Current Issues

Natural resources

Deutsche Bank Research

Electromobility

Falling costs are a must

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High hopes are held of electric mobility. Given that the earth's oil reserves are finite and oil prices on the rise, hopes are now being pinned on electricity as an alternative fuel for road transport to point the way out of this 'cost conundrum'. If, moreover, the power for electric vehicles is generated from renewable energy sources, it could additionally contribute to climate protection.

Since electromobility will achieve market penetration only gradually, we do not rate companies' first-mover advantages very highly. Having to ramp up R&D activities without the short-term prospect of this investment finding a matching market poses a challenge for the automotive industry. At the same time carmakers must work constantly on improving the energy efficiency of conventional engines, which continue to represent their core business.

In the year 2020 battery electric vehicles (BEV) in Germany could, on the assumption of high government subsidisation and rapid technological progress, attain a market share in new passenger car registrations of between 6% and 8%. However, the ideal economic scenario would be for the technology to establish itself primarily on the strength of technical progress, but in this case its market share in 2020 would be unlikely to top the 3% mark.

All in all, the high cost of E-mobility will mean that it remains a niche market in the coming years. Falling costs are the main precondition for leveraging the huge long-term potential in electrification of the driveline.

Raw material availability, electricity consumption and sources and the recharging infrastructure are a secondary problem. Initially, the vehicles' driving range is not a make-or-break criterion either, as potential launch customers will adjust to this limiting factor.

To become a lead supplier of E-mobility, a large number of specialists are required. We estimate that annual demand for graduates across the relevant disciplines will increase from around 20,000 at present to about 26,000 by the year 2020. Satisfying this demand will pose a considerable challenge for the industry.

In its promotion of E-mobility government must tread a fine line. Offering state-funded premiums to buyers is expensive – and quite the opposite of openness to new technologies. Support for basic research, on the other hand, is to be advocated. Granting manufacturers of BEVs 'super-credits' as a mechanism to offset their reduction targets for fleet-wide GHG emissions could also act as a lever.

On balance the road to an electromobile future resembles one of evolution rather than revolution. BEVS are just one option here. In the spectrum of E-mobility, plug-in hybrids (PHEV) and range extender electric vehicles (REEV) compete directly with BEVS. Over medium and long distances vehicles with fuel consumption-optimised internal combustion engines and, specifically in urban traffic, full hybrid cars are potentially the most economical alternative.

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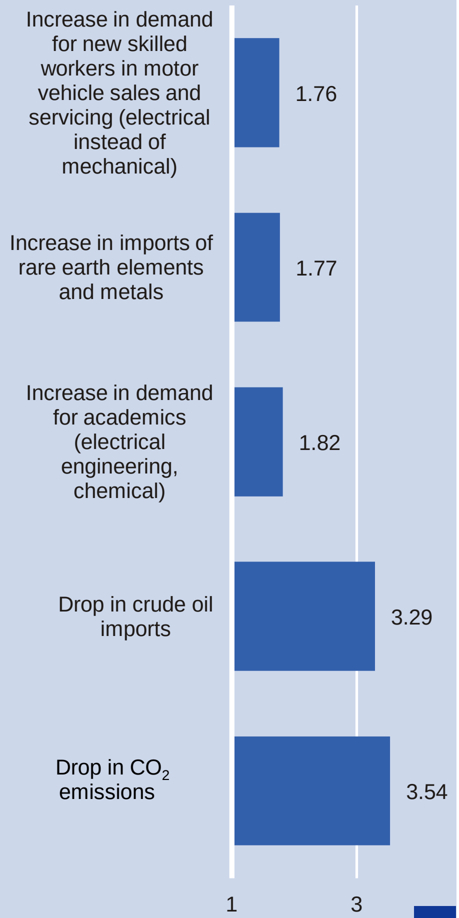
Asking the experts: Implications of E-mobility

Replies: 1: very strong; 2: fairly strong; 3: fairly weak; 4: not at all



Source: IW Cologne 1

1. Hopes pinned on electromobility

At present the issue of electromobility (E-mobility) is electrifying the public. Yet the technology is by no means new. More than 100 years ago, electric and petrol-driven cars were still neck-and-neck. But then the fossil fuels petrol and diesel drew ahead. So why is public discussion focusing so intently on E-mobility right now? Why are many governments supporting the technology just now, and why have carmakers chosen precisely this time to intensify their research and development in this area?

Essentially the answers to these questions are based on hopes that E-mobility will be able to help alleviate or resolve economic, ecological and social problems raised by road traffic:

— The oil reserves on Earth are finite and, going forward, the price of oil looks set to head north. Hopes are now being pinned on electricity, as an alternative fuel for road transport, to point the way out of this 'cost conundrum'. Germans and Europeans additionally see it as a way to reduce their reliance on oil imports.

— If we further assume that the electricity required to power electric vehicles is produced from renewable energy sources, the carbon emissions from road transport will be reduced.

— From an environmental perspective, the greater fuel efficiency of electric vehicles and low local air and noise pollution are further arguments in favour of E-mobility.

— Renewable energies are becoming more important. In Germany their share of energy consumption is projected to climb from just below 20% at present to 35% by 2020. Since the electricity generated from renewables fluctuates considerably, the electric vehicles' batteries are intended to serve as a battery storage system to buffer power, thus forming one element in stabilisation of the power grids and in securing supply.

— The German government aims to have around one million electric vehicles on Germany's roads by 2020.[1] This ties in with the idea of becoming the lead market and lead supplier for E-mobility.

— E-mobility is sometimes perceived as an element of innovative transport systems, which would be distinguished by improved, IT-supported intermodal networking of transportation carriers, more flexible vehicle use and altered ownership structures. In the process automakers would cooperate with local public transport companies to transform themselves into suppliers of integrated mobility concepts.

— And finally, customers also expect electric vehicles to satisfy their requirements of value for money, comfort, safety, performance, fuel consumption, reliability and design. In future too, the people buying the cars will rate these and other criteria very differently according to their personal preferences.

Are the expectations of E-mobility realistic?

In the following report we analyse how realistic the expectations of E-mobility are. We also examine the market-based and regulative instruments with which governments intend and are able to support

[1] Incidentally, according to a report by the National Platform for Electric Mobility (NPE) these one million electric vehicles in 2020 will comprise 45% battery electric cars, 50% plug-in hybrid cars and 5% plug-in hybrid commercial vehicles.

Gradual electrification of the vehicle driveline

There are various stages on the road from a conventional vehicle to an electric car:

Micro and mild hybrids: Vehicles that feature fuel-saving systems such as an automatic start-stop function or regenerative braking are described as micro hybrids. A mild hybrid vehicle will already possess an electric motor, which however only assists the combustion engine, mainly during start-up. All-electric driving is not possible with a mild hybrid.

Full hybrids: Vehicles equipped with an electric motor and a combustion engine are described as full hybrids; the electric driveline allows the car to drive purely on electric power for short distances. The battery can be recharged utilising the regenerative braking system, but the actual source of energy in the vehicle is the combustion engine.

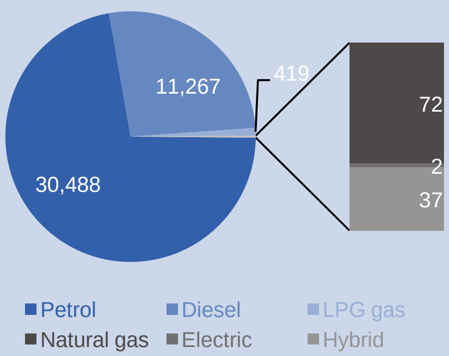
Plug-in hybrids: Plug-in hybrids **(PHEV)** are also fitted with an electric and a conventional driveline. But the dimensions of the electric driveline are such that much of the driving performance can be achieved electrically. Another feature is the option to recharge the battery from the power grid. A PHEV therefore has two sources of energy.

Hybrids with a Range Extender: With Range Extenders **(REEV)** the electric motor alone is responsible for driving the car. The combustion engine installed in the vehicle acts as a generator with which the battery can be recharged if necessary; this can also be done, however, using wall-plug electricity.

Electric-only vehicles: The battery electric vehicle **(BEV)** features an electric driveline only, whose battery is fed from the power grid.

Oil dominant

Number of cars on January 1, 2011 in DE by fuel type, in '000



Source: Federal Motor Vehicle Transport Authority

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E-mobility. Additionally, we estimate the market potential for electric vehicles in Germany in the year 2020 on the basis of various different scenarios. Where appropriate we augment our statements with the results of surveys of the Umweltexpertenpanel (panel of environmental experts) at the Cologne Institute for Economic Research (IW).

What is meant by E-mobility?

To begin with we must, of course, clarify what is meant in this report by "E-mobility", because there are many ways of using electricity in road traffic (see text box). When we talk of E-mobility in this report, we are referring to strictly, all-electric vehicles. Express attention is drawn to any departures from this definition. We refer primarily to passenger vehicles, touching only marginally on the potential of electric drives in two-wheelers and commercial vehicles.

2. Challenges to E-mobility

In this chapter we examine various aspects of E-mobility, following the value chain wherever possible.

Raw material demand – import dependence remains

Road transport is based on petroleum as the primary energy source. Of the 42.3 million cars in Germany 99.7% drive exclusively on fuels made from crude oil. The major alternative source of primary energy is natural gas. Battery electric vehicles (BEV) on the other hand are at present an absolute niche product the world over. At the beginning of 2011 a scant 2,307 BEV were registered with Germany's Federal Motor Vehicle Transport Authority.

Between 1998 and 2011 the price of crude oil has risen roughly tenfold. Amid growing demand and finite crude oil reserves many countries are looking to reduce their oil imports. In Europe at least, up to 2020 BEVs will have practically no impact on oil imports, since import volumes are determined primarily by the consumption of diesel in Europe, whereas BEVs are likely to replace mainly small petrol-driven cars – and the EU is anyway a net exporter of the fuel used to drive these (see below).

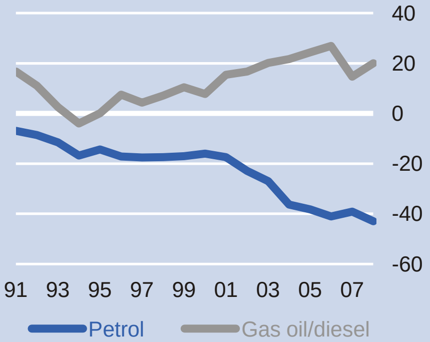
Refineries can produce only a relatively fixed ratio of diesel and petrol from a ton of crude oil. Since diesel engines are widespread in cars on the road in Europe, nowadays Europe has a glut of petrol and a shortage of diesel fuel, which is why in 2008 the EU-27 exported 43 million metric tons net of petrol. That is more than twice the amount of petrol consumed in Germany. The chief offtaker was the US. At the same time 20 million tons net of diesel were imported into the EU-27. A reduction in petrol consumption would presumably initially boost petrol exports while having little effect on crude imports – these being driven by demand for diesel –, all the more so since electric motors cannot be used in diesel powered heavy goods vehicles. Further improvements to combustion engines are therefore the more effective way in the foreseeable future of reducing demand for crude oil imports.

No geological supply risk with lithium

The construction of electric cars gives rise to additional import dependencies. In Europe there are no commercially viable deposits of the materials used to build modern batteries. Lithium occupies a prominent position here. Since lithium features the greatest electro-chemical potential of all metals, batteries would be inconceivable without it, even farther down the line. As driveline electrification

Surplus petrol in Europe

Net external trade of EU-27 in fuels, million tons



Source: International Energy Agency 3

Basic geological terminology

Reserves: Identified raw materials economically recoverable at today's prices and with today's technology.

Resources: Raw materials identified but currently not recoverable for technical and/or economic reasons, and raw materials not identified but geologically possible and potentially recoverable in the future.

Static range: The period of time for which the raw material reserves will last, given constant output.

increases, demand for lithium will therefore be ratcheted up considerably.

In principle sufficient quantities of lithium are available worldwide. In 2010 25,300 tons of lithium were produced globally. The US Geological Survey (USGS) estimates world reserves at 13 million tons, equivalent to a static range of lithium reserves in excess of 500 years. Added to this are resources totalling 33 million tonnes. More problematic is the geographic distribution of the deposits. Global reserves of lithium are concentrated in Chile, which has 7.5 million tons, and China with 4.5 million tons. The largest lithium resources, 9 million tons, are to be found in Bolivia.

