Federal Ministry for the
Environment, Nature Conservation,
Building and Nuclear Safety

Renewably mobile

Marketable solutions for climate-friendly electric mobility

Renewably
mobile

IMPRINT

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In order to prevent the most serious consequences of climate change, global warming must be restricted to 2°C above the pre-industrialisation level. According to the Intergovernmental Panel on Climate Change, greenhouse gas emissions must be reduced by up to 85 percent, however at least by a minimum of 50 percent, compared to 2000 levels in order to achieve the two-degree target.

What does that mean for Germany? Assuming uniformity across the board , i.e. assuming equal emissions per capita across all countries worldwide, even conservative estimates suggest that greenhouse gases must be reduced by more than 80 percent, compared to 2005 (see Fig. 1a). This is the Federal German government's fixed target.

The extent of the required mitigation makes it clear that all CO_2-producing sectors, which without a doubt includes the sector, must make an equally high contribution to achieving this target. According to calculations by the Federal Environment Ministry, if we want to use our cars the same way we do today in 2050, the CO_2 emissions of cars must be reduced from 221 g CO_2 per kilometre travelled in 2005 to a maximum of 43 g CO_2 per km by 2050 (see Fig. 1b).

Over the next few years, it will certainly be necessary to make greater progress in improving the efficiency of conventional drives or to consider the use of biofuels. However, this is not enough to achieve the targets set for 2050. The calculations show that the right upper emissions limit needed to reach the two-degree target of 43 g CO_2 / km per car can only be achieved if at least two-thirds of all journeys are emission-free, most easily achieved by making them in pure electric and plug-in vehicles. Fuel cell vehicles with hydrogen based on renewable energy could also contribute to meeting the targets, although their high hydrogen production related primary energy consumption and the low level of total energy efficiency are problematic issues here (see Fig. 2).

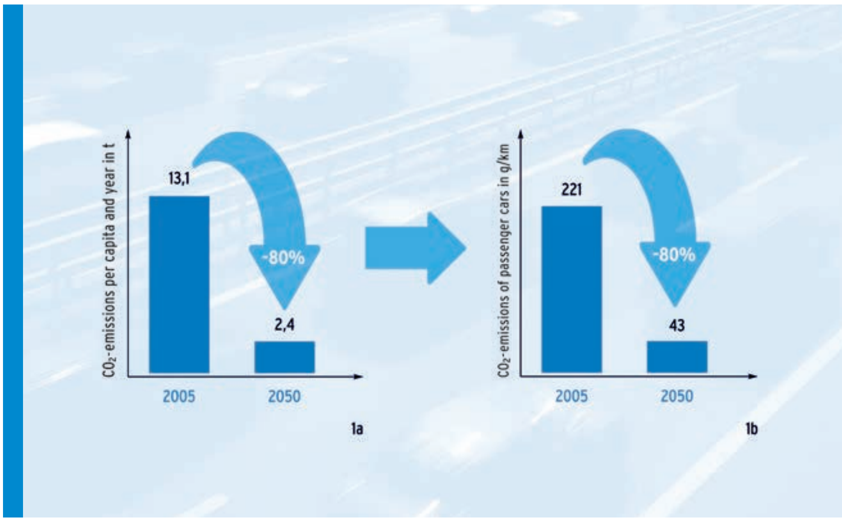


Fig. 1 a and b: Required reduction of Germany's CO_2 emissions to limit global warming to two degrees by 2050. The calculations are based on models which take various factors such as population growth or changes in the number of vehicles in use into account. Fig. 1a shows the requisite reduction of CO_2 emissions per capita, Fig. 1b shows the requisite reduction of vehicle CO_2 emissions.

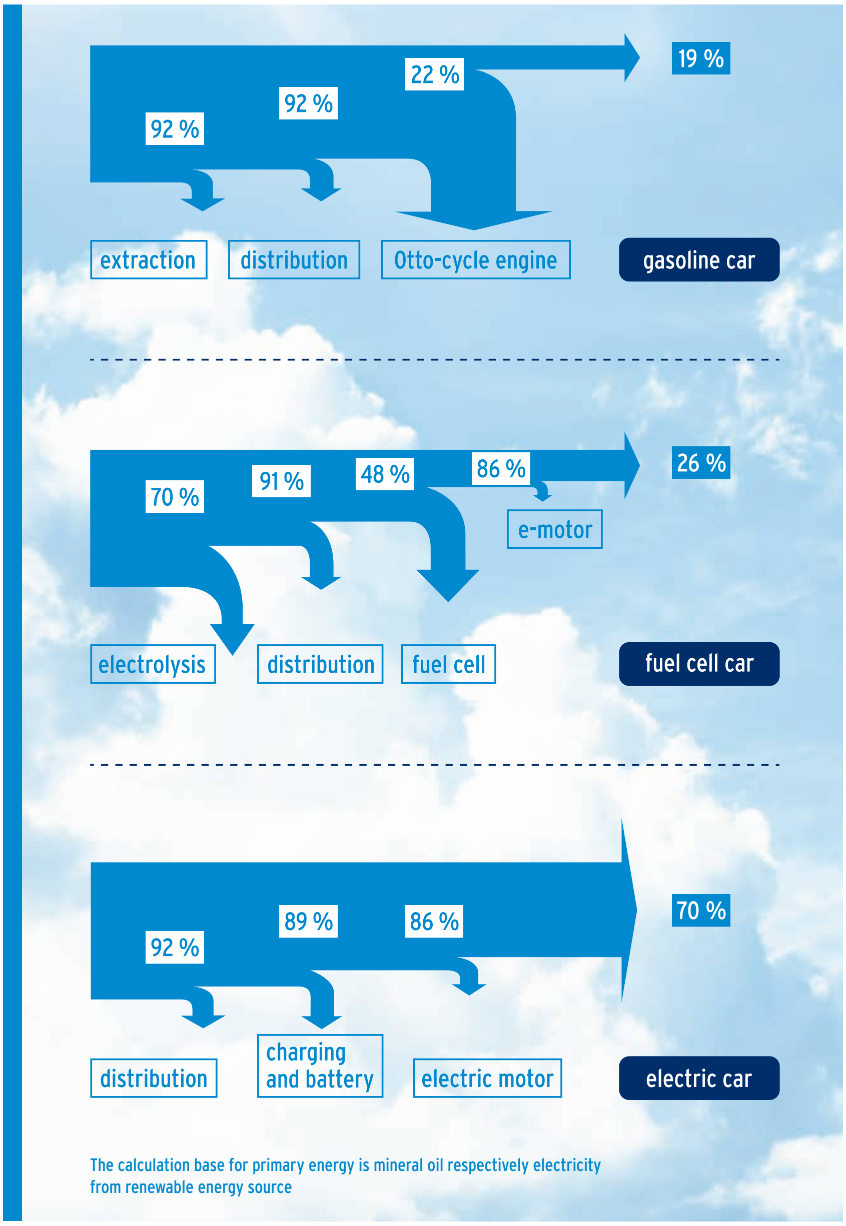


Fig.2: The energy efficiency shows what proportion of the primary energy input is converted into propulsion. For a petrol-fuelled engine, for example, this figure is only 22 percent. If fuel supply related losses are taken into account, a mere 19 percent of the input energy remains to actually serve vehicle propulsion. With an energy efficiency ratio of approximately 86 percent, an electric motor is extremely efficient. However, when using hydrogen to supply electricity to the vehicle, this advantage is considerably diminished by the upstream electrolysis process, the compression, the distribution and the conversion of hydrogen into electricity. As a result, the overall energy efficiency ratio of fuel cell vehicles amounts to just 26 percent. In contrast, electric cars sustain insignificant losses along the upstream energy chain, allowing 70 percent of the primary energy to be converted into propulsion energy.

What is electric mobility as defined by the Federal German government?

The Federal German government's declared aim is to see one million electric vehicles on Germany's roads by 2020, and six million by 2030. However, what exactly are electric vehicles in the sense of this objective?

BEV: Pure electric vehicles are fitted with an electric motor only and receive their energy from a battery located within the vehicle. The battery itself is charged via the power grid. The battery can store recovered braking energy (regenerative braking). Pure electric vehicles also no longer require a transmission system. As battery-driven vehicles are referred to as "Battery Electric Vehicles" in English, this abbreviation BEV is now also commonly used in German.

REEV: As large capacity batteries are still relatively expensive at present, a number of manufacturers have fitted their pure electric vehicles with an additional range extender (REEV = "Range Extended Electric Vehicle") which extends the vehicle's range. The range extender is a small combustion engine with a generator that only starts up when the battery power is running low. It provides additional power to the battery but does not actually drive the vehicle as such, which is the main difference to electric hybrid propulsion.

PHEV: A hybrid vehicle combines an electric and conventional propulsion and energy system (HEV = "Hybrid Electric Vehicle"). The vehicle is fitted with a combustion engine as well as an electric motor. If a larger battery is used which can be charged via the power grid, this kind of vehicle is referred to as a plug-in-hybrid electric vehicle or PHEV in English. The Federal German government's definition of electric vehicle extends only to PHEVs that can be charged via the power grid. PHEVs and REEVs are therefore relatively similar. Both offer the advantage that everyday journeys can be made emission-free and purely electricity-driven yet longer distances do

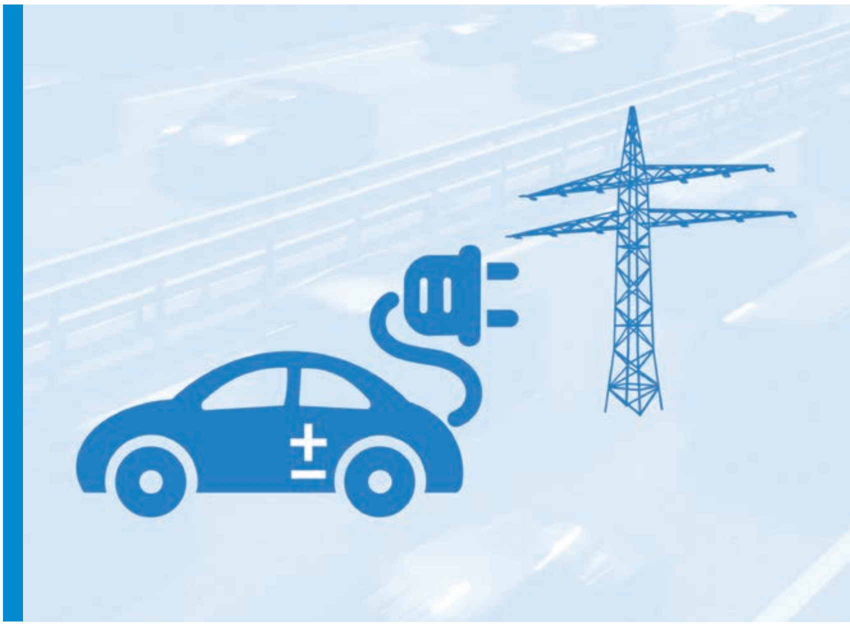


Fig. 3: Electric mobility as defined by the Federal German government includes all vehicles that are powered by an electric motor and draw most of the power they require from the electric power grid, i.e. vehicles that are externally rechargeable, including BEVs, REEVs and PHEVs.

not pose a problem, either. Due to the advances in battery technology, it will be possible to continue to gradually increase the proportion of “the electric mode” in future.

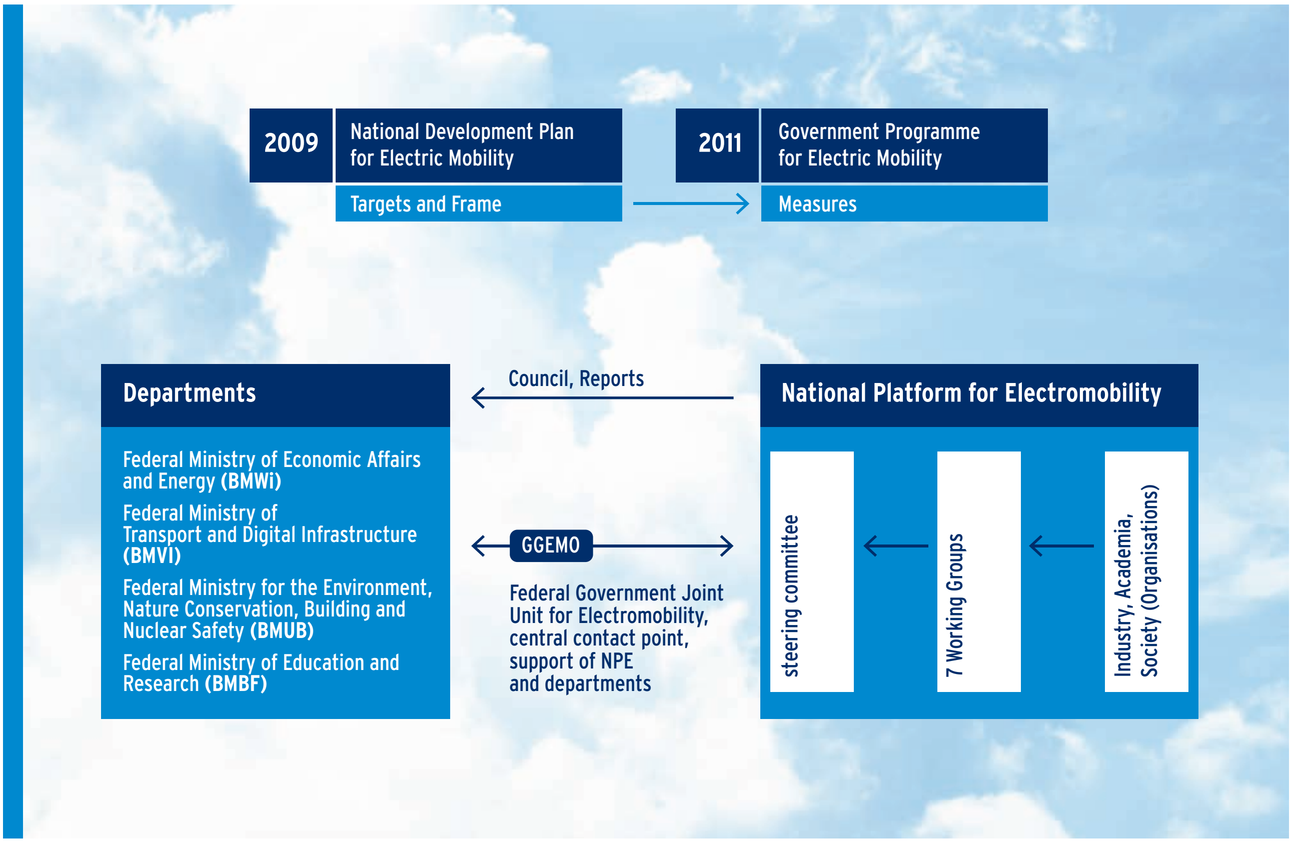
The Federal German government’s definition of electric mobility therefore includes all vehicles which

- are powered by an electric motor and
- draw most of their energy from the power grid, i.e. are externally rechargeable.

