemens, Infineon and Porsche are addressing vehicle safety from a holistic perspective. There are indeed a multitude of driver assistance components that must interact together in order to anticipate and avoid imminent accidents or at least reduce their consequences. But as yet, comparatively little has been done to research suitable signal processing platforms and chip systems. There is a pressing need for research into powerful algorithms as well as into scalable and modular hardware and software architectures suited to the task.

### 3.2 Low-cost cars

The designation 'low-cost cars', or cheap cars as they are sometimes called, is neither suggestive of high quality nor of innovation. However, as regards cheap cars, new and innovative functions are not the major consideration but rather, significant cost advantages which the industry seems to have lost sight of: in the last 20 years, the price of a new car has doubled. Apart from financially impoverished customers in the home market, there are also emerging markets in countries such as India, Iran, Russia, and Indonesia, which could be serviced by low-cost cars.

New cars from 3000 euros

Cheap cars occupy the price bracket between three and eight thousand euros. The cost advantages stem from the use of lightweight construction techniques with very little metal content, from simplified modular construction – mechanical as well as electrical – and from having simplified assembly with a manageable number of product configurations. Differences in levels of equipment are also possible. Items necessary to meet minimum requirements in Western Europe such as the catalytic converter or airbag need not be fitted in vehicles destined for the markets of the emerging countries. [Bic 07]

The Rumanian Renault subsidiary Dacia with its Logan limousine has brought the first cheap car to market in Europe at a net price of 5000 euros in Eastern Europe and 6000 euros in Western Europe. Volkswagen and Toyota for instance, with their designs 'Up' and 'IQ', are pursuing a different strategy in preferring to service the low-cost subcompact segment. Renault-Nissan are working on a 3,000-euro model, which admittedly will not reach the West European market because of its exhaust emissions. In China at the moment, an exhaust emission standard corresponding to Euro 3 is in force. It is to be introduced in India by the end of the decade.





**Illustration 28:** Dacia Logan from Renault (Source: Renault)

A perfect example of the 'low-cost' car is the Nano from the Indian manufacturer Tata. It is due to go into series production in September 2008 and will retail at a pre-tax price equivalent to 1,750 euros. The Nano has a two-cylinder 0.6-litre 24kW (33bhp) petrol engine at the rear. It is claimed to have a fuel consumption of under 5 litres per 100km and to comply with the Euro 4 emissions standard. Equipped as a four-door four-seater, this vehicle offers considerably more comfort than the motor scooters that otherwise hog the roads in India. Despite its top speed of 100km/h, the designers have not fitted it with airbags. The basic version of the Nano is only half the price of what was, until now, the cheapest model on the Indian market, the Maruti 800, essentially a copy of the 1980s Suzuki Alto. The Tata Nano has been equipped with components supplied by the German companies Bosch and Continental. Bosch are supplying – in part via their Indian subsidiary Mico – the fuel injection technology, the braking system and some of the electrics; Continental are supplying the fuel pump and the fuel gauge sensor. [Doh 08]

Bargain basement  
from India: the Tata  
Nano

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Web pages that are no longer available online can often be retrieved from the following internet archive:

<http://www.archive.org/web/web.php>

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