Market dominated by just a few companies

Market power is similarly very highly concentrated among the lithium-producing companies, with the five largest firms cornering 80% of the market. The bulk of lithium trade is conducted in the form of lithium carbonate, a feedstock for the processing of other lithium compounds. In recent years world demand for lithium carbonate has soared. According to the leading producer of lithium carbonate (Chemetall), at present around 135,000 tons of lithium carbonate could be produced from the global output of lithium, with the reserves quoted above indicating that the extraction of lithium and hence the production of lithium carbonate could be stepped up very significantly. The major customers are aluminium producers, but battery manufacturers are also substantially scaling up their demand. As a rule of thumb it can be said that about 0.6 kg of lithium carbonate is needed to make a lithium-ion battery with a storage capacity of 1 kWh. Chemetall estimates that not quite 15,000 tons of lithium carbonate would be required in the production of 1 million BEVs. These figures make it clear that the geological availability of lithium should not pose an obstacle to the development of E-mobility, even if it were to evolve into a mass market. The only supply risk that might emerge would be from high market concentration. It therefore remains to be seen whether countries such as China and Bolivia will prove permanently reliable suppliers.

Given the growth in demand, prices for lithium carbonate are likely to continue rising. Recently the selling price per kilogramme has jumped sharply. But since even this puts the price per kilo at less than EUR 10, lithium's share in the total cost of a battery system is still too low to describe it as a price risk.

Recycling becoming more important

The raw materials used in a battery could be reprocessed, suggesting that the introduction of lithium-ion batteries in the automotive industry should be accompanied by the establishment of a comprehensive battery recycling system. This could keep supply risks to a minimum. However, the present recycling systems are still expensive relative to raw material prices.

Demand for copper on the rise

Another important raw material for electric cars is copper. This is used chiefly for the electric motor and the vehicle's electrical system, which is designed for higher current flows. Global mining output in 2010 totalled slightly more than 16 million tons. With estimated reserves of 600 million tons, the static range of the reserves works out at 37 years, a little less than that reported for oil reserves. Chile is the biggest producer with a world market share of 34%. Market power does not pose any serious discernible risks, either in terms of country-specific or corporate concentration. What is more, copper is

High copper price

January 2000=100, on USD basis

Source: London Metals Exchange 4

Rare earths important for E-mobility

Besides these common metals, "more exotic" materials are also used in electric vehicles – in very small quantities, it is true, but they are nonetheless often vital to the working of the product. The most familiar here are the 17 metals subsumed under the heading "rare earths". This term is actually rather misleading inasmuch as the rare earths do not in fact occur all that infrequently. Even the rarest of the rare earths is found in the earth's crust roughly 200 times more often than gold. However, they are very finely distributed. Deposits worth working are indeed rare, and they are regionally highly concentrated. An added complication is that rare earths do not occur in pure form but as oxidised minerals from which they must be extracted. As a rule this process is energy-intensive and very damaging to the environment.

By means of an aggressive pricing policy China has secured itself a virtual monopoly on the production of rare earths. USGS statistics indicate that upwards of 97% of world production totalling 124,000 tons comes from China. Meanwhile, China has begun to use this position as a political instrument – with the imposition of export restrictions, for example. This has led to new mining projects being rolled out in other countries, but these are not yet supplying the markets. As with lithium, the risks here to the supply of raw materials for E-mobility are more political in nature. That said, demand for rare earths is absolutely burgeoning, so much so that it is expected to jump 50% between today and 2015. As a result the coming years could see supply constraints and/or steep price hikes, as finding and extracting deposits is often a lengthy process. But the price risk for E-mobility is very slight in view of the small quantity used per vehicle.

suitable for recycling. Even today the recycling rate in Germany already tops 50%, and it is expected to rise by 2020 to 70%. Owing to the high price of copper, it is likely that when vehicles are recycled a very considerable proportion of the copper used in their construction will be recovered.

Roughly 25 kg of copper currently goes into the production of a compact car. According to Wirtschaftsvereinigung Metalle, the German Non-Ferrous Metals Association, an electric vehicle is expected to need roughly 65 kg per car. In other words, the production of 1 million electric cars would push up demand by 40,000 tons (0.25% of world mining output). But since copper is used in many growth industries, demand is expanding so rapidly as to give rise to a price risk. After all, the price of copper has soared almost five fold in ten years and is currently hovering at the USD 10,000 per ton mark.

Battery technology still in great need of development

The battery constitutes the highest technical hurdle for electric vehicles. In principle all the elements of an electric driveline are highly mature industrial products. Electric motors, inverters, batteries and chargers have been around for more than 150 years. Consequently the individual components feature extremely high degrees of efficiency. The energy conversion losses in the form of heat are below 10% for all components, which explains the high efficiency of electric vehicles. However, there is comparatively little innovative potential left in plain-vanilla energy converters (electric motors, inverters). But not so for the battery, which both converts and stores energy. There is still considerable room for development here, which is why we are concentrating on the battery.

Another reason is that the battery in an electric vehicle (BEV) must differ vastly in technical terms from the batteries used these days in consumer electronics. For example, the battery in a BEV must meet requirements that have not featured prominently in previous areas of application:

— Safety: The safety aspect poses a particular problem for the lithium-ion batteries currently in use because metallic lithium ignites when it comes into contact with air and when it exceeds its melting point, and it cannot be extinguished with water or foam. On contact with water it reacts very vigorously. There is a risk of one or more of these events occurring in a traffic accident. The fire hazard therefore still needs considerable further reduction. In the event of an accident, for instance, the entire auto electrical system must also be guaranteed to discharge instantaneously (high-voltage intrinsic safety).

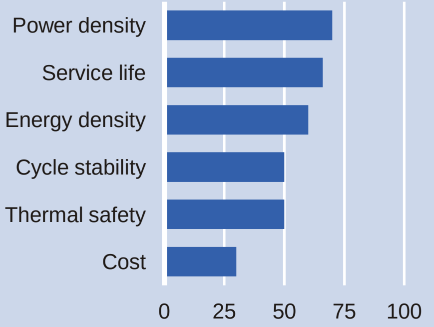
— Runtime: The battery is by far the most expensive part of a BEV. Its service life also determines the potential length of time the vehicle can be used. A BEV whose battery does not work is an economic write-off. One problem is that lithium-ion batteries 'age' over time and with the number of discharge/charge cycles because the electrodes oxidise. Once the battery storage capacity has dropped by more than 20% of its original capacity as a result of these processes, the battery is deemed to have failed. A marketable BEV battery should last for 15 calendar years or 300,000 kilometres before falling below this benchmark level; that would correspond to approximately 2,000 to 3,000 charge processes.

High-voltage intrinsic safety

In current BEVs the voltages in the auto electrical system are higher than 300 volts (against 12 volts in conventional vehicles). Voltages like this put people's lives at risk. A vehicle is considered intrinsically safe despite its high voltage if the technical measures applied to it guarantee full protection for people (passengers, technical personnel or rescue teams) at all times from electric shock and arc flash. In the event of an accident, for example, the vehicle's electrical system should shut down the power automatically and immediately.

Battery technology: Still a long way to go

Degree of target achievement*, %



* Degree of target achievement in an automotive lithium-ion battery

Source: Robert Bosch AG 5

Battery terms explained

Lithium-ion technology: Nowadays this battery technology is predominant in consumer electronics. Its key edge over other batteries lies in the energy density achievable. With lithium-ion batteries lithium is stored in the anode as active material. Nowadays cobalt or iron phosphate are often used as reactants at the cathode. With a lithium-cobalt battery the material used has a theoretical energy storage capacity of approximately 570 Wh/kg.

Battery cell: An electrochemical cell is the basic element of modern-day batteries. Each cell is a small energy store and converter, its storage capacity being determined by the amount of electrochemically active material in the cell. At present a lithium-ion cell can generate voltage of up to 4 volts and attain energy density of 140 to 170 Wh/kg.

Stack: A stack consists of several interconnected cells.

Battery system: A battery system contains several interconnected stacks. The battery system further includes control electronics and the battery cooling. As a rule the energy density of a battery system is some 40% less than the energy density of the cells used. Nowadays usable battery systems feature energy density of between 80 and 120 Wh/kg.

— A battery system for a BEV must provide far more power, voltage and energy than is necessary in consumer electronics. Consequently the integrated control electronics and the battery thermal management required must be constructed quite differently. As target parameters, a marketable battery in a BEV should operate at roughly 400 volts, achieving power density of 1,800 watts per kilogramme and energy density of 200 watthours per kilogramme; target achievement at present ranges between 50 and 65% of this.

— Temperature resistance: A lithium-ion battery operates optimally at around 35°C. Ambient temperatures below freezing point cause a drastic fall-off in performance, and in temperatures above 45°C the battery ages rapidly. Comprehensive thermal management is necessary to keep the battery pack within an optimal temperature range.

If we contrast these requirements with the values for an existing battery pack it becomes clear that a lot of development work still remains to be done. There are several major sticking points: costs, cycle stability and energy density.

The greatest problem lies in the costs, particularly for the lithium-ion batteries, which currently feature the highest energy densities. Various studies quote a cost target in the region of EUR 200 per kWh for electric vehicle battery systems, as from which the battery would be commercially competitive with petrol. There are many different statistics on current battery costs, but they all concur that the above cost target is still very far off. For end users the cost of lithium-ion battery packs will presumably range from EUR 700 to EUR 800 per kWh of storage capacity; for the battery systems currently available for electric cars prices are around EUR 1,000 per kWh. This means that the 16 kWh battery in a Mitsubishi i-MiEV costs roughly twice as much at present as an entire small car of a similar size.

Ambitious price reduction targets

In order to spare the battery, the depth of discharge (DOD) of lithium-ion batteries is limited. As a rule no more than 80% of the battery capacity should actually be utilised. This means the usable battery storage costs are actually much higher than the manufacturers' specifications. At present, significant cost reductions are expected from the mass production of automotive battery cells. Manufacturing costs are projected to fall two-thirds by 2020. That is an ambitious target, as cost components of relevance to lithium-ion batteries are very difficult to reduce through scale economies and learning curve effects in production. Raw material costs in particular will tend to escalate, with intercalation materials (electrodes) and the reactive substances in the cathode acting as price drivers. The Boston Consulting Group estimates the proportion of components independent of production volumes at up to 30% of the overall costs.

Considerably lower energy density than with liquid fuels

The second major stumbling block lies in the battery systems' attainable energy density. It is on this that the range of a BEV hinges. The aim is to double the energy density of 0.1 kWh/kg currently attainable to slightly more than 0.2 kWh/kg; in the past 15 years annual improvements averaging not quite 5% p.a. have been

What comes after lithium-ion technology?

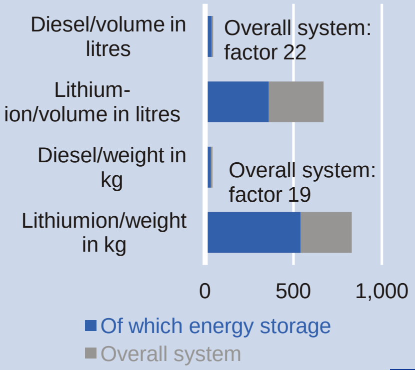
Lithium-sulphur: This concept is probably the most advanced in its development. It marries high theoretical energy density of the active material – 2,500 Wh/kg – with comparatively low costs. The major stumbling blocks are inadequate cycle stability and poor utilisation of the active material.

Lithium-air: Theoretically, lithium-air batteries can achieve the energy density of diesel. The major problems lie in cycle stability and protection of the lithium against dampness in the ambient air.

Semi-solid fuel cell: A completely revolutionary battery concept in which the energy is stored in a gel pumped into the energy converter and then charged or simply replaced. By separating the energy storage and energy discharge functions of the battery higher energy densities can be achieved at low cost. The main problem at present is increasing the power output and power input.

Too big for long distances

A 500 km range requires:



Source: Adam Opel AG 6

achieved.[2] But even if this target is met, the BEV will still be a long way off the driving ranges of conventional vehicles. A litre of diesel yields roughly 9.5 kWh, which is equivalent to 12 kWh/kg energy density. So at present the energy density of petrol is 100 times that of lithium-ion batteries. Factoring the higher energy efficiency of an electric driveline into the equation produces a ratio of roughly 1:20. This essentially confines the potential range of use for BEVs to short – at best middle – distances, because battery systems that can absorb sufficient energy for longer distances would be too big and heavy for a passenger vehicle, particularly allowing for the fact that all additional power consumers such as heating and air-conditioning systems and radios must also be supplied from the battery in a BEV. To gain a foothold in the medium and long-distance segment the BEV must seek its salvation in the development of post-lithium-ion technologies. But these are still at the basic research stage and will not come onto the market for at least another ten to 15 years. Until then, it will therefore fall mainly to PHEVs or REEVs to enter step by step into competition with conventional vehicles over medium and long distances.