This strict interpretation of the term electric vehicle, whereby the “electric” very much stands for “fuel”, was decided on for a good reason. In terms of energy efficiency, electricity is the only fuel in the energy chain that represents an improvement and, provided it comes from renewable energies, helps to significantly reduce the CO_2 balance (see Chapter “Why are we focusing on electric mobility?”). Also, we already have a usable infrastructural base for electricity in place, something that does not apply to other energy sources. For example, fuel cell vehicles that are also driven by an electric motor require hydrogen, a fuel whose production and transportation demands a high energy investment, assuming the use of current technologies. This significantly impairs their total energy and CO_2 balance. Furthermore, the creation of a nationwide hydrogen infrastructure would be costly. Continuing the development of fuel cell technology further still makes sense, though, as it offers undisputed advantages in terms of range and storage capabilities. The Federal German government has therefore established a respective funding programme independent of electric mobility; the “National Hydrogen and Fuel Cell Technology Innovation Programme”.

Electric mobility: Who is who and who does what?

As early as 2007, the Federal German government declared the promotion of electric mobility to be a key element for climate protection. Accordingly, the Integrated Energy and Climate Programme reflects this. In November 2008, a number of specific measures were discussed with representatives from industry, research and the political arena in a national strategy conference. This led to the adoption of a "National Development Plan for Electric Mobility" in 2009, with the aim of developing Germany into a lead market for electric mobility. The plan hopes to see a million electric vehicles on German roads by 2020. The four Federal German government ministries responsible for electric mobility, the Federal Ministry of Economic Affairs and Energy (BMWi), the Federal Ministry of Transport and Digital Infrastructure (BMVI), the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and the Federal Ministry of Education and Research (BMBF), subsequently intensified the promotion of electric mobility and are currently funding a number of different research projects. In May 2010 the Federal Chancellor established the "National Platform for Electric Mobility" (NPE). It consists of representatives from industry and science, policy-makers and non-politicians. They are tasked with making recommendations for the next steps and measures. The specific measures contained in the Federal German government's "Government



Programme for Electric Mobility", initiated in May 2011, reflect the contents of the National Development Plan as well as the most important recommendations made by the National Platform.

National Development Plan for Electric Mobility (NEP). The Federal German cabinet adopted the National Development Plan for Electric Mobility (NEP) in August 2009. The NEP sets out a number of objectives and framework conditions aimed at achieving major advances in battery technology and grid integration and accelerating market preparation and the introduction of electric vehicles over the next ten years. One important component is linking electric mobility to renewable energies.

Government Programme for Electric Mobility. Adopted on 18 May 2011, the Government Programme for Electric Mobility stipulates a number of further measures and framework conditions intended to contribute to the objective of making Germany the leading provider and lead market for electric mobility. The programme includes such measures as, for example, the provision of 1 billion EUR worth of funding for research and development in this field or the establishment of regional "show cases" and the development of technology "Lighthouse Projects". The Government Programme therefore brings together the various future activities of the Federal German government in the field of electric mobility and heralds the second phase of the National Development Plan for Electric Mobility. The Government Programme is the Federal-German government's affirmation of its target of a million electric vehicles by 2020, and six million electric vehicles by 2030.

Joint Unit for Electric Mobility (GGEMO). Since February 2010, the Joint Unit for Electric Mobility (GGEMO) has served as the Federal German government's single point of contact and the Federal German government's secretariat for tasks in the field of electric mobility, and as a service provider and secretariat for the National Platform for Electric Mobility (NPE). In this role, it particularly encourages the cooperation with the Electric Mobility Steering Group and the dialogue with the National Platform for Electric Mobility (NPE).

National Platform for Electric Mobility (NPE). The National Platform for Electric Mobility is an advisory body to the Federal German government and brings together key players from industry, science, politics and society for strategic dialogue. The main topics regarding the issue of electric mobility are addressed by seven working groups, each consisting of approximately 20 high-ranking representatives. These make recommendations for the implementation of the National Development Plan and the Government Programme for Electric Mobility.
The working groups are coordinated by a Steering Committee consisting of the chairs of the working groups as well as Federal German government representatives. ■

← **Fig. 4:** Overview of distribution of tasks of the various Federal German government institutions with regard to electric mobility: Steering Group, National Platform for Electric Mobility (NPE) and Joint Unit for Electric Mobility (GGEMO) work together on the implementation of the National Development Plan for Electric Mobility (NEP) and the Government Programme for Electric Mobility, both of which define the objectives, frameworks and measures for the various activities of those involved.

A driving force for Germany. Electric mobility as active climate protection.

Climate change and the depletion of fossil fuel resources will greatly change our mobility patterns. If we do not want to have to say goodbye to driving our own car, we must give it a set of "new wheels". No reason to wave goodbye to it! Cars do have a future, but what might this future look like? How will we travel by car in the future? And where will our energy come from?

Individual transport will indeed come in many different, new guises in the future; electric drive vehicles will certainly be one of these. Electric mobility offers us the chance to change the way we move from A to B in a sustainable way – towards a more eco-friendly, targeted mobility. It will make the transition from a fossil fuel to a post-fossil fuel mobility culture that focuses on clean, safe, local energy sources much easier.

Our planet's population will continue to increase – as will the need to transport goods and people. At the same time, oil reserves are running out, and the various derivatives used as fuel are becoming increasingly expensive for end consumers. Not forgetting the CO_2 emissions that are causing our climate system to change. In view of this scenario, electric mobility can make a significant contribution to the move towards the use of alternative energy sources in the transport sector. However, this requires the power for electric vehicles to originate from wind, the sun and other renewable energy sources, as this is the only way to come a huge step closer to achieving the zero-emissions goal and the phasing-out of fossil fuels.

In view of these facts, what will our everyday driving experiences look like in the future?

Electric vehicles will be firmly established in our everyday lives. The car that an ordinary commuter will have in their garage may be different to a conventional car with a combustion engine in terms of design and electronics, however, the current disadvantages of electric vehicles will no longer be an issue, as technological innovations and redesgined operating environments will have made electric mobility user-friendly. Commuters neither have to spend more money on buying a car, nor will this car be considerably heavier than today's car due to a large battery, nor will their driving comfort be

restricted in any way due to a limited range. Optimised vehicle designs and the use of lightweight construction methods throughout are one way of achieving the above.

Public and company vehicle fleets as well as the majority of vehicles for passenger and goods transport will also run on electricity, or be able to do so as and when required. Besides the various present-day microcars, there will be different vehicle types to meet the wide range of individual mobility requirements. In short, future users will be able to choose the right vehicle, whatever their respective needs.

For many city dwellers, for example, the “all-purpose vehicle” still commonplace today will be a thing of the past. Such vehicles were often purchased with long-distance journeys in mind, which were then undertaken very rarely. The emission-free, battery-operated microcar has therefore become a useful alternative for many city dwellers.

They use electric scooters and bicycles or the largely electrically powered public transport system if they have shorter journeys to make.

And if they do have to travel greater distances on a daily basis, there are a number of alternatives. Besides Plug-In-Hybrid-Vehicles with a wide range there is access to many car sharing providers, whose offer of environmental friendly vehicles includes cabriolets, sports cars and vans. The batteries of these cars are charged while the driving itself, namely by using induction systems which are embedded in the road surface over several kilometers. The time-consuming search for charging points located outside a driver’s known environment is also something long past as the network of charging points has been expanded to offer nationwide coverage, and drivers can find out where they are whenever they need to via their on-board satellite navigation system.

The overall quality of life, especially in urban areas, has become much better thanks to less direct emissions: less exhaust fumes, less particulates and less noise, which will make a huge difference, particularly in the megacities.

Electric vehicles will also make a significant contribution to grid stability. For example, the battery of an electric vehicle, parked either in a garage or somewhere else, owned by a commuter is used to store energy generated from renewable energy sources, but it can also feed this energy back into the grid if necessary. This intelligent grid integration ensures that fluctuating energy sources such as clean wind and solar energy can also be used efficiently during times of surplus.
The current problem of insufficient electricity storage capacities will no longer be a problem. This integration of private cars into the power supply is controlled in a user-friendly way by state-of-the-art technology. In fact, the traditional plug will often also be surplus to requirements, thanks to the highly efficient wireless charging technologies that have become the norm. Long charging times that require careful routing and timing no longer need to be factored in. The car will have undergone a metamorphosis, from mere mode of transport to a tool that serves the ecologically sensible management of our energy usage. All of its components are recycled, of course, and environmentally friendly materials and processes have become the norm in automotive construction.

The unique and innovative state-of-the-art technology required for the system to run smoothly has given German automotive manufacturers and automotive industry suppliers a competitive edge on the international market, Germany’s comprehensive, sustainable approach has turned out to be a particular strength.

Overall, as a clean, efficient, resource compatible and above all user-friendly solution, the (electric) car has a secure future in Germany. ■

CLEAN

Electric vehicles and wind or solar generated electricity are ideal partners – emission-free mobility.

Developing the traditional combustion engine further is an important step towards reducing CO_2 emissions, but on its own, it will never suffice to provide climate-friendly transport. Although modern cars with combustion engines are becoming more efficient in terms of technology, and individual fuel consumption is going down, these advances are offset by the fact that globally, the number of vehicles on the road as well as the distances travelled are on the increase. The number of cars worldwide is expected to double by 2030. If it does so without a substantial proportion of low-emission or emission-free vehicles, CO_2 emissions are expected to soar once again, leading to a respective impact on the climate. Oil reserves are also finite and the market price will continue to rise in the long-term.

Electric vehicles are the obvious solution. However, only if the electricity used by these vehicles is generated from renewable sources, such as wind power or solar energy. This would make them true zero-emission vehicles that contribute to environmental and climate protection. Increasingly, the "green" image of electric vehicles will also become an incentive to purchase, and correspondingly provide the manufacturers with a competitive advantage. In addition, the use of electric vehicles not only reduces greenhouse gas emissions but also nitrogen oxide, particulate and noise pollution.

Few people are aware of the fact that the continuously increasing proportion of renewable energy input into the power grids calls for intelligent grid management and storage technology solutions. The energy generated from wind and solar power is subject to strong fluctuations and at peak times, there may be excess energy which cannot be fed into the energy market due to lack of storage capabilities. This is, for example the case at night, when wind turbines rotate heavily due to strong winds whilst power consumption goes down to a minimum. This renewably generated electricity could be used to charge the batteries of electric vehicles parked at the time but connected to the grid to function as flexible "current collectors".

The use of sophisticated technology ensures that the electric vehicle's owner can easily and conveniently control charging times, for example via an online user interface. All the user has to do is enter the command "Charge battery fully by 7 am tomorrow"; and the technology does the rest. Feeding emission-free renewable energies into the system will become easier with every single one of such decentralised and time-sensitive charged electric vehicle batteries used.

They can be connected to the power grid with "intelligent" plugs. However, inductive, i.e. wireless, charging will also soon be possible. Wireless charging systems are convenient and support the use of fluctuating energy sources: a driver assistance system (similar to current automatic parking aids) will automatically position the vehicle correctly above the coil of a wireless charging point when you drive your car into a garage or a car park and connect it to the power grid for you. Most vehicles are usually parked for 23 of each day's 24 hours. The convenience increases the time vehicles are connected to the grid and thereby the options available for storing renewable energies at the best point in time. ■

ECO-FRIENDLY

is dealing with resources in a way that also takes the past and the future into account.

Many electric car components require raw materials that are increasingly becoming scarce on the global market, and correspondingly more expensive, particularly lithium, cobalt and rare earths. Given that no vehicle lasts forever or is immune to wear and tear, it is important to ensure during the manufacturing process that its individual components can be recycled or reused for other purposes (second life) later on. This reduces our dependence on key raw materials, helps to protect the environment, saves money – and therefore helps to give manufacturers a competitive edge. Electric vehicles are particularly suitable for comprehensive closed loop recycling management in the automotive industry as so many of their components either needed redesigning or had to be designed from scratch specifically for their new purpose.

In order to efficiently recycle materials from electric vehicles, we need new manufacturing methods and smart designs. On the basis of an ecological overall concept for energy and material flows, various substances whose recycling will soon become a priority can be identified at an early stage. It is also a good idea to develop collection and return concepts in order to meet the objective of a maximum recovery rate.

Another option is reusing individual components in other areas of application. This might for example apply to older batteries that no longer meet the energy storage requirements of electric cars, yet are still effective enough to be used to capacity for other purposes. All of this requires sophisticated testing methods which can be used to analyse the aging behaviour and condition of individual components to determine the best time for their replacement. The removal or replacement of such recyclable or reusable components must also be accomplished with as little effort as possible. Again this must be taken into account during the vehicle manufacturing process.

Linking product development and recycling processes is also of strategic importance for German car manufacturers and automotive industry suppliers, as it is to their advantage and has already had a positive impact on costs whilst also benefiting their future competitiveness. ■

ECONOMICAL

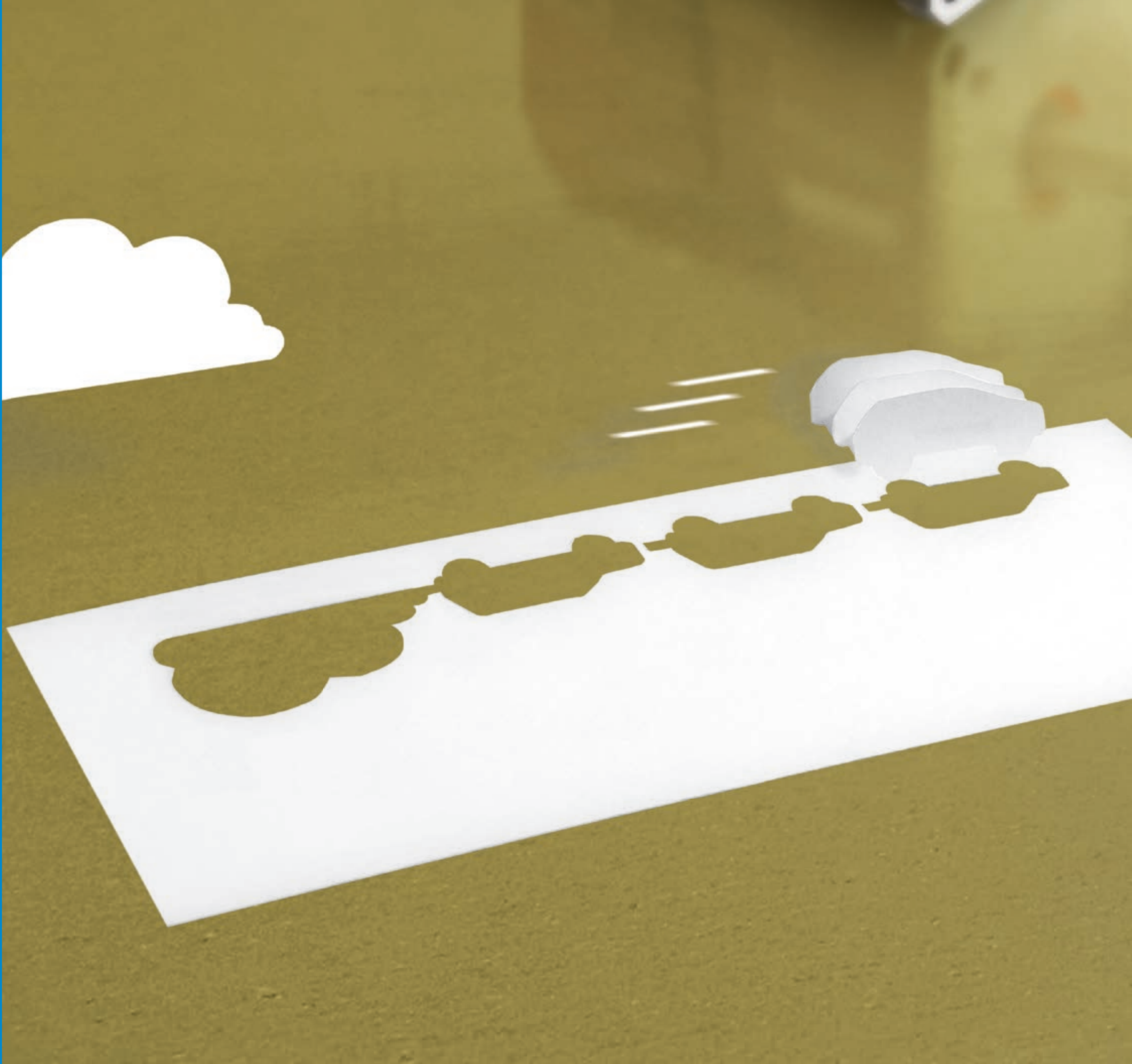
means using energy effectively and converting all of it into propulsion.

Electric vehicles are extremely efficient. Thanks to the excellent energy efficiency of their engines, a far greater amount of generated energy is converted into propulsion than in a traditional combustion engine. On the other hand, the heavy weight of the traction batteries and the limited range of the vehicles represent new challenges for the manufacturers.

Electric motors utilise over 90 percent of energy input, whereas combustion engines utilise less than 40 percent. In electric vehicles, a proportion of the energy lost during braking can also be recovered by means of modern technology to be fed back into the battery. This efficiency advantage is particularly useful in urban traffic, where frequent braking and accelerating are the norm.

Electric mobility leads to innovation. In order to continue to improve the economy of electric vehicles – and hereby their range, carbon footprint and efficiency – some of the issues that need to be resolved are reducing the vehicle weight and optimising the ancillary components. One way to achieve this is lightweight construction with materials based on natural fibres. Thermal management, i.e. controlling thermal flows inside the vehicle, also offers scope for further improvement in order to increase the overall efficiency. Innovations such as these, resulting in efficient and long-lasting technologies, can subsequently also be utilised in cars with combustion engines, benefiting both the environment and the driver's wallet.

Bridging technologies help with the transition to electric mobility. These include various plug-in hybrid vehicle (PHEV) concepts, such as range extended electric vehicles (REEV), i.e. vehicles with hybrid drive whose batteries can also be charged via the power grid. Energy efficient drive components and intelligent operating strategies can ensure that these vehicles also produce only minimal CO_2 emissions. This hybrid form of "classic" car and electric vehicle can help to encourage users who expect a long-distance vehicle range to accept electric mobility. On the other hand, many users will make the experience that they can actually make most of their journeys in pure electric mode: More than two-thirds of all cars on German roads are driven less than 40 km a day. ■



PRACTICAL

Ready for everyday use: The right electric vehicle, whatever the needs.

The transition to electric mobility is a process that will not take place over night. For a start, despite their benefits in terms of energy efficiency, electric vehicles are initially more expensive to buy than cars with combustion engines. A sensible first step to make electric mobility key to road traffic is therefore to provide funding for pioneering vehicle fleet projects. In this field, the lower operating costs already compensate a considerable proportion of the initial investment, even today. The more the benefits of electric vehicles become apparent in these areas of application, the more acceptance they will find from private buyers.

One vehicle fleet area that electric mobility is perfect for is urban goods traffic. Transport companies or mobile service providers tend to benefit more from switching to fuel-efficient electric vehicles as the conditions are well-suited to electric mobility: If the vehicles are not in use, they are parked in depots or company car parks, making it easy to implement a bundled charging infrastructure. The daily routes of urban delivery service operators are also quite regular and can already easily be covered with the ranges offered by today‘s electric vehicles. Using diesel hybrid buses for public transport is also a good idea. The recovery of braking energy from the frequent stopping and starting processes not only saves 20 percent of fuel, pure electric traffic close to bus stops also considerably reduces the level of pollution from particulates and other air pollutants the waiting passengers are subjected to.

Many people use their cars mainly for urban commuting; the shorter range of electric cars is therefore of no real consequence to them. Another advantage is the fact that electric vehicles help to reduce the noise and air pollution levels in densely populated urban areas. And, not least, the noticeably more affordable way of "filling up" already helps to compensate the higher purchase price, even today. Vehicles with a range extender offer longer ranges, i.e. they are more like the all-purpose car we know today. They are fitted with a small-scale combustion engine that supplies the battery with power when necessary, but the majority of journeys can be driven in pure electric mode using renewable energy straight from the socket. Controlled charging can make a significant contribution to power grid stability and optimum renewable energy use. People who prefer to travel by bus, train or plane anyway can also simply share an electric car with others by registering for a car-sharing scheme. They can then choose the type of vehicle that is most suitable for their travelling plans that day – anything from a compact car to a van. New service models such as the purchase of "mileage", i.e. kilometres, or the leasing of batteries can contribute to making electric mobility marketable. Designing customised, attractive offers is one element of new marketing concepts that focus on the environmental benefits. ■


Full emotion,
zero emission.
SIEMENS

1 Funding priorities and projects
Field tests for electric mobility in car traffic

The potential of electric mobility in terms of environmental policy depends very much on the electricity generation method as well as on their penetration of the passenger car market. Field tests under everyday conditions provide important insights into the technological maturity of the respective drive, the vehicle’s energy requirements and user acceptance.They are therefore of particular importance for the targeted further development of electric and plug-in hybrid drives, and for the assessment of future market trends and the volume of CO_2 emissions likely to be avoided.

It is unlikely that the climate and energy policy objectives for the transport sector can be achieved without an increased use of renewable energies. However, as renewable energies are also expected to contribute to substantially lowering the CO_2 emissions in other sectors as well, and to reduce the volume of energy that needs to be imported, it is crucial that they are used as efficiently as possible in the transport sector.

The funding was therefore used to focus on the following topics

- further development and testing of electric and plug-in hybrid electric vehicles in the passenger car sector,
- further development and testing of procedures for controlled charging and feedback of electric energy into the power grid,
- development and testing of wireless charging methods.

Joint project
Reducing climate impact through the combination of renewable energies with emission-free electric vehicles

Project partners
Bayerische Motoren Werke AG, Munich
Vattenfall Europe Aktiengesellschaft, Berlin
Chemnitz University of Technology, Chemnitz
Technische Universität Berlin, Berlin
Ilmenau University of Technology, Ilmenau

Duration
November 1, 2008 – November 30, 2010

MINI E Berlin powered by Vattenfall

Objectives of the project
The main objective of the project was to gather first experiences with respect to climate and environmental factors as well as electric vehicle usage patterns by means of a fleet test conducted during the early stages of electric mobility.

Results
In June 2009, the BMW AG made a fleet of 50 MINI-based electric cars available, to be used by selected individuals over a period of 12 months under everyday conditions in order to reveal the further development potential and requirements of electric vehicles to the stakeholders involved (car manufacturers, energy providers, grid operators, users). In addition to installing the necessary charging devices at the homes of the users, project partner Vattenfall Europe AG also developed public charging points and the respective billing systems and installed them in the city of Berlin as a trial, networked and convenient charging infrastructure system. Certificates proved that the electricity had been generated by wind power and hydropower. The project was scientifically supervised by the Ilmenau University of Technology, the Technische Universität Berlin and Chemnitz University of Technology.

The fleet test in Berlin showed the extent to which electric cars can help to reduce CO_2 emissions and local pollutants and the existing options for coupling the use of electric vehicles with the use of renewable energies. Another focus was usability and user acceptance studies, under special consideration of the potential of electric mobility with regard to the integration of renewable energies into the power grid and user behaviour of users in terms of their ability to control the charging behaviour. Methods and applications were developed which can compensate load fluctuations in the energy distribution network. On the one hand,

this relates to supply-side peak loads due to wind energy input, on the other to demand-side peak loads due to electric vehicle charging, both can be compensated for through controlled battery charging. Provided sufficiently high-performance batteries for electric vehicles are available in the future, these could function as virtual power plants and also feed their stored energy back into the power grid as and when required. A number of respective concepts were developed within the scope of the project and verified in practical tests, with a focus on demonstrating the suitability for everyday use and verifying customer acceptance of controlled charging and the use of electric vehicles in general.

The project helped to show that electric mobility on the basis of the current MINI E model is already suitable for everyday use in many respects. The results of the study show that the test participants did not feel that the limited vehicle range affected their usual mobility patterns in most cases. The necessary charging times for the MINI E were not perceived as a restriction by the users. Those who had access to a charging point at home or at work hardly needed public charging points. It could also be proved that controlled charging with the aid of the developed wind-to-vehicle application works and that users accept it. ■

Joint project
MINI E Berlin powered by Vattenfall V2.0

Project partners
Vattenfall Europe Innovation GmbH, Hamburg
Bayerische Motoren Werke AG, Munich
Chemnitz University of Technology, Chemnitz

Duration
April 1, 2010 – September 30, 2011

MINI E Berlin powered by Vattenfall V2.0

Objectives of the project
Previous projects (including MINI E) had confirmed that in principle, it is possible for electric vehicles to be charged according to current wind turbine generating capacity without any restrictions to the use of electric vehicles. However, they had also shown that the level of correlation between the timing of the wind energy supply and the vehicles available on the grid is lower than expected. In addition, public charging points were not used to the extent originally anticipated. Considering vehicle range and in-home charging facilities, there is only a very limited demand for public charging facilities. On the other hand, the results of the previous project showed that a lack of information with regard to charging points and times has a negative impact on the use of public charging facilities. The project's objectives therefore included the development of a usable mobility assistant to provide a value added service that would make the use of public wind-to-vehicle (W2V) charging facilities a simple and attractive option.

Results
Just like the MINI E project, the MINI E V2.0 project was also based on a fleet test in order to evaluate and test electric mobility in new application scenarios, albeit with a total of 70 vehicles. Additional user groups for which the data also suggested an added value for the W2V concept were identified. An essential part of the project focused on obtaining further in-depth knowledge of e-vehicle usage and applications and e-vehicle design requirements taking this extended knowledge into account (e.g. specific requirements of users who have no access to off-road parking facilities, fleet use).
For this purpose, the W2V concept was developed further on the basis of scientific analysis, which led to the provision of a respective value added service.

A mobility assistant providing customer-oriented mobility packages to support the combination of charging with parking was developed and tested to facilitate the use of this value added service. It provides user groups without in-home charging facilities with targeted information on public charging points. The future transferability of the solutions arrived at could be of particular importance for certain user groups, for example for large fleet operators that provide vehicles to different customers on a commercial basis. Suitable and efficient solutions were found to allow users who do not have access to an allocated parking space or a garage (resulting in on-street parking) to use renewable energies (W2V) as well.

Therefore, the results made an important contribution to implementing the Federal German government‘s climate and energy policy provisions. The project also supports the future viability of the key industries automotive and energy in the global competitive environment, so it also meets industrial policy objectives. ■

Project
Research and development of new vehicle concepts for electric mobility

Project partners
Bayerische Motoren Werke AG, Munich

Duration
September 1, 2009 – September 30, 2011

BMW ActiveE

Objectives of the project
Battery-electric vehicles for road use have a crucial role to play in achieving ecologically and economically acceptable quality of life improvement. They allow individuals to be mobile yet also provide improved efficiency, compared to vehicles with combustion engines. However, this requires the development of sensible new vehicle concepts that take the new requirements of a battery-electric drive system into account whilst retaining the existing vehicle-specific technological achievements in terms of safety, comfort or range. In previous MINI E field tests, conversions of existing series-produced MINI vehicles were used; the main objective of the BMW ActiveE project, however, was the development of a sustainable vehicle concept that meets all of the requirements described above. The project was also to prove that the processes for developing and reproducing new battery-electric vehicles are flexible and efficient enough to take specific technological features into account in an affordable way. Previous experiences gained in the development and production of conventional vehicles could be drawn on only to a certain extent.

Results
A new electric vehicle (BMW ActiveE) was therefore developed and, in a technologically challenging process, the resultant prototype‘s essential components and properties underwent iterative, thorough performance tests. The tests made it possible to adapt and optimise the vehicle concept at an early stage. One particular focus was the modification of the original basic vehicle in order to incorporate new components compatible with an electric vehicle. This required the redevelopment of major parts of the software necessary for the safe and convenient electric operation of the vehicle (for example for on-board power supply and operating strategy). The biggest challenge involved the integration of high-

voltage storage capacities, HV power electronics, the electric motor and the transmission system and all auxiliary equipment, e.g. heating and air-conditioning systems or high-voltage safety features, into the overall "e-vehicle" system in a reliably reproducible way. In order to investigate potential interactions between the various vehicle systems, a number of test vehicles were subjected to field tests to examine their suitability in everyday as well as extreme conditions (including crash tests and HV safety).
The experiences and findings gained over the course of the project have significantly contributed to the future development and expansion of cost-effective and competitive vehicle concepts. The overall objective of developing battery-electric vehicles with a high user acceptance and efficient energy use was therefore met. ■

Joint project
Increasing the effectiveness and efficiency of wind-to-vehicle (W2V) and vehicle-to-grid (V2G) applications and the charging infrastructure

Project partners
Vattenfall Europe Innovation GmbH, Hamburg
Bayerische Motoren Werke AG, Munich
Technische Universität Berlin, Berlin
Chemnitz University of Technology, Chemnitz
Ilmenau University of Technology, Ilmenau

Duration
May 1, 2010 – September 30, 2011

Controlled Charging V2.0

Objectives of the project
The objective of the project "Controlled Charging V2.0" was the development of suitable procedures for maximising the utilisation of renewable energies, including a load management system that improves the charging of electric vehicles under consideration of the fluctuating availability of wind energy. The system was to take energy management and vehicle-related requirements as well as user behaviour into account.