New value chains will evolve

For the German automotive industry the major challenge posed by E-mobility is the need to prepare for electric vehicles' long-term penetration of the market for passenger cars while at the same time securing their own technical edge in conventional drives. This harbours both opportunities and risks, depending partly on the position occupied along the automotive industry value chain. Products manufactured by German companies already cover a large part of the future value chain. But when it comes to battery cell production, Asian competitors are well ahead of the field. Given that the automotive value chain also encompasses upstream and downstream activities ranging from mechanical engineering to vehicle roadworthiness testing, broad swathes of German industry will have to address the evolution of E-mobility intensively.

Carmakers: High research expenditure on a small market

Established carmakers have first-mover advantages

Under its bonnet, a strictly electric car has very little in common with a combustion engine-driven vehicle. To exploit the technical potential of a BEV to the full it should therefore be entirely redesigned. This offers companies from outside the industry a chance to penetrate the automotive market, with some countries (China for one) providing massive state support for this. But present-day carmakers also have a head start in some respects, as compliance with safety and quality requirements calls for enormous systems expertise that newcomers first have to acquire; moreover, many technically sophisticated features of a vehicle are independent of the driveline. Manufacturers of established brands in particular must also be mindful not to position themselves in what is at present a niche market until the new BEV technology sits perfectly with their stringent quality standards. Precipitate market launches could otherwise weaken the brand in the market for conventional vehicles. With such a complex product as a motor car, a development of this kind takes several years and can easily cost more than EUR 1 bn for a single model. Nor does it help that BEVs are initially being rolled out in the small and compact vehicle segment, which tends to cater for the more cost-sensitive customer. Normally, new technologies are

[2] See Service, Robert F. (2011). Getting there. Science Vol. 332. June 2011. Washington.

premiered in the premium class, where the willingness to pay for innovation is high and the price mark-up relative to the overall costs lower than for small cars.

In the long run the switchover from conventional to electric drives may also pose a risk to carmakers inasmuch as their core competence lies in engine construction. Automobile brands are strongly defined by their engines. Upwards of 55% of jobs at motor manufacturers depend on engine construction. Given that the technological edge in engine construction will tend to be devalued by the rise of the electric drive, manufacturers are compelled to build up their own expertise in this field notwithstanding the high costs. But initially electric cars impose a financial burden on established carmakers, since the onerous costs of development are not compensated for by an adequate sales market.

At the same time manufacturers are also obliged to plough massive investment into the further development of conventional drivelines, which for a long time to come will remain the major line of business for carmakers. Here too, increasingly stringent statutory requirements of pollutant emissions and fuel consumption will necessitate spending on research and development. To compound the situation, CO_2 regulation has been introduced on the leading automotive markets in latter years, and fuel consumption is becoming an ever more important determinant of end consumers' purchase decisions. This means that established manufacturers are compelled to develop several technologies in parallel to ensure that they are equipped for the future. At present the German automotive industry is racking up R&D expenditure in the region of EUR 10 bn a year on the development of more efficient and new drives. That is roughly half the sector's entire R&D budget.

Electric drives for commercial vehicles

In the case of commercial vehicles the potential for battery-assisted electric propulsion varies very considerably, depending on use.

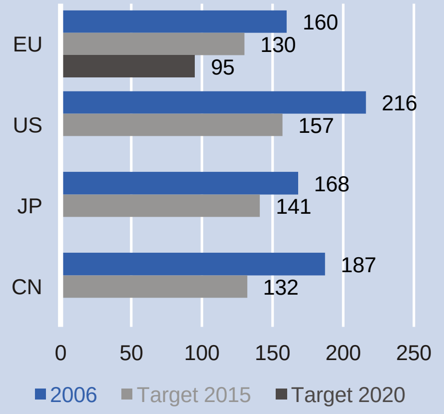
At present electric drives are inconceivable in long-distance road haulage. Not so with regard to commercial vehicles for inner-city distribution. These feature an ideal driving cycle for electric propulsion systems:

- daily distance travelled roughly 100 km;
- average speed less than 20 km/h;
- lots of stops. In practical trials by a large commercial chain more than 30 stops a minute were clocked up;
- high rate of energy regeneration due to amount of stop-and-go traffic. In the trial 79% of the energy used was recharged by regenerative braking.

Moreover, their greater space and higher load capacity mean they can fall back on more economical battery systems such as ZEBRA (Zero Emissions Batteries Research Activity) batteries. Even so, high costs pose the major obstacle even with commercial vehicles. For a state-of-the-art vehicle with a range of 100 km the extra costs are EUR 60,000 above the diesel version of the model.

Carbon limits worldwide

CO_2 thresholds for cars in g/km



Source: International Energy Agency 7

Suppliers: Systems suppliers in stronger position

For automotive suppliers, too, who represent more than 70% of value added in the automobile industry, the advent of BEVs holds out both opportunities and risks. Essentially the big tier 1 systems suppliers can look forward to opportunities. Their product portfolio encompasses many components (electronics, electric motors) used in electric drivelines. And since they can draw on extensive experience as systems integrators, they are able to act as an interface between established suppliers and market newcomers, one example being the integration of thermal management and cell production. It is also significant that tier 1 suppliers will tend to find it easier to achieve economies of scale. Particularly with subassemblies such as electric motors, large unit numbers are necessary for this, and these can best be realised if it is possible to supply more than one manufacturer.

Also on the winning side are chemicals and electronics suppliers. Today these segments add roughly 30% of value; with BEVs, that share might climb to 80%. New companies will also enter the supply market, notably battery manufacturers and producers of lightweight construction materials.

But for some suppliers markets will shrink. A conventional driveline consists of some 1,400 components, many of them made by highly specialised SME suppliers. Hybridisation and the trend towards downsizing are already reducing demand for parts. A BEV will dispense entirely with countless components. In the long run these specialists' business models are therefore at risk. As well as the actual engine, the complex exhaust system would also become obsolete and the transmission unit would be much smaller. All told,

German companies active in electromobility

The production and development of battery cells is concentrated mainly in East Asia. Similarly, at present Germany holds a scant 2% share of the world market for battery systems. However, current market data is of only limited relevance as the future battery systems for BEVs will have to differ considerably in terms of their cell chemistry, power electronics and cooling systems from those on the market today. If the expertise available in Germany is suitably concentrated, the country therefore stands a chance to make up lost ground.

Besides its well-known carmakers, the industrial base in Germany also encompasses many sectors and companies whose products and competences will be in demand for the production of electric cars. Germany is not only an automotive country. With the support of its highly efficient chemical and electrical engineering industries and strong mechanical engineering sector, Germany is also very well placed in the race to host the future production sites for electric vehicles:

Precursors: Several companies that occupy a strong market position in the production of intermediates used in manufacturing lithium-ion batteries are located in Germany. The company Chemetall, for example, is the world market leader in the production of lithium carbonate and also holds a strong market position in the production of other lithium compounds.

Functional materials: In Germany Evonik, for one, is engaged in the development and manufacture of intercalation materials for electrodes and reliable separators; this is a pivotal task in the BEV value chain.

Electronics: Germany is home to a high-powered electronics industry capable of playing a key role in the development of power electronics for batteries. Noteworthy in this context are, for example, Infineon as the biggest producer of chips for the automotive sector and Siemens. Together they manufacture a large part of a vehicle's electrical system.

Thermal management: Cooling the battery is of elementary importance in an electric car. Going forward, entirely new cooling systems will be developed for the high-performance batteries in the car, with a trend towards liquid cooling systems. The supplier Behr is very well positioned in this respect.

Systems suppliers: Several systems suppliers occupying a key position in the further development of electric drivelines are located in Germany. Continental, for example, supplies electric drivelines to a big French motor manufacturer. The world-leading supplier Bosch likewise produces across the entire driveline and has also embarked on the production of battery systems through the joint venture SB LiMotive operated together with Samsung.

more than 100 different sub-assemblies can be identified that would no longer exist in BEVs. In the longer term this will presumably intensify the process of concentration already underway among component suppliers, who are made up of small and medium-sized firms.

Mechanical engineering expected to see shift in demand

But changes in such a pivotal sector as the automotive industry will have even greater ripple effects. Fewer lathes and milling machines will be needed to produce a BEV; conversely demand for mixing and blending equipment and coating machines will jump appreciably. This would have a huge impact on mechanical engineering, for which the automotive industry is an important customer. The same applies to other sectors, some of which are even more reliant on carmakers as customers, with foundries as an example.

Strong E-mobility demand for tertiary graduates difficult to satisfy

Positioning Germany as a lead market for electric vehicles requires large numbers of newly trained specialists and timely development of the necessary skills. The skill groups involved range from qualifications obtained in 'dual' vocational training programmes (combining part-time vocational schooling with practical work experience) through advanced further training as an industrial foreman, technician and the like to tertiary graduates in technical and scientific subjects. We concentrate here on graduates, by which we basically mean in the following the specialists of relevance to E-mobility.

The courses of study relevant to E-mobility essentially revolve around technical scientific disciplines such as engineering, physics and informatics. Integrating and intermeshing these fields presents a challenge, because a large number of different areas of specialisation have to come together to form the basis for joint scientific cooperation on research, development and production. According to the Federal Ministry of the Environment's NPE National Platform for Electric Mobility, top priority in skills development at the tertiary level should be assigned to automotive engineering, for example in the fields of inverters, power electronics, drive control, range extenders and high-voltage/vehicle electrical systems. Extremely important as regards battery development are qualifications in electrochemistry, which is classified as a part of physical chemistry and hence physics. Material scientists are also required for the development of functional materials.

In our view, the challenge to education policy lies not in creating entirely new degree courses but rather in networking the knowledge already available in decentralised form in the existing disciplines and rearranging it into new combinations. The modularised courses of study introduced as part of the Bologna reforms are a huge asset here. An exemplary qualification profile for an E-mobility graduate would encompass competencies in electrical engineering, electrochemistry and materials science. A profile of this kind can be achieved in a much more targeted and efficient way by combining a Bachelor's course in electrical engineering with a subsequent Master's degree in an area of specialisation than by pursuing a classical diploma course in plain-vanilla electrical engineering. With modularisation it is, moreover, possible to adjust flexibly and promptly to the employment skills required in future, which will evolve constantly with the progressive market penetration of

E-mobility and changes in the relevant technical framework conditions (new battery technologies, drive technologies, materials etc.).

Quantitative demand analysis for graduates

Tertiary graduates and sectors of relevance to E-mobility

Relevant graduates: Academic skills are in the greatest demand in the fields of specific battery research (electrochemistry, electrical energy storage), power electronics, materials research focusing on functional materials, lightweight construction, production and automation, the charging station infrastructure and the architecture and construction of the infrastructures. For the purposes of this study graduates with degrees in the following disciplines are considered relevant to E-mobility: automotive engineering and transportation technology, engineering, physics, informatics, manufacturing and production engineering, mechanical engineering, process engineering, electricity, energy, electrical engineering, electronics and automation, telecommunications, healthcare engineering, precision engineering and industrial engineering.

Relevant sectors: For the purposes of this study the following sectors are considered relevant to E-mobility: production of accumulators and batteries, electric motors, generators and transformers, electricity distribution and control apparatus, insulated wire and cable, electrical equipment (not elsewhere classified), electronic components, instruments and appliances for measuring, checking, testing, navigating and other purposes, industrial process control equipment, motor vehicles and motor vehicle engines, bodies, coachwork and trailers, agricultural and forestry machinery, parts and accessories for motor vehicles and motor vehicle engines, motorcycles, bicycles and invalid carriages and manufacture of other transport equipment (not elsewhere classified), electricity supply, sale, maintenance and repair of motor vehicles, research and development on natural sciences and engineering, agricultural sciences and medicine, technical, physical and chemical analysis, and universities and other tertiary education facilities.

Because of this networking across individual subjects, in any assessment of future demand on the graduate labour market it makes little sense to differentiate rigidly by individual fields of study. We therefore conduct the following quantitative demand analysis at the level of all graduates of relevance to E-mobility, bearing in mind that demand exists for these graduates way beyond the bounds of E-mobility – which is competing with a whole host of growth industries (such as the IT sector) for the same specialists (e.g. electrical and mechanical engineers, computer specialists). Whilst it is an important driver of demand for graduates from these areas of specialisation, E-mobility is not therefore the only one. A rough guide to E-mobility graduate demand is demand for graduates in the core sectors of E-mobility (automotive engineering, electrical engineering and other related manufacturing sectors, the automotive trade, vehicle servicing and maintenance, university teaching staff to train the graduates needed).

Specific evaluation of the latest micro census, the representative sample population of Germany, shows that in 2009 approximately 350,000, or 28%, of all graduates in relevant fields were employed in the core E-mobility sectors.