Results
During the course of the research, various different functions for an effective charging and load management system were developed and integrated into the charging infrastructure. This included the wind-to-vehicle function (W2V): Whenever possible, the charging is timed to coincide with periods during which a high volume of wind-generated electricity is available yet demand for electricity from the grid is low. Vice versa, the vehicle-to-grid function (V2G) feeds energy from the vehicle battery back into the grid if there is little wind energy available at times when the demand for electricity is high. During controlled charging, the local load management system (LLM) ensures compliance with grid restrictions and optimum utilisation of the available capacities. The current available for vehicle charging is therefore allocated to the vehicles dynamically in accordance with grid capacity under consideration of application-dependent and individually adjustable priority rules. The adaptability of the grid-based control system with regard to user requirements was also examined.

A fleet test with BMW ActiveE electric vehicles was carried out in order to validate the overall system. A so-called charging assistant was used, together with charging and load management functions integrated in the respective charging points.

It is a smartphone-based application that displays both the current demand for renewable energy as well as its availability in terms of times and location in the form of a mobility planner, thereby simplifying the controlled charging procedure for users. During the course of the fleet test, the electric vehicle charging and discharging processes were centrally controlled in accordance with current wind power and grid load whilst observing the users‘ individual mobility requirements. A prior project, MINI E Berlin 1.0, had revealed that improved effectiveness and efficiency require a higher degree of engagement and interaction between charging point and e-vehicle. A bi-directional communication system involving both was therefore developed and used in the “Controlled Charging V2.0” project to allow charging point and electric vehicle to coordinate the charging process.

The project made it possible to thoroughly examine the technical, economical and ecological effects of controlled charging to achieve improved effectiveness and efficiency based on the interaction between energy infrastructure and vehicle fleet. ■

Joint project
Wireless electric vehicle charging (W-Charge)

Project partners
Audi Electronics Venture GmbH, Gaimersheim
Fraunhofer IWES, Kassel
Paul Vahle GmbH & Co. KG, Kamen
Volkswagen AG, Wolfsburg

Duration
January 1, 2010 – September 30, 2011

Joint project
Contactless charging of electric vehicles (Conductix)

Project partners
Conductix-Wampfler AG, Weil am Rhein
Daimler AG, Sindelfingen

Duration
March 1, 2010 – September 30, 2011

Wireless electric vehicle charging

Objectives of the project
Electric vehicles can make an important contribution to improving the integration of fluctuating renewable energies into the power grid. However, this requires the electric vehicles to be connected to the grid as frequently as possible, which is very difficult to achieve with the current standard, wired charging technology as the electric vehicle field tests conducted to date have shown that users do not connect their vehicles to the power grid until the battery is almost empty.
Inductive electric vehicle charging considerably reduces the effort required to connect the vehicle to the grid and provides innovative, completely unobstructed grid accessibility. Anticipated advantages include increased safety, a high level of convenience due to automated procedures, and improved battery maintenance through regular recharging and more frequent and longer connection to the power grid.
The objective of the three cooperative projects was the development and practical demonstration of wireless charging technologies under various basic conditions. The DKE Working Group 353.0.1, which virtually all project partners belong to, also supported the project due to the resultant benefits for the industries concerned, namely the respective technology suppliers and car manufacturers.
Important work on the improvement of the wireless charging system primarily involves technical and scientific issues related to finding solutions with regard to inter-operability and compliance with protection goals (EMC) as well as questions regarding future international standardisation.

Results
The cooperative project “IndiOn” focuses on developments with regard to achieving the highest possible energy efficiency during the energy transfer process between road and vehicle. An intelligent control

Joint project
Contactless Charging of Battery-Electric Vehicles (IndiOn)

Project partners
Siemens AG, Munich
Bayerische Motoren Werke AG, Munich

Duration
April 1, 2010 – September 30, 2011

system automatically starts, controls and finishes the charging process. The current set-up allows the achievement of energy efficiency levels of up to 95 percent.

The cooperative project "W-Charge" addressed issues such as vehicle and secondary wireless device integration. In a series of tests, the precision achieved during unaided positioning of the vehicle to line up with the road-side primary coil was evaluated to determine the respective impact on transmission efficiency. An energy efficiency level of up to 90 percent was achieved if the vehicle was positioned within approximately +/- 10 cm of the coil.

The "Conductix" cooperative project consisted of the development of a wireless charging unit for a range extender vehicle. To achieve this, the charging coil was integrated into the vehicle floor pan. Various structural and technical requirements with respect to the exhaust system, the positioning of the coil were looked at, and different materials and methods were explored to produce an optimised version. Again this project also addressed the achievable energy efficiency level.

All of the developments complement each other and take the prior experiences made by the joint project partners into account. The results from the three projects serve the realisation of a still innovative, direct charging technology with the objective of providing easy, convenient and reliable charging both in public areas as well as at home. The technology can significantly improve customer acceptance and the marketability of electric and plug-in hybrid vehicles. ■

Joint project
Risks and opportunities related to wireless electric vehicle charging and technology impact assessment for a key technology in the electric mobility breakthrough phase

Project partners
ifak - Institut für Automation und Kommunikation e. V. Magdeburg at the Otto-von-Guericke University Magdeburg, Magdeburg
Kiefermedia GmbH, Offenburg

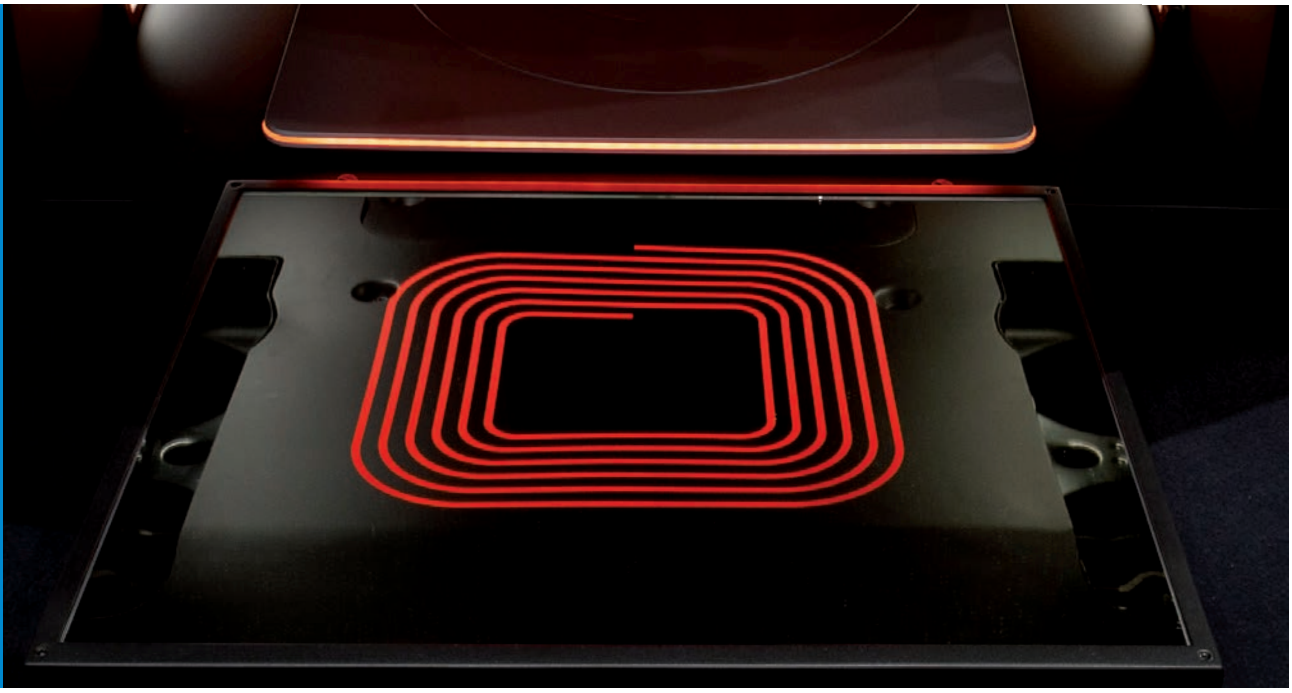
Duration
October 1, 2010 – September 30, 2011

JustPark

Objectives of the project
A research project aimed at assessing the respective advantages and disadvantages of conventional charging technologies compared to wireless electric vehicle charging was conducted concurrently to three FuE projects on the latter subject.

Results
In terms of the system energy efficiency, wireless charging is expected to achieve the same values as wired charging from around 2015 onwards. The current average energy efficiency in the case of resonant induction charging of approximately 90 percent is expected to increase to approximately 95 percent by 2015. The assessment of energy efficiency levels also takes the system efficiency into account, i.e. the chain from primary input to the battery terminals in the vehicle. It also considers the proven fact that renewable energy usage may be increased through user-, grid- and battery-friendly wireless charging with a lower charging capacity and shorter charging times due to the high level of regularity and controllability and the automation of the charging process. The comprehensive study also revealed a more rapid reduction of life cycle costs compared to those associated with wired charging.

As electric mobility is becoming more widespread, leading to a broader range of experiences, electric vehicle users and fleet operators are also becoming increasingly aware of the charging cable‘s disadvantages, and of the costs caused by vandalism, theft, contamination and wear and tear. Wireless charging is therefore expected to make a significant contribution to the spread of electric mobility from 2015 onwards. Even today, the charging process is the second most important “deal breaker” when it comes to electric mobility; however, unlike the currently most important purchasing barrier, the



limited range, this aspect is seldom addressed. The results of this study led to the assumption that precisely the opposite will in fact soon be the case as the possible ranges will increase much faster than anticipated due to increased electric powertrain efficiency, technical advances with respect to the batteries and, above all, lower costs. The components necessary for wireless charging are also expected to be available to prospective buyers from 2013 onwards. Another positive effect results from the fact that users/consumers learn very quickly how much range they actually need and which driving profile is best served by an electric vehicle. In consequence, the range issue loses its significance compared to convenience aspects (accessibility). These also include the use of park assist systems to allow a fully automated positioning of the vehicle precisely above the primary coil to achieve the best-possible transmission rate. Another assumption is that driverless, autonomous parking ("valet parking") will become a future driving force for wireless, fully automatic charging. This will also contribute to wireless charging with 3.3 kW charging capacity becoming the norm. ■

Project
Grid-fleet management: Optimisation of electric vehicle energy efficiency and operating costs

Project partners
Siemens AG, Munich

Duration
July 1, 2010 – September 30, 2011

4S

Objectives of the project
The primary aims of the 4S project were to improve electric vehicle fleet energy efficiency and to minimise the respective operating costs. On the one hand, this was to be achieved by developing a new vehicle drive structure, and on the other through a self-optimising operating system. Another focus was the intention of creating a standard, easy-to-use and efficient fleet management tool for fleet operators such as, for example, car hire companies, municipal vehicle fleets or public utility companies.

Results
The work primarily involved increasing energy efficiency by reducing the losses sustained when recharging and driving. At the same time, operating costs were to be reduced further, for example by means of a fleet scheduling system, a fully-automated billing system, the avoidance of traffic caused by drivers looking for parking spaces and through increasing vehicle capacity utilisation. Specially developed simulation software contributes considerably to the improvement of planning and supply security.

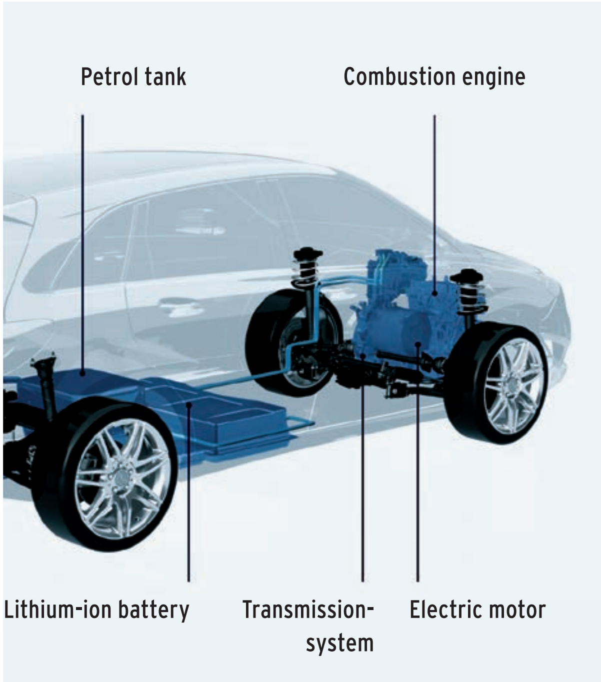
For the in-house car sharing concept implemented for this project, vehicles based on the Suzuki Splash were converted into electric cars. This required the development of a high-performance 800 V on-board power supply along with the required powertrain, a battery and the requisite charging management system, and their integration into the fleet vehicles. The vehicles used in the car sharing project had a central engine. However, the project extended to the construction of a further test vehicle featuring two wheel hub motors on the rear axle, which offers a number of advantages to vehicle fleet operators (such as less weight and more space inside the vehicle due to the removal of the differential, pure electric motor driven braking via the rear axle etc).

Siemens has now deployed 100 of these vehicles as part of a fleet test at their company sites in Erlangen, Munich and Berlin; the various sites have also been equipped with the appropriate infrastructure (charging points). The vehicle fleet is controlled and managed with the aid of the developed grid-fleet management system (e-car sharing management software) from a central control room. One of the software's features is that vehicle reservations may be made via the intranet. The on-board unit in the vehicle can also identify the driver by his or her employee pass, unlock the car and deactivate the immobiliser. During the journey, it shows available charging points and allows the driver to pre-book one of these. At the end of the journey, billing data based on time and distance is transmitted to the control room via the mobile phone network.
This revealed the time and location dependent parameters of the fleet operated and allowed their control. The experiences made during the project allow the electric drive, charging points, network control and fleet management systems to be optimised and developed further. The 4S project made it possible to comprehensively examine the previously rather theoretical relationships and interactions between various factors such as range, usage intensity and demand, and the time and location dependent availability of renewable energies in practice. The project allowed the testing of a number of different business and operating models and the assessment of their impact with respect to the demands electric mobility solutions must meet. ■

Project
Battery vehicle with range extender (REX)

Project partners
Daimler AG

Duration
September 1, 2009 – March 31, 2011



REX

Objectives of the project
The implementation of a range extender concept is particularly relevant for the further development of battery-electric vehicles with an extended range, a high level of customer acceptance and energy-efficient operation. The advantage a vehicle fitted with a range extender has over a pure battery-electric vehicle is the relatively small battery size, as this also reduces the cost of the battery proportionally. The technical concept of a range extender vehicle also combines the advantage of local emission-free driving (e-drive) with the convenience of a wider range (combustion engine). The objective of the REX project was therefore the hybridisation of an electric vehicle and a combustion engine. In a set-up like this, the combustion engine typically drives a generator which in turn ensures that there is enough electric power to drive the electric vehicle with the electric power generated even when the battery is getting low and there is no charging facility. However, situation-led it is also possible for the combustion engine to drive the wheels directly.