Three main determinants of rising employment needs

The need for labour with academic qualifications that will arise up to the year 2020 can be divided into three components. Firstly, employers must replace the staff that reach retirement age and cease gainful employment; in this instance reliable, age-differentiated statistics are available on the present employment situation in this segment of the labour market, so that the demographic replacement demand up to 2020 can be estimated quite accurately. Up to 2014, on average not quite 25,000 graduates a year with relevant qualifications will retire on age grounds, roughly 7,000 of them in the core E-mobility industries. By 2020 this annual replacement demand will have risen above the 34,000 mark economy-wide, climbing to 8,800 people in the core E-mobility sectors. The steady growth in demand is due partly to the fact that during the period considered more and more baby boomers will reach the statutory retirement age.

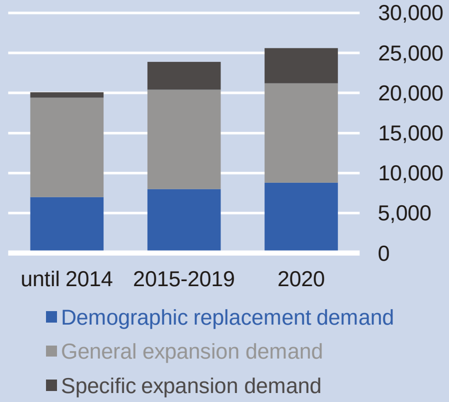
Secondly, a general expansion in demand, driven by structural developments such as the preference for employing highly skilled labour and the long-term economic growth trend, will begin to make itself felt. Between 2000 and 2009 the employment of graduates with relevant areas of specialisation outside the core sectors expanded on average by 2.7% or 21,200 people p.a. and within the core sectors by as much as 4.3% or 12,400 people a year. We expect this demand to develop along a similarly strong, if not stronger, growth trajectory in the current decade, not least in view of the global rise in the importance of renewable energies.

Specific expansion demand mainly for graduates

Thirdly, the roll out of E-mobility will trigger specific economic effects, such as changes in the automotive value chain and invest-ment in the necessary infrastructure. These will unleash E-mobility-specific expansion demand, but without any decline in the need for specialists in conventional drive systems. The NPE expects an extra roughly 30,000 jobs net by 2020, based on a targeted stock of 1

Graduates in demand

Annual electromobility demand for graduates*

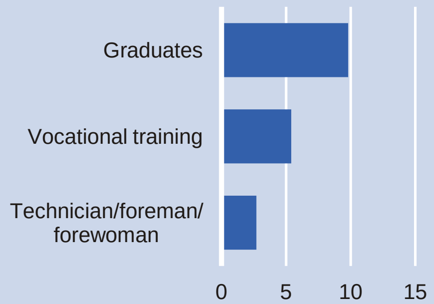


* Annual demand for graduates in the sectors and with the qualifications relevant to E-mobility

Sources: Micro Census 2009, IW Cologne 8

Women not electrified

Percentage of women in E-mobility*



* Percentage of women in the sectors and with the qualifications relevant to E-mobility

Source: Micro Census 2009 9

million electric cars. Most of these positions will be created in automotive engineering, but many will also arise in complementary sectors such as power supply. The bulk of the net increase will call for tertiary-level qualifications. For calculation of the specific expansion-driven demand for graduates we are pencilling in a share of 80%. To begin with, the specific additional demand will be moderate, at roughly 700 extra graduates a year, given the very gradual increase in market penetration by electric vehicles; but by the end of the review period the roughly 4,400 additional graduates p.a. will assume an economically relevant dimension.

More than 20,000 graduates a year will be required

All told, at present 20,000 relevant graduates are needed each year in the core E-mobility sectors to replace the employees retiring from work on age grounds and to meet additional demand. By 2020 this overall demand will have risen steadily to 26,000 a year. Economy-wide annual demand for relevant graduates is likely to climb from currently 59,100 to more than 72,000 in 2020. In 2009 roughly 56,000 graduates in relevant first-degree courses were taught at German universities, many of whom left Germany again after passing their exams (see below). In addition, between 2002 and 2008 the electrical engineering places on offer decreased by nearly 11%, despite which recent statistics show that only 77% of the places available were taken up. Notwithstanding the recent positive trend in graduate numbers from relevant courses of study, demand for labour thus already clearly exceeds supply. Even now, many professions are suffering from a shortage of skilled staff, and this situation threatens to become even worse given that the growth in demand will outpace the increase – or, indeed, possibly even a decrease – in supply.

Specialist academic potential for E-mobility

This brings us to the question of what specialist potential can now be unlocked to meet future demand for graduate labour in E-mobility.

— Women graduates: In 2009 less than 10% of all graduates employed in the core E-mobility sectors were women, whereas women accounted for 38% of graduates in other fields such as economics and law. Nor does the currently low proportion of women among first-degree graduates from relevant areas of specialisation (e.g. 7.7% electrical engineering graduates in 2009) signal any reversal of the trend in female participation. Indeed, the share of relevant study courses is declining among first-degree female graduates as a whole. In the areas of specialisation relevant to E-mobility the strong overall expansion in female graduates had a below-average impact. To summarize, it seems doubtful whether, in the period up to 2020, female graduates could play a substantially greater part in satisfying demand for graduate E-mobility specialists than they have done so far.

Part-timers offer little potential

— Graduates in part-time employment: In 2009 less than 6% of all relevant graduates employed in the core sectors were part-timers.[3] And of this low number of part-time workers less than one in five was in involuntary part-time employment. Even if it were possible to get all the graduates currently in involuntary

[3] Part-time employment is defined as employment for less than 32 hours a week. Of relevance here is the number of working hours agreed in the employment contract and not the number actually worked.

part-time employment back into full-time jobs, this would involve fewer than 4,000 people – and on a one-off basis. This quantitatively insignificant potential that could be activated by restoring graduate part-timers to full-time positions is confined to the relevant qualifications. The proportion of other graduates in part-time work was 21%.

Vocational training also poses great challenges

Whereas the provision of graduate specialists for E-mobility is mainly a quantitative problem, the challenge in basic, further and advanced vocational training is rather one of quality, specifically one of equipping employees with the necessary skills. The qualification profiles of already tried and trusted training courses, such as automotive mechatronics fitters, electronics technicians for automation technology and information system technicians, can be adapted and expanded with suitable further and advanced training (e.g. working on high-voltage intrinsically safe vehicles, maintenance of high-performance batteries). Besides strictly vehicle technology, skilled workers are also required in system services (e.g. network supply, integration and feed-in), the recharging infrastructure (e.g. control technology) and vehicle service (e.g. rescue operations involving open high-voltage systems). Participation rates for women in the vocational training courses of relevance to E-mobility are even lower than with their graduate counterparts. In the core E-mobility sectors fewer than 3% of all relevant technicians and forepersons and roughly 5% of all people who complete relevant vocational training are women. However, since no economically relevant additional demand will arise for graduates from vocational training courses – unlike university graduates – this situation is not (yet) acting as a constraint on the supply of skilled staff.

— Unemployed graduates: In August 2011 2,680 electrical engineers in Germany were registered unemployed. At the same time the Federal Employment Agency (BA) alone had 3,064 vacancies for electrical engineers on its books. Industry-wide no fewer than about 20,000 vacant posts were immediately open to electrical engineers. In the case of mechanical engineers (3,960 unemployed, 5,177 BA-registered vacancies, more than 30,000 positions vacant altogether) demand for specialists has likewise considerably outstripped supply for a long time. In many areas of qualification surrounding E-mobility the present situation is one of practically full employment. And according to the Federal Employment Agency's Institute for Employment Research (IAB), less than 25% of all unemployed graduates in this segment remain out of work for a year or longer. Most of the jobless are therefore in temporary frictional unemployment (i.e. search or transitional unemployment). All in all, there is very little labour market potential to leverage.

— Foreign students: A disproportionately high number of the graduates in relevant subjects in Germany are foreign students[4] – in electrical engineering around 20% of the total. In 2009 the proportion of foreign students in first-time graduates from relevant courses of study worked out at about 10%. Many of these came from China, India and Turkey. But the restrictions still confronting graduates from non-EU countries who subsequently wish to take up employment are a major factor in causing two-thirds of the foreign students educated in Germany to leave the country again once they have completed their studies, meaning they are not available to the German labour market. Yet this group of people offers the prospect of especially smooth integration, since local employers are familiar with the content and quality of their degrees and the graduates usually already possess a comprehensive command of German. On the conservative assumption that 50% of foreign students in a relative graduate year (around 5% of all graduates), leave Germany again after passing their exams, the loss – and hence the potential workforce that could be leveraged – currently exceeds 2,800 graduates each year.[5] Even today, and also from the perspective of 2020, these foreign students represent the most significant potential for securing the availability of skilled E-mobility personnel. This needs to be unlocked systematically by means of pro-active public retention and integration policies.

More foreign students needed

Businesses and educational establishments should be at pains to attract more students from abroad to German universities. In the US the National Science Foundation quotes the share of foreign students among people studying technical and scientific subjects

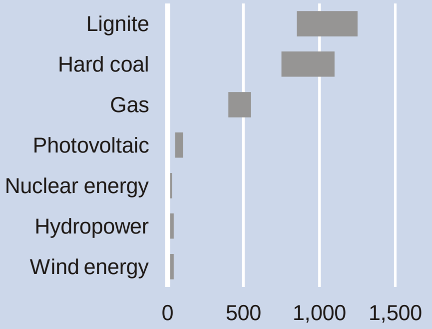
4 Foreign students are people who have acquired their eligibility to tertiary education abroad and are, as a rule, foreign nationals.

5 From a fiscal aspect, too, the German economy would benefit from retaining these foreign students. So far the German government has borne the brunt of their education costs, whilst as a rule the returns on this investment in education are reaped by their home countries or by other countries with skills-based immigration policies.

at around 25%. And fully one in three doctor's degrees in this field is awarded to foreign students.

Potentially large differences

Range of possible carbon emissions by primary energy sources in g/kWh*

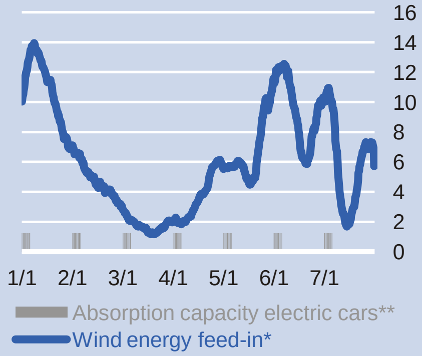


* Plausibility range indicated by literature research

Source: BWK – Das Energiefachmagazin **10**

Limited receptivity

In the course of one week in gigawatts



* Wind energy feed-in in January 2011
** Assumed stock of 1 million electric cars

Sources: EnBW, TenneT TSO, Amprion, 50Hertz Transmission, own calculations **11**

Wind energy: Feed-in profile and consumption

The wind energy supply in Germany exhibits different cycles. In the winter output tends to be higher than in summer, but so too does the fluctuation in power. In the example we have chosen from January 1 to January 7, 2011, the power fed in from the wind turbines varies between 13,700 MW und 850 MW.

In daily cycles of the input from wind energy, peak performance in our example was often delivered in the hours after midnight, while feed-in is relatively low in the hours around midday. In the week in point the wind energy supply between midnight and 3am averaged not quite 7,200 MW, falling between midday and 3pm to just about 4,950 MW.

Typically, however, peak electricity consumption is registered during the midday hours and early in the evening. In the night, on the other hand, power consumption falls well below the daily average.

Power demand and power source currently no problem

Only slight rise in power demand at first

For the time being, the extra electricity required for E-mobility will be negligible. Assuming that one million electric-only vehicles drive on Germany's roads, that these vehicles feature annual average consumption of 20 kWh per 100 km (compact class to middle class) and that they travel an average distance of 10,000 km a year, their power consumption will be 'only' 2 million MWh. In proportion to Germany's gross electricity consumption in 2010 this is a scant 0.3%. The power station network does not therefore need to be expanded immediately just to cope with the rise of E-mobility, particularly since many electric vehicles are likely to be charged at night, when demand is otherwise off-peak and low.

Modest contribution to network stability

The possibility of recharging electric cars at night has aroused the interest of power grid operators – who, with the development of renewable energies, increasingly have to contend with what are characteristically irregular renewable electricity feed-ins. Wind energy, for instance, exhibits significant feed-in fluctuations. This puts very considerable pressure on the stability of the electricity network and has to be balanced out by conventional power stations or pumped storage. But the power fed into the grid has to be accessed immediately. In the past, on windy nights this has already led to negative electricity prices on the European Energy Exchange in Leipzig. Demand for electricity to recharge electric cars at night may help smooth out such peaks and troughs. However, it is important to keep a sense of proportion when assessing the potential of electric cars here. If one million BEVs were registered in Germany, even on favourable assumptions[6] their energy storage capacity would be around 5,000 MWh. If it took roughly four hours to recharge these vehicles the potential subscribed capacity would amount to 1,250 MW. Whilst that is a buffer, in terms of capacity it is roughly on a par with one big pumped storage plant; the nominal output of all pumped storage plants in Germany totals roughly 7 GW (storage roughly 40 GWh). Graph 11 illustrates the limits to the absorption capacity of electric cars.

To keep the power grid stable, even in the future these fluctuations will still need to be evened out mainly via the conventional power station network. BEVs can play only a minor role here, particularly when we consider that the installed capacity of wind and solar energy is scheduled to roughly double by 2020. In theory the stored energy could also be released back into the grid during peak times to ease the load in peak consumption periods. But this would require sophisticated architecture comprising both the appropriate power grid connections and the invoicing technology. It would also imply a marked increase in annual charging cycles, which could potentially reduce the service life of the car battery. It is not yet an economically viable proposition.

[6] Assumptions: 50% of BEV hooked up to the mains; battery storage capacity 20 kWh; capacity actually usable15 kWh; depth of discharge 66%.

Power source in the EU environmentally irrelevant, …

An interesting environmental aspect is how the power for electric vehicles is generated. Whether the electricity that an electric car consumes is produced from renewable energy or nuclear-generated (i.e. largely carbon-free), or whether it comes from coal-fired power plants, certainly does make a considerable difference to its carbon footprint.

With the present German electricity mix (data from the German Federal Environmental Agency) carbon emissions for a vehicle in the compact class with consumption of 20 kWh per 100 km are slightly more than 110 grams per kilometre. In a petrol-driven car, that would equate to consumption of roughly 4.6 litres per 100 km. While this level is one that many small cars and full hybrid autos already achieve, or even undercut, it is far better than the average carbon emissions of newly registered cars in Germany (2010: 151.7 g/km) and below the EU's target mentioned in Chapter 1.

… since emissions trading caps emissions

But in Germany and the EU it actually makes no difference for the calculation of an electric car's carbon footprint whether the electricity is produced from renewables or a coal-fired power plant. This is because the energy industry is subject to the EU Emissions Trading System (EU ETS), which sets an upper limit, or cap, on carbon emissions by the sector. If, as a result of higher numbers of electric cars, demand for electricity from fossil fuels and consequently for emissions allowances rises, the emissions trading system will lead to emissions being cut back elsewhere. The carbon footprint will not alter and will be just as high in the energy sector as if the electric cars were powered by carbon-free electricity.

Development of renewable energies not specifically necessary to promote E-mobility, as the electricity industry is subject to emissions trading anyway

At present, EU policies not only treat BEVs as vehicles causing no carbon emissions, they also offer the possibility of multiple credits towards the manufacturers' overall fleet targets for the (presumed) zero emissions by electric vehicles. Since the electricity produced for the vehicles is subject to emissions trading, this reasoning can be followed providing the number of emission allowances is not raised due to the growing proportion of electric cars. BEVs' effective participation in emissions trading means that their actual emissions are determined by the electricity mix; no distinction is made in the allowances for the source of electricity. Parallel to the growing importance of E-mobility, there is also a political drive for the development of renewables. Whilst this may be beneficial with regard to customers' acceptance of E-mobility, it is not necessary from an environmental point of view if, despite greater use by electric vehicles, the number of allowances remains the same and the projected annual lowering of the emission cap is not adjusted accordingly.

CO_2 emissions of road traffic

In other large industrialised countries, too, energy-efficient combustion engines have already caused the increase in CO_2 emissions from road traffic to be checked or indeed lowered. Germany is the trailblazer here, with emissions already below those of the Kyoto base year 1990. In Japan carbon emissions from road traffic are also falling. And even in the US their rate of increase has slowed significantly. The steepest rises are registered in China, where emissions from road traffic have jumped roughly five-fold since 1990. In absolute terms they are now more than twice as high as in Germany.

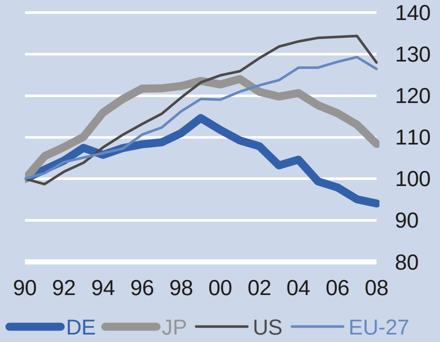
Electric vehicles indirectly subject to emissions trading

The positive impact of E-mobility on the climate stems chiefly from the fact that greenhouse gas emissions are reduced in a sector that does not come under the EU ETS.[7] Instead, rising demand for electricity, and presumably also for emissions allowances, encounters limited supply in each case. Were the one million electric vehicles in Germany to replace the corresponding number of cars with the same annual mileage (10,000 km) and average fuel

[7] The positive effects of E-mobility on local pollutant and noise emissions are undisputed.

Germany is the frontrunner

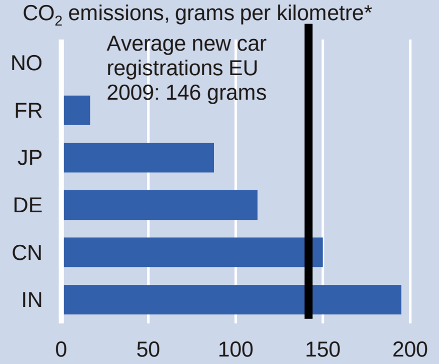
CO_2 emissions of road traffic, 1990 = 100



Source: International Energy Agency **12**

Energy mix the decisive factor

CO_2 emissions, grams per kilometre*



* Based on an electric car with consumption of 20kWh per 100 km

Sources: Federal Environmental Agency, Emissionfactors.com **13**

E-mobility in China – the motives

China will presumably push ahead with E-mobility not primarily to protect the climate or lower greenhouse gas emissions, focusing instead on the goals of reducing the country's reliance on oil imports and ameliorating air pollution in its fast-growing cities. Additionally, China is looking to carve itself a technological lead in E-mobility, given how far it lags companies from Europe, Japan/Korea and North America in traditional drive technologies. In this fledgling technology the Chinese aim to sit at the top table from the outset, which explains their substantial financial support for E-mobility and domestic companies.

consumption of 6 litres per 100 km, the carbon footprint would shrink by about 1.4 million tons. Considering that since 1999 annual carbon emissions from road traffic in Germany have fallen by 30 million tons (rd. 18%), the contribution that electric cars can deliver is, if anything, rather modest.

Said contribution by electric autos in 2020 will be equivalent to roughly 1% of present-day carbon emissions from road traffic in Germany. This ratio in itself indicates that in the coming decade the reductions in emissions required, and to be expected, will still have to be achieved primarily through more efficient combustion engines. Progressive hybridisation will play an increasing part here. However, hybrid and electric vehicles share a problem inasmuch as the reductions in emissions that they deliver come at extremely high avoidance costs. In the case of BEVs the avoidance costs per ton of CO_2 at present run into the thousands of euros, whereas the economy-wide avoidance costs simulated in emissions trading will presumably be well below EUR 50 per ton in 2020 (against EUR 13 at present).

Climate impact of electric cars not necessarily positive

However, in countries without an emissions trading system the situation is different. There, the carbon intensity of the national electricity mix is the sole determinant of electric cars' climate compatibility (graph). For example, the carbon footprint of an electric car would be much larger if the electricity were produced from the Chinese power station network, which features a high proportion of coal-fired power plants with low efficiencies. Applying this to our example above, carbon emissions based on the Chinese energy mix would be in the region of 150 g/km.[8] Since neither the energy sector nor industry as a whole in China are subject to an emissions trading system, developing E-mobility there would not, under current circumstances, lead to an economy-wide reduction in carbon emissions versus a scenario without E-mobility (see graph).

In Norway on the other hand – which does not participate in emissions trading either – E-mobility can help cut carbon emissions. Owing to the very high proportion of largely zero-carbon hydroelectric power there, a comparable electric car would leave a carbon footprint equivalent to only 1g/km.

The customer viewpoint: When is an electric car worth it?

Many discussions of E-mobility concentrate on technological aspects. This frequently sidelines the customer's role, even though switching to electric vehicles calls for considerable changes in drivers' behaviour. The most striking of these is that, in contrast to the present situation, they must make do with shorter driving ranges that at present. And customers must also be prepared to spend considerably more than on petrol- or diesel-fuelled cars, an investment that pays off only if they drive very long distances.

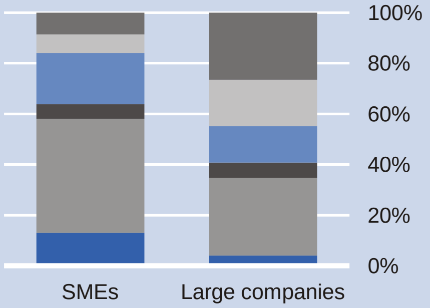
The profitability of electric vehicles and cars propelled by combustion engines is commonly compared on the basis of Total Costs of Ownership (TCO). This is justified since it takes into account all the cost components involved in purchasing and using a vehicle. In its May 2011 report the NPE also carried out profitability comparisons of this kind using the TCO approach. According to

[8] The figure is based on the statistics reported at www.emissionfactors.com on average CO_2 emissions by the power station network per kWh. But higher values – considerably so in some cases – can be found in literature and the press.

these, at the beginning of the current decade electric cars suffer a cost disadvantage of between EUR 5,000 and EUR 11,000, depending on the vehicle segment and vehicle owner (private or commercial). By 2020 the gap would narrow to between EUR 2,000 and EUR 4,000. The NPE therefore calculates that the overall cost disadvantage of electric vehicles, whilst falling appreciably, will nevertheless still be significant even in ten years' time.

Improvements needed in technology and costs

What extra costs are acceptable? Survey of 118 companies



Source: IW Cologne 14

Cost comparison assumptions optimistic for E-mobility

In our view, the assumptions used merit critical analysis. The NPE's cost comparison rests on the assumption that the cars for comparison in the compact class will drive 15,000 km a year, with middle-class vehicles racking up as much as 30,000 km. In our opinion this is extremely high, given that the average distance covered at present in Germany by petrol-driven cars is less than 12,000 km, with diesels driving roughly 20,000 km. We consider it unlikely that electric vehicles (BEVs and PHEVs) will travel such long average annual distances. In a TCO comparison such assumptions are stacked heavily in favour of E-mobility owing to their low variable costs versus the combustion engine.

What is more, enormous technical progress is assumed. It is predicted that battery costs will be halved from around EUR 800 per kWh at present (according to the NPE) within just three years; as previously explained, we consider this rate of progress ambitious, to say the least. This assumption similarly causes electric vehicles to perform better in the cost comparison than we deem probable.

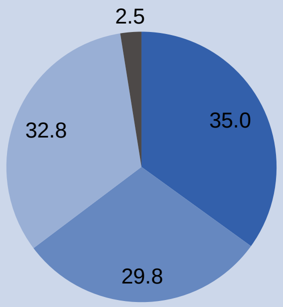
The TCO comparison is further based on a useful life of ten years for the vehicles. In fact, automobiles are already presumably used for considerably longer on average.[9] The impact of this assumption on the cost comparison is not unequivocal: A longer useful life (and hence greater mileage) has a positive effect on the electric car's TCO performance. The (expensive) battery may well attain a service life of more than ten years, but it will definitely degrade over time.

Finally, the NPE's assumptions with regard to the price of oil (USD 99 per barrel in 2020) may be too conservative. We expect the oil price to be considerably higher by then – with consequent rises in petrol and diesel prices. That, in turn, would impinge on the competitiveness of vehicles with combustion engines versus electric cars in comparison to the NPE assumptions – provided, of course, electricity prices are unchanged.

On balance we are of the opinion that as a result of the assumptions made, the NPE's TCO analysis casts electric vehicles in too favourable a light versus cars with combustion engines. We take a particularly critical view of the high annual mileage presumed and the speed of technological progress. Nonetheless, we do concur with the opinion that the cost gap will narrow.

High average age

German cars on the road by year of registration; shares in %



Source: Federal Motor Vehicle Transport Authority 15

High mileage needed to recoup outlay

As an alternative to the TCO approach we have drawn up two different payback calculations to compare the relative profitability of electric and combustion. The key determinants are the purchase price of the vehicle and the variable energy costs of running it. We assume that there are no decisive differences between electric

[9] The Federal Motor Vehicle Transport Authority no longer reports data on vehicles' age when deregistered. The average age of the cars currently registered in Germany is 8.3 years. Not quite 15 million (or 35%) of the automobiles owned in Germany at present were registered in or before 2000.