Results
The construction of a prototype range extender vehicle required the development of new components and an optimised overall operating strategy designed specifically for this particular drive concept. The vehicle developed during the course of the project features a range extender unit consisting of a traction electric motor, transmission system, combustion engine, generator and power electronics. This range extender unit is designed in such a way as to allow the combustion engine to drive a generator in order to charge the battery on the one hand as well as to directly transfer its drive power to the drive gears via a mechanical drive shaft on the other. The power from the combustion engine and the electric drive may also be used simultaneously in certain operating modes

(e.g. when overtaking). Thanks to an intelligent operating strategy, the combustion engine operates at optimum energy efficiency level in most driving situations, thereby producing only relatively low CO_2 emissions. The outcome of the project is a sustainable vehicle and drive concept that reduces CO_2 and pollutant emissions. A reduction in pollution levels was achieved both in urban area as well as open countryside mode. In urban areas, it is achieved by operating the vehicle on a purely electric basis (i.e. zero pollutant emissions). In countryside mode, emissions are still reduced by using both the electric drive and the combustion engine. The performance capabilities of the range extender were proven in everyday situations. The resultant vehicle has a range of approximately 80 km in pure electric mode, and a range of up to 600 km when operated in combination with the combustion engine.

Considering the fact that the energy storage systems for pure electric vehicles do not yet demonstrate an acceptable level of performance (range). The resultant range extender vehicle, modelled on a compact car, will be developed further in order to make future serial application possible. ■

Joint project
Full emotion, zero emission

Project partners
RUF Automobile GmbH, Pfaffenhausen
Siemens AG, Munich

Duration
October 1, 2009 – September 30, 2011

Full emotion, zero emission

Objectives of the project
The dynamics of the electric drive make it possible to drive at high speeds with zero emissions. High-performance electric cars can therefore contribute significantly to reducing CO_2 emissions in the sports car segment. The Emotion project therefore intended to show what a sustainable concept for an electric car might look like, choosing a sports car as an example. Besides focusing on the vehicle concept itself, the project also addressed the issue of the vehicles' effective connection to the power grid.

Results
In terms of drive technology, the project succeeded in developing a highly efficient and high-performance drive whose modular design allows a variety of drive concepts. This meant that a central drive with fixed gears, a double engined concept with switchable transmission with a two-stage gearbox and a double engined concept with "torque vectoring" option were all possible. Each concept offers specific advantages with respect to cost, longitudinal dynamics, transverse dynamics and efficiency. The electric motor for the double engined concepts is a permanently agitated synchronous machine with a peak output of 125 kW at a rated voltage of 700 V. Combined with a two-stage manual gearbox to optimise the longitudinal dynamics, or as a double engined concept on the rear axle with electronic differential, it opens up new options in terms of transverse dynamics. A high-performance, temperature-controlled battery was also developed to ensure efficient usage of the stored energy. Effective connection to the power grid was ensured through the development of an integrated bi-directional charging system with 22 kW and the respective charging infrastructure. Combined with a high power rating, the bi-directionality makes it possible to utilise the synergies between electric vehicles and a smart grid. In this instance, "integrated charging

system" refers to the integration of the charging system into the power electronics already in place for driving purposes. This was successfully realised with a high-voltage concept where the battery voltage is between 650 V and 800 V, depending on charge status. The RUF Automobile GmbH was also in a position to draw the energy the test fleet needed from their own on-site hydroelectric power plants, making this a completely regenerative system. The project therefore serves to demonstrate a fully integral approach to electric mobility: An effective integration of vehicles into an available power grid and highly efficient drive systems combined with renewable energies.

A total of ten test vehicles were built. The work and results, both particularly challenging from a technological perspective, can be transferred to other vehicle categories and therefore represent a significant contribution to the future competitiveness of the German automotive and supplier industry. ■

Project
Integration of electric wheel hub motors in existing conventional drive technology to improve the CO_2 value and reduce general noise levels under consideration of practical aspects (E-Ramo)

Project partners
BRABUS GmbH, Bottrop

Duration
December 1, 2010 – September 30, 2011

E-Ramo

Objectives of the project
Retrofitting conventional cars with an additional electric drive is a currently largely untapped market segment. However, particularly this alternative to purchasing a new hybrid vehicle could be an important step towards hybrid technology achieving a higher market penetration in the automobile sector. This is the tie-in of the E-Ramo project. The objective of the project was the development of a hybrid system based on a wheel hub motor that could be integrated into a conventionally powered vehicle (in this instance, an E-Class Mercedes Benz). To study the technology's potential within a possible major user group environment, e.g. the taxi industry, the prototype was tested over a three-month test period during the second part of the project.

Results
The E-Ramo project showed that it is possible to integrate innovative wheel hub technology into existing vehicle concepts. The project consisted of linking the wheel hub motors to the drive axle of a Mercedes E220 cdi Bluetech. Thanks to short paths in the high-voltage network, the only structural modification the vehicle required was losing the spare wheel recess in order to incorporate the Li-ion battery. The spare wheel was replaced by a standard breakdown kit; both the interior and boot remained fully functional. The battery consisted of ten individual modules with ten single lithium-ion cells to achieve a total storage capacity of 18.6 kWh. This allows a range of up to 120 km in pure electric mode. The battery is recharged either via the on-board charger or via the wheel hub motors as these feed energy back during the braking process. Each motor generates 80 kW; both together therefore provide a total of 160 kW pure electric drive power. This power can be accessed either on its own or in combination with the power provided by the diesel motor, leading to a peak of 207 kW/418 PS in

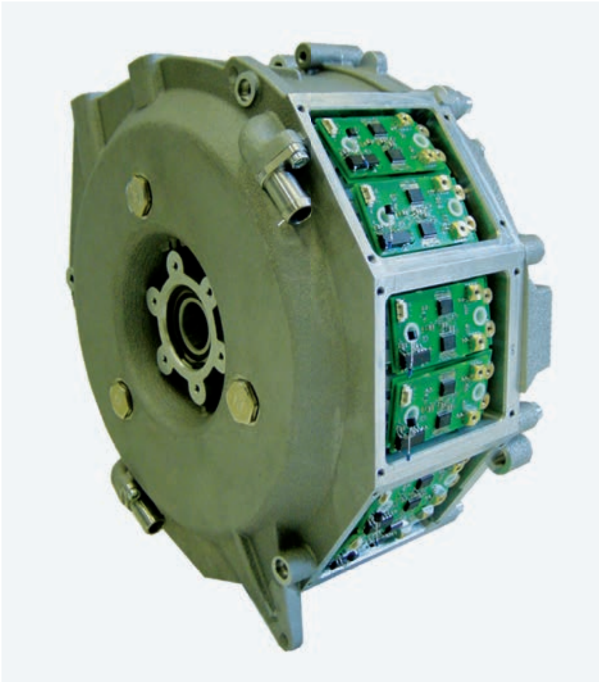
combined mode. Despite the increased unladen weight of 1990 kg, it is still possible to accelerate from 0-100 km/h in 7.4 seconds and to achieve a top speed of 220 km/h.
The project included extensive finished prototype vehicle tests with respect to range, regenerative braking, power consumption, noise and pollutant emissions as well as CO_2 emissions. Handling and braking performance and various safety aspects were also tested.

Especially the taxi industry represents a potential user segment. At present, hybrid vehicles are rarely used by taxi company operators because of the high initial acquisition costs involved, even though the resultant image gain in the eyes of the customers may represent a considerable market advantage within the segment. A more affordable retrofitted additional electric powertrain could be an attractive alternative here and should contribute to increasing the share of hybrid vehicles within this segment of the transport trade in the medium-term. ■

Project
Development and testing of an innovative drive concept based on Volkswagen plug-in hybrid technology: “Leistungsdichte Elektro-Maschine” (LDE-M), power density electric drive

Project partners
Volkswagen AG, Wolfsburg

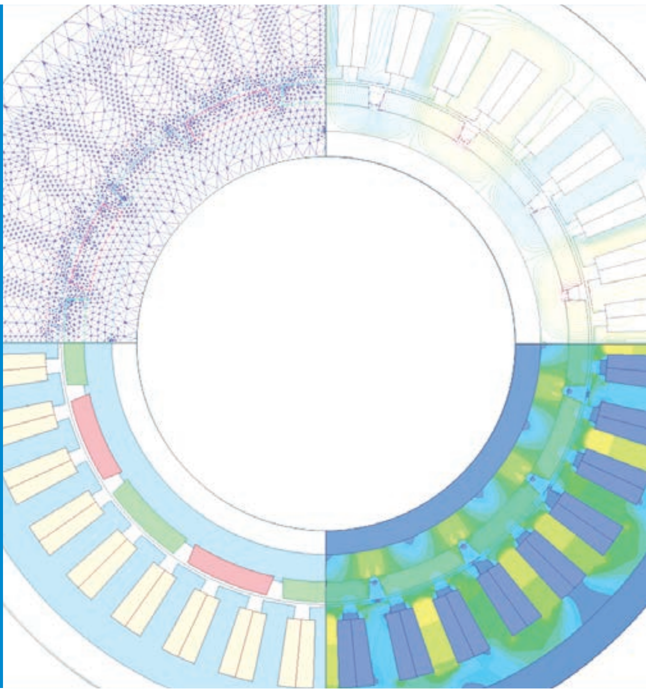
Duration
January 1, 2010 – September 30, 2011

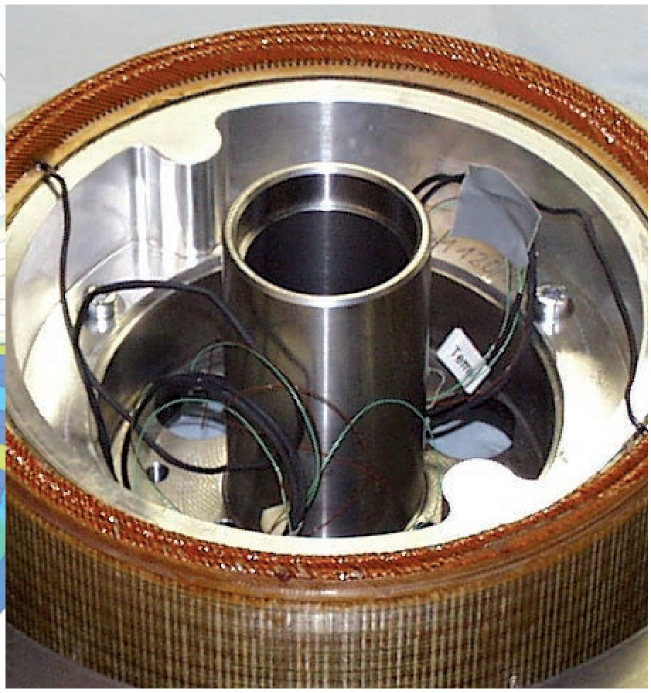


LDE-M

Objectives of the project
Improved drive concepts for electric vehicles make both the efficient use of stored energy as well as increases in the electric range possible. However, this also requires extremely compact yet also very powerful electric drives. The drive systems, which consist of electric motors and power electronic actuators, do not only have to fit into an extremely restricted space but must also meet specific automotive requirements and environmental influences. Current electric and hybrid vehicles feature power electronics and electric motors that have been built into the vehicle as separate components. They need separate cooling systems; the installation of the respective pipes is complex. Therefore, the LDE-M project focused on developing an integrated and optimised cooling process suitable for both the power electronics and the electric motor.

Results
Development of a cooling system ensuring the optimum extraction of heat losses both in the electronic part as well as in the e-drive was developed under consideration of complexity of installation and cost. The drive motor was also optimised with respect to the electromechanical motor concept and the magnetic or electric parameters. The electromechanical requirements were met through an internal rotor fitted with permanent magnets together with an external stator with integrated power electronics and cooling system. The electromagnetic concept made better use of the available winding space (fill factor) in order to increase the current bearing capacity, thus providing a more powerful magnetic field. In addition, premium quality magnetic steel sheets and better wires were used. The magnetic circuit thus optimised increases the requisite wave torque whilst also reducing engine losses. The control concept of the permanently





excited DC machine with electronic commutation was also improved.

The outcome of the project was an electric drive that has a higher power density than similar synchronous motors. The drive achieves a peak power of approximately 85 kW with 300 Nm torque. The rated capacity (continuous output) equals 50 kW with 150 Nm torque and a revolution rating of 12,000 min^{-1} per minute (rpm). The extremely compact dimensions of 28 cm in diameter and an axial length of 11 cm (i.e. motor "width") are an important aspect. The results were obtained by way of simulations and several optimisation cycles during the design process. The functionality and performance data was validated through dynamometer tests. Even in the initial design stage, care was taken to ensure that the drive would be suitable for actual future inclusion in hybrid and electric vehicles made by Volkswagen.

To conclusively calculate the drive's energy efficiency and therefore its CO_2 reduction potential, VW intends to carry out a number of similar vehicle field tests simulating everyday conditions. The project has made a significant contribution to improving the performance of electric drives, thereby helping to promote the expansion of electric mobility. ■

Joint project
Electric mobility fleet test (TwinDrive)

Project partners
Volkswagen AG, Wolfsburg (coordinator)
Deutsches Zentrum für Luft- und Raumfahrt e. V. (German Aerospace Center), E.ON Energie AG
EvonikLitarion GmbH, Kamenz
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. (Frauenhofer Organisation for the Promotion of Applied Research)
ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research, Heidelberg)
Westfälische Wilhelms-Universität Münster (University of Münster)

Duration
July 1, 2008 – June 30, 2012

Twin Drive

Objectives of the project
This project was to consist of designing a small fleet of plug-in hybrid vehicles and testing them in a fleet test. The project focused on assessing the performance of plug-in hybrid vehicles in realistic conditions under consideration of vehicle-related, i.e. technical, research topics such as electric traction and Li-ion traction batteries for plug-in-hybrid vehicles as well as issues such as the power supply architecture.