Payback calculation I

Actual example: We compare two cars that are actually on the market, similar in size and features, based on present-day petrol and electricity prices. On the one hand we consider the Toyota Aygo with a petrol engine (1 litre cubic capacity). The list price (high-end features) is around EUR 11,000. It has combined average consumption of 4.6 litres of fuel per 100 kilometres. But we assume that the vehicle is driven mainly in urban environments and therefore take the consumption in built-up areas, which is 5.5 litres per 100 kilometres. We further assume a petrol price of EUR 1.60 per litre. With this car we contrast the Mitsubishi i-MiEV, an all-electric vehicle driven by a lithium-ion battery with a capacity of 16 kWh. The list price is a touch above EUR 34,000, but the features are slightly more comprehensive than in the Toyota Aygo. Standard consumption is roughly 10 kWh per 100 kilometres. We reckon with an electricity price of EUR 0.22 per kWh. On these assumptions the higher purchase price for the electric car does not pay off until the vehicle has driven more than 330,000 kilometres. Neither car is likely to achieve this mileage in its life cycle. Its smaller driving range aside, in economic terms the present electric car is completely outdistanced by the rival model with a combustion engine.

Payback calculation II

Fictional example in 2020: In our second profitability comparison we assume rapid technological progress on battery technology, leading to a very significant cost reduction. Our example refers to a vehicle in the compact class. The difference in purchase price is now 'only' EUR 10,000. We set consumption by the petrol-driven car at 7 litres per 100 kilometres. For the electric vehicle we reckon with (only) 15 kWh per 100 kilometres. It is further assumed that the price of petrol will rise faster than that of electricity. We pencil in a petrol price of EUR 1.85 per litre and an electricity price of EUR 0.24 per kWh. It is presumed that the government will not compensate for any revenue shortfalls from energy tax (petroleum duty) by putting up the tax on electricity. Even on these positive assumptions for the electric vehicle, the time at which it starts to pay off is not reached until its mileage exceeds 100,000 kilometres. A full hybrid used mainly for driving in town would pay off far earlier, mainly because the purchase price is closer to its rival model.

Conflict of aims in E-mobility

With strictly all-electric cars a conflict of aims exists in that they would ideally have to be driven as much as possible for the user to benefit from the low variable costs. At present, though, the cars' short driving ranges, the long recharging times for the batteries and their limited number of charging cycles run counter to this aim.

vehicles and cars powered by petrol or diesel in respect of the running costs (e.g. maintenance, tax, insurance). Certainly, the cost of maintaining an electric vehicle should be lower than for a car with a combustion engine, for one thing because it has fewer wearing parts. But then any repair costs for electric cars are likely to be higher, partly because at first only very few garages will be able to carry out the necessary work. As the law stands at present, electric vehicles are exempt from motor vehicle tax for five years. On the other hand, it will cost more to insure an electric car owing to the higher purchase price.

We consider a payback calculation of this kind justified inasmuch as it dovetails more precisely than a TCO analysis with a private buyer's considerations. We assume that no subsidies whatsoever are granted for the purchase and use of electric vehicles.

Limited range not fundamentally a problem …

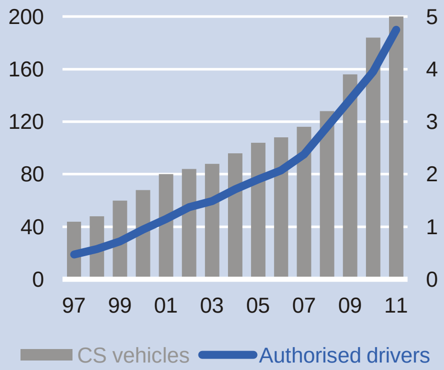
The model calculations (see text boxes) illustrate what a challenging assignment it is to make electric cars competitive, especially as advances continue to be made in the technology for petrol- and diesel-powered autos. By 2020 average consumption is likely to have fallen by at least 25% – as a result of engine downsizing, for instance, gasoline direct injection and lightweight construction. The high costs of BEVs thus pose the major obstacle to their market success. We do not perceive the limited range of electric cars as a make-or-break criterion for customers, the average distance travelled on a car journey in Europe being between 30 and 40 kilometres a day. And on 80% of all days a car is driven less than 40 kilometres. These are distances that can even be covered by PHEVs or REEVs in full electric mode.

… for potential first-time customers

Economic aspects aside, BEVs, PHEVs and REEVs are therefore suitable as second cars for families, short-distance commuters and people living on the edge of town or as city cars; parking in a garage with a power outlet is helpful for acceptance. Companies operating urban delivery or mobile nursing care services, for example, would make ideal commercial customers. They clock up low daily mileage, which can be coped with by electric-only. And they have a major advantage in that they can easily install the recharging infrastructure on their business premises; since many vehicles are likely to be recharged over night, a simple socket will usually suffice. Of course many companies will invest in electric cars anyway. Also among the first customers will be wealthy, technophile private individuals for whom the extra expense does not constitute much of a financial burden – and indeed, they are already in the market.

As a general rule BEVs will not be an economical proposition in the near future either, with batteries as the main cost driver. Going forward, battery costs will need to be reduced by around 70% to 80% through advances in technology and economies of scale in production if all-electric cars are to offer an economically viable alternative (without subsidisation) for customers in the mass market; as previously discussed, this is unlikely to happen by 2020. Since the batteries in PHEVs and REEVs are smaller than in strictly all-electric cars, they may become price-competitive sooner, particularly since these forms of electric drive will also benefit from technological progress. They are, moreover, interesting to a wider potential clientele, which will presumably make it easier to leverage economies of scale in production early on.

Car sharing increasingly popular
Germany, '000



Source: Bundesverband CarSharing e.V. **16**

Alternative mobility concepts gaining in importance …

Recently, alternative mobility concepts have started to gain prominence in Germany. Often they revolve around the idea that what customers want most is mobility and not necessarily to possess their own vehicle. Depending on their mobility needs, they resort to the combination of means of transport that best suits their purpose (e.g. car, local public transport, bicycle). Car sharing, which has registered steady growth in Germany in recent years, or different car hire options are instances in which cars play a prominent part. They allow people to enjoy the flexibility of individual car travel – even if this does require some advance planning – without incurring the high fixed costs that come with a car of their own. The use of modern information and communications technologies can facilitate the take-up of offers of this kind by, for example, helping the customer to locate the nearest car. Concepts of this kind are particularly interesting for young, urban population groups who very seldom require a vehicle of their own in their day-to-day life. This gives rise to business openings for the automotive industry and dealers as providers of mobility services.

... but they alone will not achieve a breakthrough for E-mobility

Fuel-efficient compact cars with combustion engines economically more lucrative for modern mobility concepts

It is often maintained that mobility concepts of this kind are an ideal way of boosting market penetration for E-mobility. At first sight good arguments can be found to back this up, because many concepts are geared to inner-city traffic. What is more, customers do not incur the high cost of purchasing their own electric cars. But on closer scrutiny, doubts surface. Apart from low local emissions, electric cars possess no unique selling point to set them apart from other vehicles such as small cars with petrol engines. To put it bluntly, car sharing and car rental models also work very well with cheaper cars driven by a conventional combustion engine, and they are financially more lucrative – at least as long as the government does not massively increase the cost of, or ban, their use in city centres, something that would be politically very difficult to enforce. Apart from their lower price, combustion engines have the advantage that owing to their greater range and shorter refuelling periods they are at customers' disposal for longer.

Electric propulsion for two-wheelers

Unlike the automotive sector, a market solution is already emerging for electric powered two-wheelers. In 2010 more than 30 million electric bicycles (pedelecs) were already sold worldwide, over 90% of them in China. Their commercial success in China can be explained partly by the regulatory framework there. No permits are required to ride these bikes, whereas in some cities motor scooters are banned. Demand for all-electric two-wheelers (electric scooters) is also growing rapidly.

This rapid market penetration is due to the lower costs, as the battery needs only be very small. Consequently a pedelec in China costs little more than USD 200. Electric scooters are available in Germany for less than EUR 1,000.

Another advantage lies in the avoidance of many problems that beset BEVs:

— Two-wheelers are ideal for short distances, so that effectively there is no range problem.

— An extensive recharging infrastructure is not absolutely necessary. The domestic power connection is often sufficient, as many battery models can be taken into the home and recharged there.

Ultimately electric bikes are based on an entirely different technology than electric cars.

Battery leasing or switch stations: Who foots the bill?

There are further ideas, and some initial offers, to make E-mobility available to a wider clientele. One option is that instead of buying electric cars (or the batteries installed in them), customers can simply lease them and return them to the manufacturer or dealer after a certain time (e.g. three years). Again, the main argument in favour of the leasing model is that rather than having to buy an expensive electric car, the customer 'only' needs pay a monthly lease instalment covering the cost of electricity, maintenance etc. At first sight this construction also looks promising. But it, too, fails to address the crucial problem: Someone along the line must foot the higher costs – be it the vehicle manufacturer or the dealer through cross-subsidisation, the customer through higher lease instalments or the government through subsidies.

Another idea similarly based on the principle of the customer not owing the battery also seeks to solve the problem of the distances electric cars can drive. It revolves around battery switch stations, where discharged batteries can be swapped for fully charged ones. In our view, however, there are enormous obstacles to the area-wide realisation of what is essentially a good idea. It means more than one battery is needed for each electric car, pushing up the cost of the system. Massive investment would also be required in the relevant infrastructure. If a large number of vehicles were to use the switch stations, the logistical challenges (e.g. battery transportation and storage) would be daunting. Moreover, the concept calls for a high degree of standardisation in vehicle and battery construction, because looking farther ahead batteries will need to be changed for luxury saloon cars as well as for compact-class models. This poses technological problems: batteries and undercarriages must be standardised; the exact connection to the wiring system or ventilation must be uniform and safe. This standardisation would impose limits on the scope of vehicle design, which is unlikely to appeal to carmakers.

As matters stand at present, the problem of short driving ranges will be addressed more realistically by PHEVs or REEVs. The driveline electrification possibilities are much more flexible and make more economic sense. Ultimately, the concepts outlined for the development of E-mobility highlight yet again that falling costs are the linchpin on which market acceptance of E-mobility hinges.

Recharging infrastructure: selective development to begin with

Embarking on E-mobility will require the build-up of a recharging infrastructure. The following aspects are important here:

— With market penetration by electric autos expected to be a slow process, the recharging infrastructure can also be built up step-by-step. The NPE says approximately 900,000 charging points would suffice for one million electric cars (by 2014 not quite 120,000 EV charging stations. Most recharging points would presumably be located on private and commercial customers' properties.

— Building up the recharging infrastructure will require huge investment. The NPE estimates that charging points in public places cost between EUR 4,700 and EUR 9,000 per station, and fast charging facilities are currently still considerably more expensive. It is obvious that this investment cannot be recouped through the volume of electricity sold alone. We see only limited potential for generating additional income through advertising or value-adding services (e.g. the provision of information). Public charging points will therefore be dependent on government subsidies or cross-subsidisation by industry or the energy sector. Recharging points on private or commercial property (often a simple socket) are much cheaper or already available. Car park operators can add value for their customers with charging stations, which may offer them an incentive to invest in these points.

— Most private and commercial launch customers for electric vehicles will presumably have their own recharging point or be able to install one at comparatively low cost. Being aware of the initially limited public charging network at their disposal, these early-stage customers will presumably plan their use of the vehicles. That is to say they will be able to fall back on an alternative for longer routes.

On balance there are sufficient potential users of electric cars who could reliably access a recharging point (socket) in their private and/or work environment at no great expense. As empirical indicators we can take the more than 10 million single-family homes

Early start on investment in infrastructure

The automotive industry and power utilities are well advised to start stepping up their investment in the public and semi-public charging infrastructure already, together with suitable partners (e.g. retail trade, local authorities), despite the considerable uncertainties. Firstly, electric cars (BEVs, PHEVs, REEVs) will increase their market share only gradually in the coming years; it therefore makes sense to accompany this structural change from the outset by building up the infrastructure at a moderate pace. Secondly, by developing the infrastructure now, valuable experience can be gained which will help increase profitability further down the line and drive technological progress forward; companies can also familiarise themselves with the bureaucratic processes (licences for charging points). Thirdly, the growing visibility of E-mobility and the attendant recharging infrastructure should heighten potential customers' acceptance. That the (unsubsidised) provision of public recharging infrastructure will initially be a loss-maker for the suppliers is something they will have to accept, like it or not, if they want to help E-mobility to achieve a breakthrough in the long run. The uncertainties involved are likely to complicate the financing for this investment and make it more expensive.

It almost goes without saying that the public recharging infrastructure should be freely available to all users without discrimination, irrespective of its ownership, and that payment and settlement systems need to be uncomplicated. Data protection aspects also need to be addressed.

in Germany, most of which on the urban periphery will presumably have a garage or parking space. Initial practical trials with smallish electric vehicle fleets suggest that the users adapt quickly to the restricted driving range. We do not therefore necessarily consider the almost entire absence of an additional public or semi-public recharging infrastructure (e.g. on supermarket parking lots) as a fundamental stumbling block to the rise of a mass market. The only substantial potential that will be very difficult to leverage without the development of a public recharging infrastructure is that of urban customers who do not possess a garage or permanent parking space. Here, suppliers need to work with the relevant local authorities to find practicable solutions (such as power connections via street lamps) that will convince these potential customers to buy an electric car. Admittedly, the logistical problems (number of parking spaces, settlement systems) are not insignificant.