Results
Based on the Volkswagen Golf Variant, a fleet of 20 plug-in hybrids was constructed. Due to the way the powertrain is constructed, these vehicles are suitable for use as privately-owned cars as they are not subject to current range restrictions. The plug-in hybrid vehicles developed during the course of the project offer the advantage of emission-free operation when driving locally, which helps to reduce the pollutant emissions and traffic noise in urban areas. The intelligent vehicle operating system always selects the optimum operating mode according to the respective route and situation, i.e. the most efficient combination of electric motor and combustion engine. The fleet test with a representative selection of vehicle users took a range of different possible traffic scenarios into account. Further vehicle-related and grid-based research topics, socio-economic and ecological analyses made it possible to design an intelligent vehicle/grid interface. The interdisciplinary project structure allowed the further advancement of battery cell technologies for automotive applications currently still in the development stage. The batteries were developed further with regard to life span and cost reduction, which represented yet another major contribution towards a breakthrough with regard to the large-scale production of electric drive vehicles. The fleet test served to prove that plug-in hybrid

vehicles are certainly one way of significantly reducing the CO_2 emissions produced by the current volume of car traffic, i.e. in everyday conditions. However, to ensure that emissions are not simply shifted in terms of their place of origin, i.e. from vehicle to power plant, the electricity used must come from renewable sources. ■

Golf Variant twinDRIVE

Vehicle data	
Fuel consumption (Plug-in hybrid guidelines)	2.1 l/100 km or 134.5 MPG (49 g/km CO_2)
Top speed (TSI and e-drive)	approx. 170 km/h
Top speed (electric)	approx. 120 km/h
Peak power when accelerating	up to 120 kW/163 PS
Range (electric)	up to 57 km
Overall range (electric and combustor)	up to 900 km
Powertrain	
Li-ion battery weight	approx. 150 kg
Battery capacity	11.2 to 13.2 kWh
Rated capacity (electric drive)	65 kW/88 PS
Peak power electric drive	85 kW/115 PS
Peak power combustion engine	1.4 TSI, 85/kW/115 PS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2 Funding priorities and projects
Field tests for electric mobility in commercial transport

The usage profile of delivery vehicles is clearly more structured than the car usage profiles of individuals. Goods delivery and mobile services are usually carried out during regular working hours within a relatively limited area of operation. Daily routes of delivery vehicles are generally planned in advance. Outside of working hours (evenings and nights), the vehicles are normally parked in pre-defined locations such as logistics centres, depots or company premises. The respective charging infrastructure must therefore meet relatively simple requirements and offers optimum conditions for controlled charging and steady grid utilisation in the evenings and at night. The frequent stopping and starting during operation typical for urban goods traffic are perfect for regenerative brake systems, which makes regional delivery services the ideal field of application for battery-electric vehicles.

The field tests funded by the BMUB mainly focused on the testing different ways of integrating renewable energies in commercial transport under everyday conditions. They also served to determine the volume of energy likely to be required for these vehicles and the encouragement of vehicle user acceptance.

The funding was therefore used to focus on the following topics

- research and testing of commercial vehicle models suitable for everyday use under consideration of urban distribution traffic requirements,
- research and development of an innovative drive technology and a newly designed vehicle body for electricity-powered light goods vehicles,
- research and development of battery-powered heavy goods vehicles (battery AGVs), and field testing of such vehicles.

Joint project
Testing commercial vehicle specific e-mobility (EMIL)

Project partners
Volkswagen AG, Wolfsburg
Deutsche Post DHL, Troisdorf
Braunschweig University of Art (HBK), Braunschweig

Duration
June 1, 2010 – September 30, 2011

EMIL

Objectives of the project
The main objective of the project was to investigate and test a commercial vehicle concept that allows the efficient performance of urban logistics services whilst also taking the specific needs of commercial users in terms of effective distribution into account. In the first part of the project, ten box van type vehicles (VW Caddy) designed for conventional drives were fitted with electric drives and tested in everyday urban operations by the company Deutsche Post DHL over a period of around three months. Based on the knowledge gained, the concept vehicle eT! was then designed, equipped and constructed completely from scratch, along with all the e-traction specific components, in the second stage of the project. In addition, numerous innovative, delivery service specific components were integrated into the new eT! in order to provide significant time savings during delivery operations, thus contributing to an additional increase in the efficiency of urban distribution.

Results
The three-month practical test as part of DHL's urban delivery operations took place in Potsdam and Stahnsdorf. Five short wheelbase vehicles were used in Potsdam to deliver mail, and five long wheelbase vehicles were used in Stahnsdorf to deliver mail and parcels. The field test has shown that electrically powered delivery vehicles do not cause any significant mobility restrictions. On average, the vehicles travelled up to 50 km a day. During normal delivery operations, range-related restrictions tended to be psychological rather than actual, as some of the drivers felt that the remaining range display lacked accuracy. All users agreed that the main benefit of driving an electric vehicle was its operation, which was easy throughout. The vehicle's speed is usually controlled by a pedal, as the vehicle's electric motor also decelerates through regenerative braking. This makes the vehicle operation easier for the driver and represents an optimisation of the delivery

operations. The lack of operating noise was also perceived as a positive feature of the vehicle. The measured energy consumption levels in the fleet test were also lower than those of combustion engines. A charging time of approximately one hour was normally sufficient. Not least, it is also worth noting that electric vehicles communicate an environmentally aware corporate philosophy. However, the fleet test also showed that it is not only the vehicle that is important, but also the accompanying measures such as infrastructure, organisation and technical support. Yet another important finding is the necessity of an unbroken process chain from electricity supplier right through to the vehicle itself. The eT! was designed, equipped and built as a brand new electric delivery vehicle on the basis of the results of the fleet test and a comprehensive user survey. The electric powertrain features two wheel hub motors and one electronic control system for each motor. A vehicle-specific loading concept focuses on safe and space-saving transport and ergonomically beneficial movement sequences for the delivery agents. Additional time-saving features are the design of the vehicle's right-hand side, which allows the driver to exit the vehicle quickly, the integrated stand-up seat with drive stick control, and the "FollowMe" function, which relieves the driver of having to make additional trips back and forth to the vehicle. The tight turning circle of just 8.50 m also allows the vehicle to be turned around in one movement, rather than having to perform the customary three-point turn. ■

Joint project
Electrification of Mercedes-Benz LGVs in Development and Production - EMKEP

Project partners
Daimler AG, Stuttgart
Vattenfall Europe Innovation GmbH, Hamburg

Duration
August 1, 2009 – September 30, 2011

EMKEP

Objectives of the project
Commercial transport, and particularly urban commercial transport, is expected to be one of the primary areas of application for electric vehicles. Current electric vehicle performance levels make them particularly suitable for typical urban driving profiles as well as the average distances usually travelled on a daily basis in urban areas, including frequent vehicle stops and starts. The requisite preconditions with respect to infrastructure are also relatively easy to create as the vehicles typically return to a common base at night. The main objective of the EMKEP project was therefore to investigate the use of battery-powered light goods vehicles with respect to suitability for everyday use. For this purpose, a number of LGVs from the future Vito E-CELL range were developed, constructed and tested. Besides the usual usage-related aspects (e.g. handling, reliability), the tests also focused on the energy footprint.

Results
A completely new design, compared to similar vehicles with a combustion engine (e.g. switch to front-wheel drive, construction of an underfloor battery box), made it possible to develop a fully-fledged light goods vehicle suitable for urban deliveries. With a range of approximately 130 km, a potential payload of up to 900 kg and no restrictions in terms of ground clearance, the Vito E-Cell meets the average user requirements within the area of application in question. In order to ensure a high level of energy efficiency, a regenerative braking system was integrated into the vehicle. The challenge here was optimising the interaction between the various brake and stability control systems (e.g. ABS, ESP ASR). Temperature resistance tests with test vehicles confirmed that the Vito E-CELL can also be operated safely in extremely hot as well as extremely cold temperatures. The results of the crash tests showed that the battery and

HV system also meets the Daimler AG's high safety standards for the vehicle category light goods vehicle in full. Subsequent to the respective inspection, the Federal Motor Transport Authority (KBA) granted European type approval for the Vito E-CELL. This eliminates the need for specific driver instruction including HV training, making it easier to implement the shift system that is standard in the transport industry.
During the course of the project, 65 test vehicles were handed over to users for fleet testing purposes. A charging concept with wind-to-vehicle (integration of wind power with asynchronous fluctuation to demand) and local load management (optimum balancing of existing on-site power capacities) was developed by project partner Vattenfall and installed at the users' premises. This also allowed a demonstration of the potential of electric vehicles with regard to their benefits for the environment and the climate in the course of the trials. Fields of application were delivery services (e.g. postal and parcel deliveries), service vehicles and works transport. Important insights into velocity distribution, route lengths per trip, battery charge status and charging times were gathered in the field tests, which involved numerous established companies such as Deutsche Post DHL, Hermes Logistics, WISAG and Deutsche Bahn. The practical trials continue, even though the project has been completed.

Overall, the EMKEP project proved that electric mobility is a sensible option in the segment of light goods vehicles used for urban transport purposes. The project represents the basis for the use of other Vito E-CELL vehicles in other applications and regions as well, and its findings will also be transferred to other model ranges in this category. ■

Project
Electromobility for heavy commercial vehicles to reduce their environmental impact on densely populated areas (ENUBA)

Project partners
Siemens AG, Erlangen

Duration
July 1, 2010 – September 30, 2011

ENUBA

Objectives of the project
Freight transport also has to contribute to achieving the target reduction levels for CO_2 emissions produced by the traffic sector. Particularly in view of the fact that the levels of traffic related to freight transport are expected to grow considerably. Furthermore, a significant proportion of the local pollution (NOx, particulates, noise) in densely populated areas is caused by heavy goods vehicles. Improving the efficiency of combustion engines, increasing reliance on rail transport (existing rail network would require extensive expansion) or the use of biofuels (limited availability) will not be enough to reduce emissions to the necessary extent. The objective of the ENUBA project was therefore to examine whether heavy goods vehicles for road freight transport could be converted to electric, contact wire-based operation, and to demonstrate the technical feasibility of the system on a test track.

Results
The work focused on the development of the necessary systems for the electrification and operation of commercial vehicles. This included the electrification of the powertrain (serial diesel-electric hybrid drive), including the integration of electric double layer capacitors, and the development of a suitable current collection system. The development of the respective automation technology and sensors, such as systems for monitoring the insulation, for controlling the contact wire uplift or for automatically monitoring the contact wire (e.g. for open or short circuits) was particularly challenging.
For instance, in combination with other sensors, it is possible to automatically activate and deactivate the current collector in the event of non-electrified road sections or overtaking manoeuvres. Communication between the vehicles and the infrastructure was made possible in order to allow a future transfer of the respective vehicle data to an operational

control centre or a control room for operations management and monitoring. Another focus was the development of an overhead line and power supply system converted to a DC voltage of 750 V for demonstration purposes. A system that prevents damage to the overhead line system was integrated and equipped with a sensor to monitor the quality of the current collector.

In order to demonstrate the practical potential of the entire system, two commercial vehicles were fitted with a diesel-electric drive and a current collector, and a suitable test track was equipped with the necessary overhead line system and the respective power supply. Procedures such as the automatic activation and deactivation of the power between current collector and overhead line, the regenerative braking system, which feeds energy back into the grid, or overhead line detection in extreme weather conditions were thoroughly examined during numerous test runs. Overall, the technical feasibility of the system chosen for electrified road freight transport, consisting of vehicle, overhead line system and power supply, could be ascertained on the test track. Concurrent ecological analyses considering various factors such as the proportion of electric and "combustion engine" journeys proved the potential environmental benefits of contact wire-based goods traffic.

In summary, although there is certainly a need for further development, the ENUBA project has certainly laid the foundations for an innovative, ecologically oriented concept for the transportation of goods. ■

Joint project
Research, development and construction of battery-powered heavy goods vehicles (battery AGVs) and a field test of such vehicles at the Altenwerder container terminal in Hamburg.

Project partners
Gottwald Port Technology GmbH, Dusseldorf
HHLA Container-Terminal Altenwerder GmbH, Hamburg
ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research)
RWTH Aachen – Institute of Automotive Engineering

Duration
June 1, 2010 – September 30, 2011

B-AGV

Objectives of the project
The B-AGV project was aimed at helping to contribute to the reduction of global and local emissions and noise pollution through the development and testing of battery-electric automated guided vehicles (B-AGV) to transport containers in commercial ports. Given that the requirements for ports with respect to air pollution control are also becoming more stringent, the reduction of pollution caused by local pollutants (nitrogen oxides, soot particles) is of particular importance as it is a prerequisite for ensuring the further expansion of container handling. It should be noted that for any nation heavily dependent on exports, such as Germany, sea ports are of extreme importance for the movement of goods.

Results
A number of different challenges had to be overcome during the conversion of diesel-electric AGVs to pure electric vehicles. Besides the development of an electric drive concept, this also applied to the integration of the battery and electronic controls. To ensure a high level of vehicle availability, a battery switch frame with the necessary guides was developed to allow the automatic replacement of batteries in a battery changing station. A number of new features, such as battery charge status controls and heading automatically for the battery changing station, had to be incorporated in the vehicle controls. A completely new type of changing and charging point was developed for changing and recharging the battery. It consists of a high-bay rack and rail-guided stacker cranes (STCs) with a special telescopic extension. The STC is capable of handling batteries with a mass of up to 12 t to position them precisely in the B-AGV and in the storage rack.
To allow the vehicles to operate automatically in the container terminal, a number of different software systems needed to be adjusted, such as the AGV controls, the changing and charging point controls

or the terminal coordination controls. Likewise a number of charging strategies were developed in order to take all of the requirements and constraints of charging point, power supply and battery availability into account and design a charging management system that would contribute to determining the correct charging periods. For the field test, two B-AGVs were built in the container terminal. These vehicles performed a number of test routines during normal port operations in order to gain insights into vehicle and battery behaviour, the integration into the logistics system as well as economic and ecological evidence. The vehicles operated almost faultlessly for a 24-hour period and may be used continuously for twelve hours. It takes less than five minutes to change the battery, which ensures a high level of availability.
A vehicle life cycle based comparison (taking all aspects into account, from the vehicle manufacturing process to its operating life right through to final recycling) of the currently used diesel-electric vehicles with the new vehicles with a battery-electric drive system shows significant improvements to the overall CO_2 footprint. Local emissions are almost zero. The results of the B-AGV project show that the battery-electric drive concepts that were developed could potentially also be used for other port handling equipment and heavy goods vehicles. ■


Public Transport
Hybrid City Bus
MAN
HYBRID
M AN 3086

3 Funding priorities and projects
Hybrid buses for environmentally friendly public transport

The Federal Environment Ministry (BMUB) supported the extensive market launch of hybrid buses in the public transport sector with the funding programme "Hybrid buses for environmentally friendly public transport", and provided approximately 10 million EUR worth of funding for this purpose. Particularly due to the frequent stopping and starting processes during the operation of scheduled bus services, it makes sense to encourage the use of hybrid technologies in this area as a sizeable proportion of the energy lost during the frequent braking process can be regenerated and used to drive the electric motor. The vehicles used for scheduled bus services rely on their electric motor mainly when moving off. It also supports the diesel engine when it is running at low-end torques. This not only saves fuel and helps to reduce CO_2 emissions, but also has a noticeably positive impact on the level of air and noise pollution in the immediate vicinity of bus stops. The resultant reduction of the environmental impact of public transport helps to contribute increasingly to the appeal and acceptance of environmentally friendly solutions, particularly in urban areas.

The programme made it possible for 12 transport providers to integrate a total of 50 hybrid buses into their regular scheduled bus services. The funding was linked to strict compliance with stringent environmental requirements in order to establish high environmental standards right from the start, at the point of market launch. For example, the hybrid buses had to demonstrate an efficiency improvement of at least 20 percent compared to similar diesel buses as well as compliance with stringent noise and air pollution standards. They also had to have a closed-flow diesel particulate filter system fitted.

A comprehensive accompanying programme verified compliance with various environmental criteria and monitored the efficiency and technical reliability of the hybrid buses during the commissioning phase.

The funding was therefore used to focus on the following topics

- reducing public transport CO_2 emissions as well as air and noise pollution,
- supplementing current Federal German government measures for meeting the climate and environmental protection targets,
- supporting market penetration with existing highly efficient vehicle technologies,
- providing an economic impetus to public transport and the associated supplier industries,
- establishing a firm place for hybrid technology in the vehicle fleets of public transport providers.

Projects
RegioHybrid cooperative project
Üstra Hannoversche Verkehrsbetriebe AG
Stadtverkehr Lübeck GmbH

Duration
May 1, 2010 – September 30, 2011

Individual projects funded by the programme "Hybrid buses for environmentally friendly public transport"
A total of 12 transport authorities took part in the funded project. For example, üstra Hannoversche Verkehrsbetriebe AG purchased ten Solaris articulated hybrid buses, which have been used in the Südstadt area of Hanover since September 2011. The successful operation of hybrid vehicles helped to contribute to the target üstra has set itself in compliance with the Region of Hanover's climate package, namely to purchase an additional 61 hybrid buses for use in Hanover's urban transport system by 2016. Diesel or natural gas fuelled buses are to be phased out and no longer operate in the regional capital by 2020; correspondingly, üstra will purchase only hybrid buses. Urban public transport operator Stadtverkehr Lübeck GmbH also introduced five MAN Solo hybrid buses to their fleet in August 2011, along with five articulated hybrid buses from Carosserie HESS AG in order to integrate both size concepts.
A total of 24 MAN Solo hybrid buses and six articulated hybrid buses from Carosserie HESS AG were purchased within the scope of the joint project RegioHybrid, which involved ten transport authorities in the German federal state of Saxony.
The following operators were involved:
- Leipziger Verkehrsbetriebe AG and Leobus GmbH (Leipzig public transport authority)
- Dresdner Verkehrsbetriebe AG (Dresden public transport authority)
- Regionalverkehr Dresden GmbH (Dresden regional public transport authority)
- REGIOBUS Mittelsachsen GmbH, Verkehrsgesellschaft Döbeln mbH, Verkehrsbetriebe Freiberg GmbH (regional public transport authorities for Central Saxony, Döbeln and Freiberg)
- Verkehrsgesellschaft Meißen mbH (Meißen public transport authority)
- Müller Busreisen GmbH (a coach operator) and
- Satra Eberhardt GmbH (a commercial coach operator and freight transport company).

Thanks to intensive public relations efforts by the participating transport authorities and operators, including city festival participation, dedicated press events, respective information on the company

websites or eye-catchingly designed hybrid buses, the local population responded extensively and enthusiastically to the scheduled bus services with the latest efficiency technology. The participating public transport authorities and operators therefore not only improved their carbon footprint, but also their public image.

The accompanying programme

A separate project to accompany the funding programme was carried out by TÜV NORD, the regional quality and safety experts. Its objective was to check compliance with the environmental funding criteria for hybrid buses. This included CO_2 savings, exhaust treatment system effectiveness and compliance with noise regulations. Another key focus of the programme was the collection of economic and technical data,which formed the basis for examining the economic viability of operating hybrid buses and their technical reliability. Above all, the accompanying programme was also used to develop optimisation recommendations for transport authorities and operators seeking to integrate hybrid buses into their fleet in the future as the financial, environmental and technical data as well as the practical experiences gained with respect to integration into daily operations contribute significantly to overcoming current barriers with regard to potential future purchases.

Principal results

CO_2 mitigation and the effectiveness of exhaust after-treatment systems when subjected to the standardised Braunschweig cycle was maintained on the chassis dynamometer for all hybrid bus models that were tested. The various Federal Environment Ministry requirements with respect to noise measurements were also met. The noise emissions were below EU limits for all models. Overall, the models tested offer significant advantages with respect to noise pollution compared to conventional diesel buses. The avail-ability of the hybrid buses averaged approximately 250 km/day; the average time in operation per day was 15 hours. Passenger and transport authority/operator staff responded overwhelmingly positively to the hybrid buses in a respective survey. ■


CO2

4 Funding priorities and projects
Accompanying scientific research

The BMUB has initiated several interdisciplinary research projects in order to be able to judge the ecological and economic effects of electric mobility in more detail.
Within the scope of these projects, the Öko-Institut and ISOE have produced the first comprehensive analysis of the impact which an “electric mobility system” would have on emissions. The macro level played an important role in this respect; or rather, the interaction between vehicles that need electric power and the power plant fleet that is generating the current renewable and conventional energy mix.

The Institute for Energy and Environmental Research (ifeu) studied the various micro-effects at vehicle level: Which drive type and what form of usage is likely to be the most efficient, thereby also producing the least emissions, as well as the lowest-possible fuel costs for the user? The research project conducted by the European School of Management and Technology related to the impact the various electric mobility development paths are likely to have on growth and employment.

The funding was therefore used to focus on the following topics

- development of a model for the economic and ecological long-term analysis of electric mobility for the period up to 2050,
- assessment of the potential environmental benefits of electric vehicles that is not purely vehicle-based but also considers their interaction with the energy market,
- consolidation and analysis of the findings from current Federal German government fleet tests,
- redevelopment and further development of instruments that link the market launch and funding of electric mobility in Germany to the use of locally produced renewable energies.

Joint project
Optimising the environmental benefit potential of electric vehicles – an integrated consideration of vehicle usage and the German electricity sector (OPTUM)

Project partners
Öko-Institut e.V., Berlin
Institut für sozial-ökologische Forschung (ISOE) GmbH (Institute for Social-Ecological Research), Frankfurt am Main

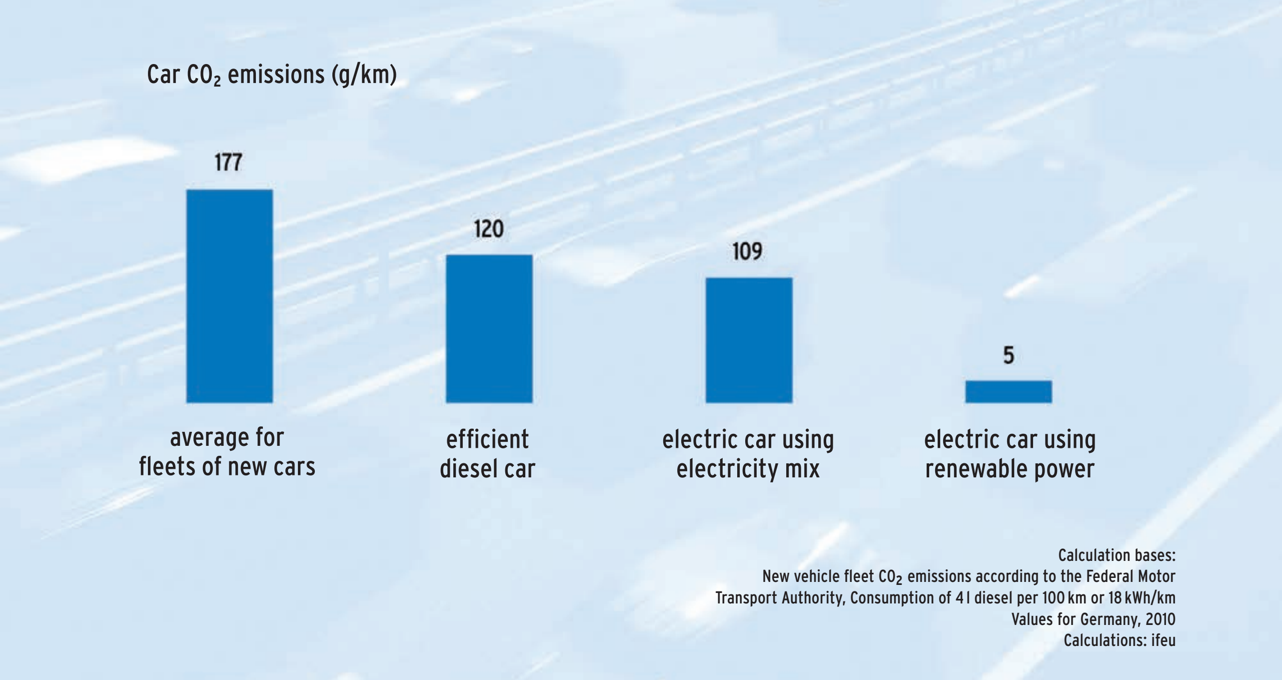
Duration
September 1, 2009 – September 30, 2011

OPTUM

Objectives of the project
The OPTUM project focused on an integrative approach for assessing the potential environmental benefits of electric vehicles that not only takes the vehicles themselves into account but also the interaction with the energy market. The first step of this multi-level project consisted of determining the market potential of electric vehicles on the basis of surveys and mobility data. The transfer of market data to specific driving profiles then made it possible to create a timed schedule of the electricity demand. The electricity generation structure was subsequently simulated in an energy market model based on electricity demand. This allowed the respective traffic to be assigned to the various power plant types and their specific CO_2 emissions. The projects's research horizon spans the period up to 2030.

Results
The calculations show that the potential environmental benefit of electric mobility depends entirely on the way the electricity is generated and on the market penetration of electric vehicles, and can only be fully utilised if the energy is supplied by additional forms of renewable energy in the future. Linking electric cars with wind and solar-generated electricity is therefore particularly advantageous. The EU Emissions Trading System, which also covers the capping of CO_2 emissions from electricity generation, can also provide an additional safety net. However, the project also shows that conventional vehicles must become more efficient over the next few years in order to mitigate total vehicle traffic emissions even further.

Other important results from the project:
- The empirical study of user acceptance revealed a considerable number of potential plug-in hybrid (PHEV) and pure battery electric vehicle (BEV) buyers. Accordingly, approximately 60 percent of



buyers in all vehicle categories would not want to purchase a vehicle with a combustion engine in 2020. Particularly relevant factors in this respect include the cost of electricity for electric vehicles, the cost of petrol and the electric range.

- Electric vehicles provide good coverage of daily mobility patterns. Considering acceptance and market diffusion, the analysis concluded that there could be 1 million electric vehicles on Germany's roads by 2022, and 6 million by 2030. In addition, eleven percent of all journeys by car will be made in electric vehicles by 2030.
- The temporal structure of the electricity demand is crucial for the deployment of power plants (merit order). If renewable electricity is used, it is safe to assume that electric mobility will be virtually emissions-free. In this case, emissions from rolling stock could be reduced by more than 5 million tonnes by 2030, compared to a reference scenario without electric mobility. This equals a total emissions reduction of 6 percent by 2030.
- In 2020, the electricity consumed for electric mobility purposes will total approximately 1 TWh, which is less than 0.2 percent of the current total annual net electricity demand. It will total approximately 10 TWh by 2030, which is around 1.5 percent of the net electricity consumption.
- Analysis of the various energy system interaction options reveals that in the medium-term, a charging management system is the most cost-effective option for electric vehicles in order to provide the flexibility renewable energies require.

The project results are illustrated in detail in a brochure, available at www.erneuerbar-mobil.de. ■

Joint project
Environmental assessment of electric mobility – Consolidation and analysis of the findings of current fleet tests conducted by the Federal German government (UMBReLA)

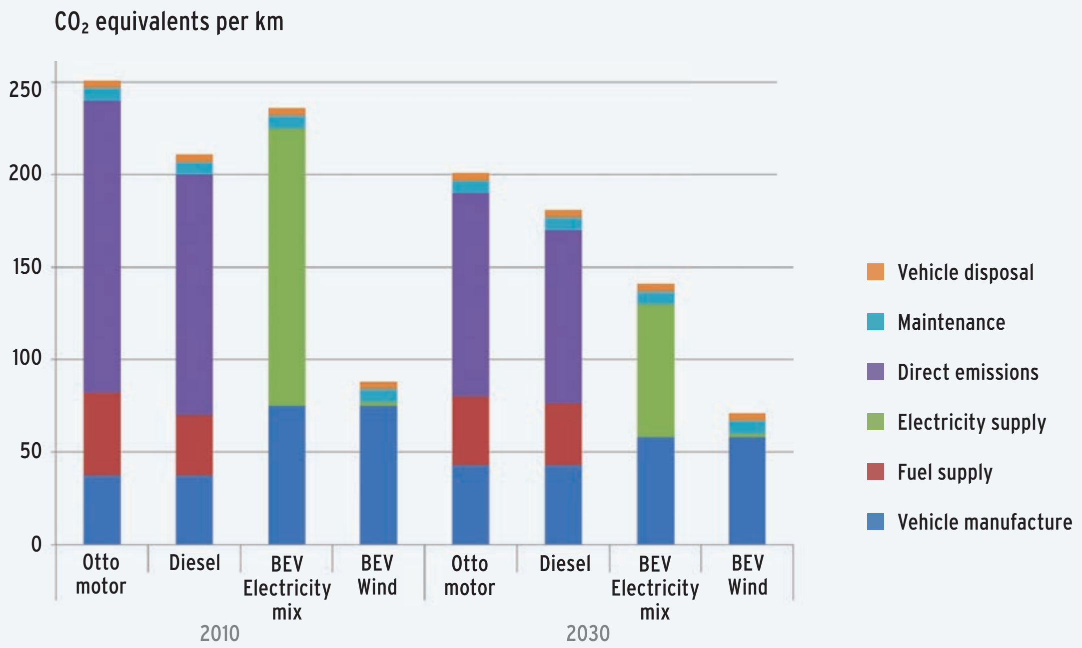
Project partners
ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research)

Duration
October 1, 2009 – September 30, 2011

UMBReLA

Objectives of the project
This project was aimed at providing a comprehensive assessment of the environmental impact of electric vehicles and an overall summary of the environmentally relevant results of fleet tests run by the Federal Environment Ministry and other current research projects in the field of electric mobility. General objective was the analysis of the "cradle-to-grave" environmental impact of electric vehicles. For this purpose, a great number of different project results were reviewed and fed into a newly developed life cycle assessment model, eLCAr (Electric Car Life Cycle Assessment). The model covers the entire life cycle by looking at vehicle manufacture, energy supply, usage and disposal as well as taking different vehicle types into account. In addition, the use of sensitivity analyses and case studies allowed the definition of fields of application where the use of electric vehicles would be particularly advantageous. A system comparison with fuel cell vehicles was also carried out. The project's research horizon spans the period up to 2030.