In the longer term economic and environmental considerations make it desirable for the vehicle batteries to be recharged automatically in off-peak periods. This requires investment in intelligent electricity networks and meters (smart grids).[10] One way of encouraging customers to make this investment would be by reducing the price of electricity at times when demand is slack.

3. Political options for promoting E-mobility

We have demonstrated that owing to the high costs and other uncertainties E-mobility is still far from being an economically viable mass market, but that in the long term it does fundamentally offer considerable potential. Governments in many countries can be seen offering support, or the prospect of support, for E-mobility with a range of different measures.

High subsidisation of the technology surprising

It is surprising that a niche product like the BEV, which does not look like becoming economically competitive at any time in the foreseeable future, and causes high CO_2 avoidance costs, should enjoy such prominent political backing – and not only in countries with an automotive industry of their own. Such early commitment to promoting a specific technology harbours particularly high (financial) risks for government when no end-date is set for phasing out this support. It is, moreover, the precise opposite of a technologically open-minded state subsidisation policy, because it potentially blocks the way for any better storage technologies (such as hydrogen). In principle therefore a very critical view can be taken of state support for E-mobility in view of the static efficiency of the technology, but this does not alter the fact that it is political reality.

Political motivation varies

Finite oil resources an acceptable justification for state subsidies

The overriding motives behind the promotion of this technology presumably lie chiefly in the fact that global oil reserves are finite and policy-makers wish to embark in good time on transition to the “post-oil era” to avoid sudden economic friction. They also hope to make their contribution to combating climate change, even though there are cheaper ways of reducing carbon emissions. With confidence in technological progress (dynamic efficiency), a case could then be made for subsidising what is not yet a competitive technology.

What is more, the motives behind political backing vary greatly from one country to another. In nations whose automotive industries are

[10] See Auer, Josef and Stefan Heng (2011). Smart Grids: Energy rethink requires intelligent electricity networks. Deutsche Bank Research. E-conomics 84. Frankfurt am Main.

important as providers of jobs, support for domestic industry undoubtedly comes into play, even though companies in the various countries have made varying degrees of headway on the development of E-mobility. When all other automotive nations are promoting the technology, considerations of a level playing field make it difficult for politicians to justify their country being the only one not to join in the 'subsidy race'.

Industrial policy plays a prominent role in many countries

Industrial policy will presumably be a prime mover in China, given that it is easier to build up international champions with state aid in a fledgling industry. But the promotion of domestic business interests is arguably also acting as a powerful incentive in France and the US, with the added bonus for France that nuclear energy, which is virtually carbon-free, makes up a large part of the electricity mix. So far the German government has not held out the prospect of direct grants towards the purchase of electric vehicles, but there are plans to promote the technology, and hence local industry.

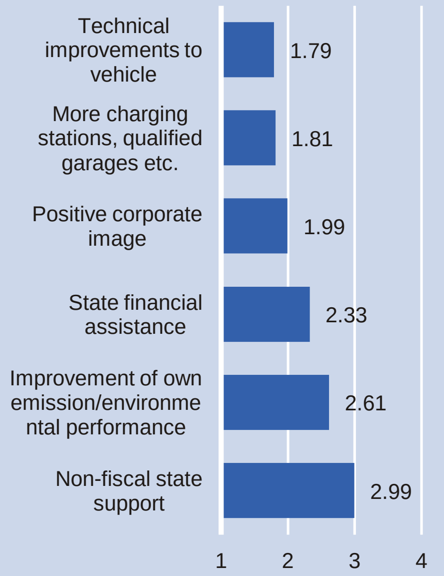
Another justification for encouraging E-mobility is the possibility of lowering local noise and pollutant emissions. The carbon reduction argument discussed previously carries particular weight in countries that promote the technology even though they do not have their own automotive industry (e.g. The Netherlands, Denmark). The fact that the carbon avoidance costs of E-mobility are extremely high is evidently not all that important an aspect in policy-making there.

Privileges in road traffic no problem

For the foreseeable future electric vehicles will not be economically viable. If policy-makers nonetheless wish to provide direct or indirect support for the technology, they can set about this in many different ways, each of which has its specific pros and cons. A distinction can be made between monetary and non-monetary measures and between measures that kick in with end users or at industry level. In the following we examine various promotion options.

Expert survey: Tool effectiveness

Reply categories: 1: very high, 2: fairly high, 3: fairly weak, 4: none at all



Source: IW Cologne 17

Among the classic non-monetary incentives to end users to encourage E-mobility are privileges for electric vehicles in road traffic (e.g. the use of bus lanes and specially designated parking spaces). From a regulative point of view these kinds of measures are relatively unproblematic; preferential treatment vis-à-vis vehicles with combustion engines can be justified by lower local pollutant and noise emissions. Whilst legal and technical prerequisites must be put in place for this, it should be possible to do so even within a short time frame. Of course this type of privilege will reach its logistical limits as the number of electric vehicles increases, making it likely that its effect will wane in the long run. What is more, the Umweltexpertenpanel (panel of environmental experts) at the Cologne Institute for Economic Research suggests that privileges of this kind tend to play a fairly minor role in purchase decisions. Privileges for electric vehicles could of course be beefed up by road user charges or even driving bans on conventional passenger vehicles in certain parts of town (e.g. city centre tolls), which admittedly have a monetary flavour. In the short and medium term we consider widescale regulations of this kind neither appropriate nor politically enforceable.

Monetary incentives …

Basically, the monetary measures to encourage E-mobility can be subdivided into direct subsidisation of car purchases and indirect financial incentives. Additionally, tax amendments could re-weight relative prices in favour of E-mobility. Raising the duty on petrol and diesel, while simultaneously lowering electricity tax or the levy on renewable energies for users of electric cars, would give EVs an even greater variable cost edge; but in our view this would be disproportionate.

Many countries favour a mixture of direct and indirect subsidisation, with total amounts running into the tens of thousands in some cases – for which sums it is possible to buy a well equipped small car. Indirect subsidies consist primarily of various types of tax relief, improved depreciation arrangements and cheaper car loans for electric vehicles.[11]

… harbour considerable risk

Direct premiums for buyers have the advantage over indirect subsidies of being more transparent and presumably entailing lower transaction costs. Moreover, the group of potential beneficiaries from lump-sum grants is wider than with indirect tax arrangements.

There is considerable risk of betting on the wrong technology

If the political goal is to bring as many electric cars as possible to market, then state premiums for buyers are extremely effective. But there are a number of reasons for taking a very critical view of monetary incentives. They represent market intervention in favour of a specific technology for which policy-makers presently have no way of knowing when it will be able to hold its own in the market without government support. It is true that generous subsidies will help a technology to achieve breakthrough in a narrowly defined market, but at the same time there is a danger of other options that would be more economical and/or environmentally better in the long run not getting off the ground. What is more, subsidies establish perceived 'vested rights' that are then always difficult to remove again. Once subsidisation of this kind has created jobs in the relevant branches of industry, for example, phasing it out again will be difficult until such time as the technology can be offered as a sustainable business model.

Should government indulge in subsidies when exchequers are low?

As a matter of principle it might be questioned whether, with public exchequers at chronically low ebb, governments should indulge in subsidies of this kind. After all, given the considerable current and medium-term cost disadvantage of electric vehicles, government funding to lead E-mobility out of its niche existence will quickly become very expensive. Were the one million vehicles (including PHEVs) targeted in Germany by 2020 to be incentivised with a sum of 'only' EUR 5,000 per car, for example, the government would need to find subsidies of EUR 5 bn – admittedly spread over nearly ten years. And even this would not close the cost gap with conventional cars.

If financial support, then with a clear end date

If politicians decide to grant monetary incentives to purchase electric cars, in view of the risks described we believe that such incentives should be degressive, limited in their annual amount and granted for a set period. This should be made clear from the outset. For example, as from a certain year the purchase of a predefined number of electric vehicles could be subsidised with a fixed grant. Over time, the grant per vehicle and the maximum number of subsidised cars should be reduced until, at the end of the previously set period, the financial support would expire. Subsidies could be granted each year on a first come first served basis, with the quickest customers benefiting. Of course, the number of vehicles,

[11] The NPE discusses potential monetary incentives in its latest report.

the amount of the grant and the maximum period during which subsidies are offered should be open to discussion. Consideration could also be given to the possibility of carrying over promotion quotas not utilised in any one year (fewer premiums granted to buyers than the maximum possible) into subsequent periods, albeit at a lower subsidisation rate.

Calculation model for government promotion

It is assumed that from 2015 in Germany the sale of maximum 250,000 electric cars (BEVs, PHEVs, REEVs) will be promoted with incentives of EUR 10,000 per vehicle.

It is further assumed that the maximum number of subsidised vehicles will fall on a linear basis by 25,000 a year and that a linear reduction of EUR 1,000 a year will also be made in subsidies. As from 2025 no further cars would then be subsidised in this example.

If the promotion quotas were fully utilised each year, the government would be faced with a maximum nominal funding bill of slightly more than EUR 9.6 bn – spread over ten years. In this example 1.375 million cars would enjoy subsidies.

An arrangement along these lines would have the advantage for the government that the maximum subsidies payable could be calculated from the outset, as illustrated in a notional model (see text box). Another merit of this (or a similar) model for the government would be that running the scheme down over time would create incentives to technical advances within the technology. And the industry itself would benefit from being able to plan with a set number of subsidised units and from knowing when the promotion scheme would come to an end. It could then gear its investment in E-mobility to its own expectations of, for example, technical progress.

On the downside, a promotion policy of this kind would lead to freeloading effects in the event of rapid technical advances. And granting subsidies on a first come first served basis is not without its problems either. Another practical difficulty will presumably arise with the need for promotion policies of this kind to be internationally harmonised to some extent.

To make it quite clear, we take a highly sceptical view of monetary incentives to purchase electric cars. In Germany the financial inducements to buy electric cars will reportedly be low. Whilst this will run counter to Germany's aim of becoming the lead market for E-mobility, that goal is ambitious anyway given the scant size of the home market. But this need not necessarily be bad news for the domestic industry, because if it develops competitive products and brings them to market it can benefit from the higher subsidisation in other countries.[12]

Promotion for the industry impacts on competition

No regulatory concerns over support for basic research

Incentives so far have been directed at the end customer, but policymakers can additionally bolster E-mobility by subsidising the relevant businesses. This is also a well-tried means of attaining the goal to become lead supplier in the field. Grants for basic research are a suitable tool that raises no regulatory issues if the funds are granted in a non-discriminatory way. Government should also work together with the industry in a push for standardisation in some areas of E-mobility (e.g. in the recharging infrastructure), without excluding competition a priori.

Then of course, government could directly subsidise certain sections of the value chain (with direct investment grants, for instance, or tax perks or convenient depreciation arrangements). In practice this form of industrial policy plays a prominent role. In the US, for example, the government massively subsidises the construction of battery production facilities. However, this example also starkly highlights the negative impact of such a subsidisation policy, which harbours the danger of a subsidy race between the automobile producing nations – and, moreover, a headlong dash to what in the long term may be suboptimal technology. On the other hand, premiums for buyers that differ from country to country do not constitute a problem from a competition policy perspective if, as a

[12] For example, in the photovoltaic industry foreign manufacturers of solar cells and modules benefit from the high feed-in tariffs in Germany.

general principle, car buyers can take advantage of them for all marques. In the EU this would be guaranteed by European competition policy.

Regulative legislation: Requirements on CO_2 emissions an important lever

One of the most effective, but as a rule most inefficient environmental policy tools is regulative legislation (see text box), which includes the aforementioned privileges in road transport. Already, regulative legislation plays an important role for E-mobility through a different channel, with the requirements regarding the reduction in CO_2 emissions by vehicles acting as one of the key drivers in the 'promotion' of this technology: The EU target of lowering average emissions of carbon dioxide from new cars to 95 grams per kilometre by 2020 will act as a powerful incentive for driveline electrification, since high penalties can be imposed in the event of non-compliance. Other countries have also imposed carbon limits, although so far these are not as strict. Driveline electrification is an important factor in meeting these reduction targets and avoiding fines.

We would consider the political promotion of E-mobility based on these parameters appropriate. Allowing multiple credits for the low emissions from newly-registered electric vehicles (BEVs, PHEVs, REEVs) towards each individual manufacturer's fleet CO_2 emission targets for a certain time (and degressively) would be a conceivable option. Multiple credits of this kind are currently used by the EU, although the practice is controversial. It would offer the industry an incentive to sell more electric vehicles and to lower their purchase price through a process of mixed costing.