Results
The project shows that electric vehicles, subject to current production and energy supply conditions, have a carbon footprint that is similar to the carbon footprint of vehicles with combustion engines. In comparison to a petrol-fuelled car, offset of the climate impact of the battery does not commence until a distance of 100,000 km has been travelled. If additional renewable energies are used, the offset commences at just 30,000 km. Electric drive proves particularly efficient in urban areas; however, due to the shorter distances travelled in non-commercial traffic, the battery production has a considerably more negative impact on the carbon footprint in this environment. The use of electric vehicles in commercial traffic, on the other hand, can already serve to significantly reduce the current burden.



The environmental impact of electric vehicles has clearly improved, thanks to the increasing share of renewable energies in the electricity mix and more efficient and longer-lasting battery technologies. Through the use of a charging management system and additional renewable energies, the greenhouse gas emissions from electric cars throughout their entire life cycle are considerably lower than those produced by conventional vehicles. The environmental impact within the other impact categories analysed, such as acidification potential, particulate matter, smog and eutrophication, is also increasingly becoming lower, and is typically below the impact of petrol or diesel fuelled cars.

A comparison of electric cars with fuel cell vehicles shows that the carbon footprint of both vehicle types is essentially the same: Both technologies offer significant advantages, provided they use clean electricity. Fuel cell cars tend to perform worse in the other impact categories. However, there is a clear difference in overall efficiency levels: In battery electric cars, 77 percent per 100 percent electric energy used transfers to the wheels, whereas in fuel cell vehicles, this figure is only around 26 percent. This is due to the fact that high losses are incurred during the generation of hydrogen by way of electrolysis and its subsequent conversion to electricity in the fuel cell, whilst the battery storage capability of electric cars is already very efficient.

The complete project results may be viewed at www.emobil-umwelt.de. An additional environmental calculator shows the carbon footprint of different electric vehicle applications as well as providing a like-for-like comparison with conventional vehicles.

Project
Market Model Electric Mobility (MMEM)

Project partners
ESMT European School of Management and Technology GmbH, Berlin

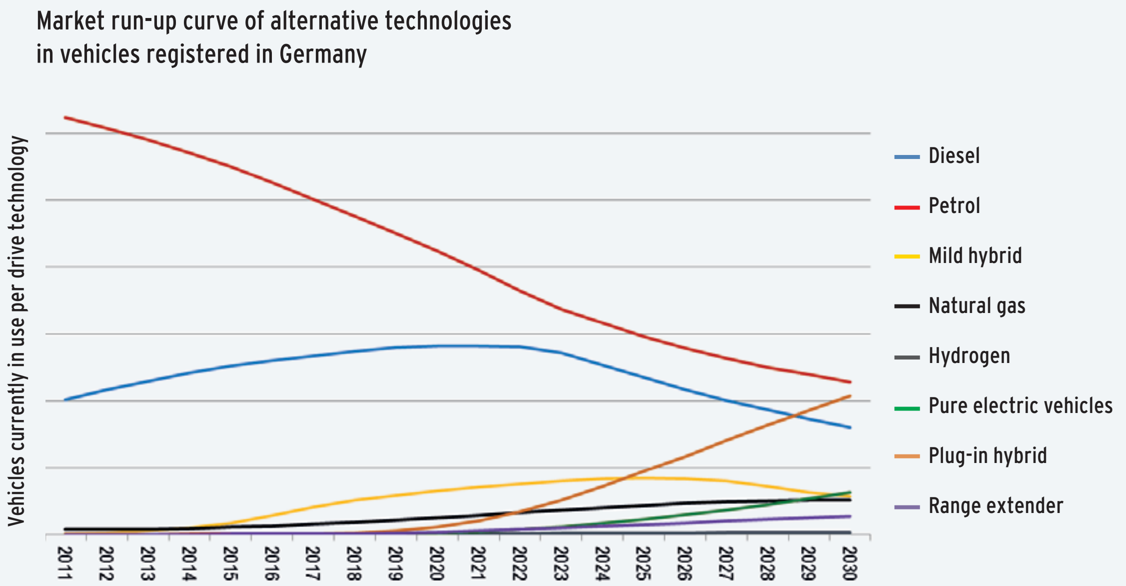
Duration
December 1, 2009 – September 30, 2011

MMEM

Objectives of the project
In addition to the climate policy aspect, the cost-efficiency of electric mobility will also play a decisive role in the future. A transparent, detailed illustration of the economic and ecological cost-benefit ratio is a particularly suitable instrument for accelerating the introduction of electric mobility to the German market. The MMEM project simulated the market penetration of different drive technologies (petrol, diesel, various hybrid technologies, gas, biofuel, electric cars, fuel cell) taking various conditions such as fuel and electricity price or the development of battery cost into account. A number of different policy options were examined, such as CO_2 limits and research funding, in order to be able to forecast and assess their impact on the economic segments in question, i.e. consumers, producers, government and the environment, and the technology diffusion of electric vehicles. The model results show the benefits of policy decisions, their contribution to emissions reduction and the retroactive impact on employment and growth in comparison to the reference scenario.

Results
Mild hybrids, plug-in hybrids and vehicles with range extenders are particularly prevalent in the reference scenario without policy-led intervention. The Federal German government's target of six million vehicles with electric drive by 2030 will be achieved. However, the reference scenario predicts only 460.000 electric vehicles on the road by 2020 if there is no funding whatsoever. In the reference scenario, pure battery electric vehicles penetrate the market only marginally, and fuel cell vehicles play no role at all.

The continuation of combustion engine optimisation in combination with hybridisation has an extremely high potential of drastically reducing emissions in the long-term. In the reference scenario, a 50 percent



reduction in annual CO_2 emissions will be achieved by 2035 without any further intervention, assuming fleet emission standards of 95 g/km. With the EU Emissions Trading System (ETS) in place, the proportion of electric vehicles will not cause any additional emissions if these electric vehicles are in fact replacing vehicles with a combustion engine. Another of the project's important findings is that framework instruments such as fleet emission standards interact with other instruments. For example, the funding for electric vehicles has an impact on the stringency of the permissible CO_2 limits for the entire new vehicle fleet. Due to such side effects, the different instruments must therefore be coordinated with each other and developed further as a whole. In view of this fact, the study recommends the temporary use of selected measures with a volume cap; choosing the right point in time to commence the measures and the right combination of measures is essential. It should also be noted that the benefits enjoyed by a particular economic sector (e.g. consumers or manufacturers) from each instrument will inevitably have a negative impact on another sector (e.g. government tax revenues). The results of the study make it easier to assess the impact of individual measures.

The project results are also available to the general public via a website with integrated online tool (www.mmem.eu). ■

5 Funding priorities and projects
Battery recycling

On an international level, procedures for the recycling of lithium-ion vehicle batteries are currently still at an early development stage. The BMUB therefore funded research and development work on recycling processes for lithium-ion traction batteries under consideration of financial and environmental aspects. Established sophisticated recycling concepts are also of major importance for battery manufacturers during battery production set-up and as a safety measure when it comes to returned batteries and their subsequent recycling. Efficiency and environmental standards are also expected to gain increasing importance globally over the next few years, and raw material prices for commodities such as cobalt or lithium are also expected to rise. The early development of effective recycling processes with high recovery rates are therefore of particular strategic importance for the competitiveness of the German automotive industry and its suppliers.

The funding was therefore used to focus on the following topics

- Development of safety concepts that allow the safe breaking of batteries (safe disassembly concept),
- procedures to separate the various battery components,
- research and development to record life cycle data and test procedures,
- exploration of various alternative recycling procedures for lithium-ion batteries based on the materials contained therein to recover "battery-suitable" lithium as well as other substances contained therein in order to achieve the highest possible recovery rate,
- procedures to link product development and recycling process as the product properties and processing technologies have a major impact on the recycling process.

Joint project
Development of a feasible recycling concept for the high-performance batteries of future electric vehicles (LiBRi)

Project partners
Umicore AG & Co. KG, Hanau (coordinator)
Daimler AG, Stuttgart
Öko-Institut, Darmstadt
Clausthal University of Technology,
Institute of Mineral and Waste Processing,
Waste Disposal and Geomechanics

Duration
September 1, 2009 – August 31, 2011

LiBRi

Objectives of the project
One of the main objectives of the LiBRi project was to research and implement procedures for the disassembly of lithium-ion traction batteries and the processing of battery cells to allow them to be processed further in existing pyrometallurgical plants. Another objective was to investigate the recycling process for lithium and manganese from slag and dust produced by the pyrometallurgical process.

Results
The research regarding the disassembly covered the entire process, from procedures to remove the battery from the vehicle and transport it safely to testing it, from controlled discharge to the separation of the battery case from other functional components (e.g. cooling system), right through to the separation of the lithium ion cells. The developed battery testing system makes it possible to specify defined discharge sequences in order to set up individual discharge curves for a wide range of different battery systems. The device also allows the simultaneous recovery of residual energy, which is then fed back into the power grid. The “remanufacturing” of batteries was also examined with the aid of the test plant. Various different options such as further use in other applications (“second life”) or the repair or reuse of individual components were taken into account. The tests showed that the economic aspects of various reuse and further use options may also be of particular interest. However, prior to implementation, additional research work is needed on the ageing behaviour of batteries and cells, and designs that make removal and disassembly easier must be developed.

A pilot plant was built and commissioned on the basis of the various disassembly processes developed. The plant covers all process stages, from the initial

battery inspection to battery discharge, right through to the mechanical pretreatment and formation of defined material fractions. The plant meets the current technical and legal requirements, including compliance with the EU Battery Directive 2006/66/EC, which also contains specific provisions for environmentally-compatible recycling. The pilot plant forms the basis for the processing of lithium-ion cells to allow their inclusion in the existing pyrometallurgical process; it therefore allows the recycling of key raw materials such as nickel or cobalt. An efficient recovery process for lithium and manganese from the slag and dust produced by the pyrometallurgical process was also developed. A hydrometallurgical treatment process was designed for the various types of slag examined, making a future lithium recovery process that is more ecologically and economically efficient than recovering lithium from silicate ore (spodumene) a distinct possibility.

The accompanying life cycle assessment of the LiBRi project's recycling processes proves the ecological benefits of the procedures chosen. Availability analyses regarding the resources of lithium and cobalt were also carried out. The availability analyses clearly show that, in view of the many lithium exploration projects and the extent of the global reserves, there are sufficient primary raw materials to cover the demand for lithium for a long time to come, even in the event of electric vehicles achieving strong market penetration. The situation looks more critical where cobalt is concerned, but on the other hand, cobalt-free alternatives are also available in the form of lithium iron phosphate cathodes or future metal-air batteries. The results of the LiBRi project provide a sound basis for the transition of the developed recycling processes to an industrial scale. ■

Joint project
Recycling of lithium-ion batteries (LithoRec)

Project partners
Technische Universität Braunschweig (coordinator)
Audi AG, Ingolstadt
Chemetall GmbH, Frankfurt
Electrocycling GmbH, Goslar
Evonik Litarion GmbH, Kamenz
Walch Recycling & Edelmetallhandel GmbH & Co. KG, Baudenbach
H. C. Starck GmbH, Goslar
I+ME ACTIA GmbH, Braunschweig
Recylex GmbH, Goslar
Süd-Chemie AG, Moosburg
University of Münster, Münster
Volkswagen AG, Wolfsburg

Duration
September 1, 2009 – September 30, 2011

LithoRec

Objectives of the project
The objective of the LithoRec project was the development and testing of procedures for lithium-ion battery recycling. The approach was comprehensive, covering the entire life cycle from recyclable initial design to the technological processes required for disassembly, material processing and metallurgical recovery, as well as different recycling concepts.
In contrast to the LibRi project, this project's research focus was on the development of hydrometallurgical processes for the recovery of important battery materials, particularly lithium.

Results
The hydrometallurgical processes that were developed allow the recovery of up to 95 percent of the lithium from the separated cathode material, depending on material composition. Another advantage of the procedure is the fact that the recovered materials have proven battery qualities when processed mechanically on a laboratory scale, resulting in a closed loop of strategically important battery raw materials. For example, lithium hydroxide was precipitated from lithium iron phosphate and new lithium nickel cobalt manganese oxide (NCM) of a quality suitable for batteries was produced from NCM active materials. Two pilot plants for the hydrometallurgical processing of separated coating powder from lithium-ion batteries were installed. One plant deals with the processes necessary for extracting lithium and other transition metals; a further plant serves the purification of the lithium salt solutions and their transformation into lithium hydroxide or lithium carbonate as a raw material for new cathode materials. Both plants were successfully commissioned and operated on a pilot scale.

Besides the metallurgical processes, methods for battery disassembly, cell dismantling and the separa-

tion of active materials from the electrodes were also explored. This showed that particular attention must be paid to the prevention of cross-contamination when separating individual material fractions. For example, it was noted that aluminium contamination impedes the hydrometallurgical processing of the active materials. The possibility of automating certain disassembly stages was another aspect examined in the course of the project. The conclusion here was that certain dedicated disassembly stages show a distinct potential for automation. Respective designs included, for example, a gripper system prototype capable of removing the battery cells whilst simultaneously determining the state of the cell.
This research contributes to making the recycling process more efficient. In addition, new approaches for the recovery of solvents and conducting salts from electrolytes were also identified. The vacuum condensation procedure and extraction by means of supercritical carbon dioxide achieved first successes on a laboratory scale.

The pilot plants used for the hydrometallurgical recovery of active materials are the basis for future translation into large-scale industrial recycling processes. The accompanying life cycle assessments also demonstrated the positive environmental impact of the procedure in all impact categories. ■

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