An argument in favour of multiple credits is that they cost the government very little. The only factor of note would be lost revenues from the payment of fines for manufacturers' failure to meet their targets; but these are of no budgetary impact anyway, being due to the EU. A disadvantage of the regulation is, of course, that actual emissions by the manufacturers' fleet are higher than calculated in the multiple credit system. Critics of multiple credits also see a danger of the automotive industry relaxing its efforts to reduce carbon emissions. But this risk could be dispelled for the most part by limiting multiple credits to a period during which electric cars are considered to be a niche product. Besides which, rising oil prices will presumably prompt the industry to reduce the specific emissions from its vehicles.

State support is a balancing act

State support is evidently a fine balancing act for governments. Whilst high direct subsidies are likely to have a relatively fast impact, they are expensive – even with a time limit. Direct subsidies for the industry cause problems for reasons of fair competition. Support for research, on the other hand, is a good thing and may also have beneficial effects on the manufacturing country's industrial policy (lead supplier being the keyword). Privileges in road traffic and support for basic research are not an issue in regulatory terms and comparatively cost-effective. For the time being, however, they will not suffice to speed up market penetration by electric cars. Finally, many countries have already decided to subsidise E-mobility, with monetary incentives featuring most prominently. In Germany the debate is still in full swing. Concessions on motor vehicle tax and privileges in road traffic look like winning the day. The federal

CO_2 avoidance costs in road transport very high

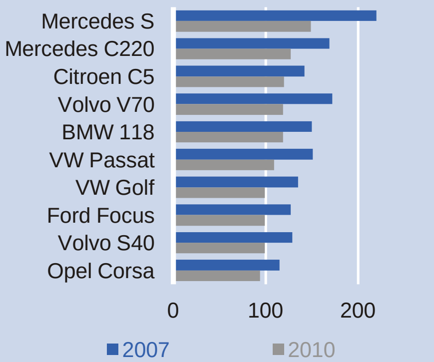
A fundamental criticism of the regulation of carbon dioxide emissions by vehicles centres on the high CO_2 avoidance costs of alternative drive technologies such as E-mobility. Ultimately, government-set parameters result in the creation of different prices for what is a homogenous good – CO_2 – which is, moreover, tradable in the EU. This is an indication of environmental and economic inefficiency – but it is a political reality.

In theory it would be better to include emissions by the transport sector in emissions trading as well. This should be organised in such a way that those companies that introduce fuels into the market are also obliged to provide proof of their emission allowances (upstream approach). That would save transaction costs in comparison to a solution in which all road users had to take part in emissions trading. Given the very marked willingness to pay in the transport sector, the reduction burdens would presumably be shifted chiefly onto the energy-intensive industries, which would have economic policy implications. In practice we are, of course, still far removed from regulation of this kind.

See Sinn, Hans-Werner (2008). Das grüne Paradoxon: Plädoyer für eine illusionsfreie Klimapolitik. Berlin.

Conventional vehicle advances

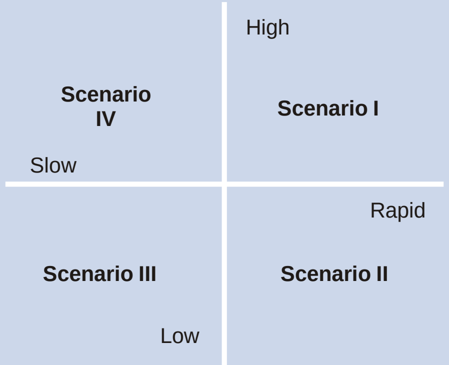
CO_2 emissions by the best diesel version of a model, g/km



Source: Transport & Environment 18

Diagram of the four scenarios

X-axis: Technical progress
Y-axis: State support



Sources: DB Research, IW Cologne 19

Scenario analysis of market potential

In **Scenario I** (high subsidisation, rapid technical progress) the share of BEVs in new passenger car registrations in 2020 could be in the order of 6% to 8% (with 7% equivalent to not quite 220,000 units). The rapid pace of technical progress and high subsidisation have made the cars an interesting alternative for a significant group of customers. In this scenario PHEVs and REEVs will probably together notch up a market share of a similar size – on condition that the financial incentives are high.

By way of contrast, in **Scenario II** (low subsidisation, rapid technical progress) the market share will probably work out at a mere 1% to 3% (2% representing slightly more than 60,000 units). Notwithstanding rapid technological advances, most customers will be deterred by the high – unsubsidised – overall costs. PHEVs and REEVs could perform slightly better because rapid technical progress will mean their cost disadvantage vis-à-vis cars powered by combustion engines and versus full hybrids has narrowed more than for BEVs.

In **Scenario III** (low subsidisation and slow technical progress) even in 2020 BEVs will still not have emerged from their niche existence, in which case their market share of new registrations will be less than 0.5%. PHEVs and REEVs will likewise register market shares of less than 1% as customers do not consider these vehicles economically interesting.

Finally, in **Scenario IV** (high subsidisation, slow technical progress) BEVs could see their market share in 2020 reaching around 3% to 4% of new car registrations (not quite 110,000 units at 3.5%). In comparison to Scenario II it emerges that higher state subsidisation rather than rapid technical progress would encourage potential customers to buy, particularly since subsidies are still considerable in Scenario IV. PHEVs und REEVs could rack up a similar market share with similar subsidisation.

government is also making funding available for research and development.

The instrument that costs the government very little but offers palpable incentives for the sale of electric vehicles is allowing multiple credits towards automobile manufacturers' fleet CO_2 targets. We see this as an important way of leveraging more rapid market penetration by electric vehicles, with the automotive industry stepping up to shoulder the bulk of the costs. For commercial clients and private users of company cars special depreciation arrangements and concessions on company car regulations (e.g. applying a lower gross list price) could offer tangible incentives – admittedly of a financial nature.

4. Market potential in Germany: Four scenarios

We have outlined four scenarios on the basis of which we estimate the sales potential for BEVs in Germany in the year 2020 (see text box). For this we decided on two drivers as key determinants of the market potential: first the amount of state monetary incentives to buy electric cars and, second, the degree of technical progress on E-mobility crucial to the development in costs. The state incentives may be strong or weak and technical advances may progress quickly or slowly. Depending on the constellation of the two factors, four scenarios result (see diagram).

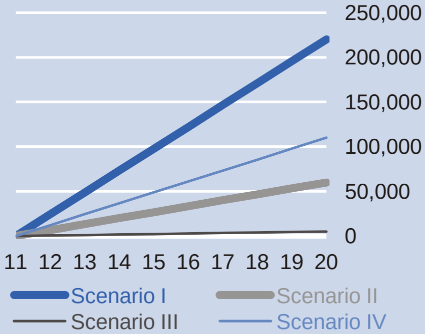
We denote (direct/indirect) state support as strong when amounts of (considerably) more than EUR 5,000 per vehicle are involved. Depending on the vehicle segment, a subsidy of this order would help narrow a significant proportion of the cost gap between electric and conventional cars. We rate state subsidisation by amounts of between EUR 0 and EUR 2,500 as low; EUR 2,500 was the amount of the bonus paid under the car scrappage incentive scheme.

We assume rapid technical progress with a reduction in battery costs of two-thirds or more by 2020 (this is roughly in line with the assumptions by the NPE). Rapid technical progress also implies significant improvements in battery energy density and hence in the driving range of the vehicles they power (on average more than 200 kilometres). By slow technical progress we mean a cost reduction on the status quo of less than 50%.

Economic environment in 2020: No surprises

All scenarios are based on further assumptions on the automotive environment. By that time real GDP in Germany will have grown by slightly less than 1.5% per annum on average; partly as a result of demographic developments, structural unemployment will have fallen to around 2.5 million. Hardly any change will have taken place in the number of potential car owners, even though the number of over 65 year-olds will have risen by at least 2 million on the present figure (at the expense of the age cohorts of 20 to 64 year-olds). The number of cars will have risen by 2020 from 42.3 million to roughly 44 million units. Approximately 3.1 million cars a year are likely to be sold on average in Germany. Petrol, diesel and electricity prices will all have increased. The relative price differences will have remained fairly constant, although arguments can naturally be advanced in support of ratio shifts in both directions. Average consumption by strictly fuel-powered cars and diesels has dropped 30%. We are not pencilling in any regulatory restrictions on vehicles with combustion engines, such as driving bans or city centre toll charges. However, in some cities with high traffic volumes electric cars will be granted special privileges.

Scenarios compared
New registrations of BEVs in Germany in accordance with scenarios*



* Assuming linear development in new registrations
Sources: DB Research, IW Cologne 20

The various scenarios (see text box on page 25) show strong fluctuation in the sales potential for electric vehicles in 2020, depending on the two main determinants; literature on the subject cites estimates ranging between 1% and 10%. It is apparent that the target of 1 million electric cars (BEVs, PHEVs, REEVs) would presumably only be achieved with certainty in Scenario I. However, from an economic perspective we consider Scenario II the more sensible, because in this case the technology would gain (gradual) ground primarily on the strength of technical progress and less by virtue of state subsidisation. In the light of current debate in Germany, in which the political powers-that-be are sceptical of support for electric vehicles – at least of a strong, direct stamp – Scenario II could well be the most likely.

Global market potential slight to begin with

The scenarios are beset by considerable uncertainty over technical progress and promotion policies. And these uncertainties become much greater as we attempt to assess the global potential for electric cars in 2020. It is obvious that electric vehicles will carve themselves the largest share of the market in countries with constantly high support (e.g. China, France and the US). Meanwhile, market share will presumably be negligible in those emerging economies that do not subsidise the technology quite simply because it is too expensive. Without state support, even in ten years' time the market share of electric vehicles in, say, India, the ASEAN states and Latin America will be purely for homeopathic purposes. Bosch, the world's largest automotive supplier, expects only about 3% of the more than 100 million global sales of passenger cars and light commercial vehicles in 2020 (roughly 70 million in 2010) to be BEVs or PHEVs.

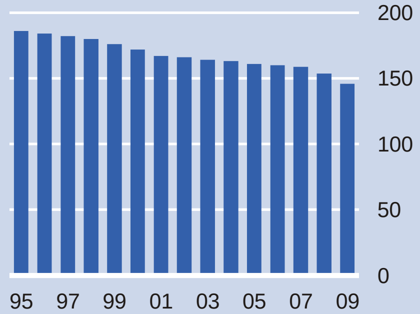
Forecasting beyond 2020 is extremely difficult because technological progress as from then is shrouded in far greater uncertainty. But the stage is currently being set so that at least in the passenger car segment driveline electrification will continue to grow beyond the year 2020. The German government is targeting 6 million electric cars in the total number on the road by 2030, a share of roughly 14%.

5. Conclusion and outlook

At present, and in years to come, high costs and the state of battery technology development will confine E-mobility to the realm of a niche market. Falling costs are by far the most important prerequisite for leveraging the technology's potential. All other challenges, such as the short driving range, recharging infrastructure and power source, initially pale in comparison to the cost issue. In the long term, however, the electric motor can at least be expected to enhance the combustion engine.

In what form and to what extent this will happen is an open question today. BEVs are just one option. In the E-mobility spectrum PHEVs and REEVs compete directly with BEVs, on different scales of intensity depending on the vehicle segment. For the present the disadvantages of the aforementioned vehicles in terms of cost and/or range will remain significant. For the time being economical vehicles powered by combustion engines and full hybrids, above all in urban traffic, are the main contenders as the most cost-efficient alternative on medium and long routes. The road to an electromobile future resembles an evolution rather than a revolution anyway. BEVs, PHEVs and REEVs will rise above their niche status most

Falling steadily
CO_2 emissions by newly registered cars in the EU, grams per km



Sources: European Commission, Transport & Environment 21 quickly in those markets where they are most heavily subsidised. But support of this kind can quickly become very expensive for governments. For them promotion policies constitute a very fine balancing act.

Painstakingly gradual, and in most cases state-subsidised market penetration by E-mobility is the big challenge confronting the automotive industry. It must ramp up its R&D activity in this area without the prospect of finding a market in the short term commensurate with this investment; indeed, much of its spending may have the character of sunk costs if it fails to achieve a breakthrough into the mass market. At the same time carmakers must work constantly on improving the energy efficiency of conventional drives. Companies should start scouting around for the relevant specialists as soon as possible, with the spectre of skills shortages already looming; grants or cooperation with universities would be an option here.

Given the evolutionary nature of E-mobility, we see scant first-mover advantages for businesses in this field. The best offers in the market, and not necessarily those first out of the starting blocks, will present the brightest business prospects for companies in the long run. In view of the uncertainties surrounding market development, being a second mover may have a distinct upside.

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